|CURIEUX|

ACADEMIC JOURNAL

December Issue

Part 3 Issue 2

Editing Staff

Chief-In-Editor

Caroline Xue

George Hasnah

Chief of Operations

Anshal Vyas

Assisting Editors

Olivia Li

Luzia Thomas

Madalyn Ramirez

Shefali Awasthi

Soumya Rai

Sarah Strick

Table Of Contents

Page 6: Can AI Outsmart Human Intuition? A Study on Scam Detection Efficiency By Dhruv Mutatkar

Page 10: Boeing's Success After WWII and Aviation Accident By Tianyu Li

Page 29: Can Meaning-Making Through Song-Lyrics Help with Emotional Regulation? By Ryan Lee

Page 38: Comparative Study of Performance and Efficiency in Digit Recognition between Spiking and Artificial Neural Networks By Ben Shlafman

Page 56: A Systematic Review on the Impact of Chronic Illness on Education and Social Functioning of Adolescents By Jonghwan Kim

Page 68: Beyond Nutrition: Assessing the Association Between India's Midday Meal Scheme and Foundational Learning Outcomes By Aarav Chokhani

Page 80: Resilience by Choice: How Mindset Guards Against Inferiority By Irene Shin

Page 85: Evaluating Machine Learning Techniques for Predicting Insurance Costs By Elijah Rebholz

Page 94: How Does Differential Language Acquisition Affect Cognitive Development in Bilingual and Monolingual Infants? By Elif Yaren Gürcü

Page 109: Analysis of Genetic Factors and Diseases that Influence Human Aging By Yuhan Sun

Page 133: The Fragility of Progress: A Feminist and Constructivist Analysis of Women's Education in Afghanistan By Zoe Smallman

Page 148: Performing Ourselves: A Sociological Analysis of Power, Capital, and Control in Social Media Sociology By Ivan Hua

Page 168: How Hazardous Chemicals Present in Low-Cost Products from Popular Chinese Online Commerce Shops Can Affect Human Health By Steve Kim

Page 177: Estrogen Replacement Therapy and Alzheimer's Risk in Postmenopausal Women: A Review By Sasha Ali

Page 183: Effect of Saving Rates on Pension Policies By Vihaan Agarwal

Page 196: Contradictions of a Colonial Legacy: A Contrapuntal Reading of Etel Adnan's Sitt Marie Rose By Norah Grigoresco

Page 203: Broadly Neutralizing Antibodies: Our Future By Mannas Malik

Page 217: High Metallicity in Early Galaxies By Ethan Ding

Page 227: Characteristics of MHL Programs for Adolescents in School Setting By Hannah Rhim

Page 233: Deep Learning for Seismic Phase Picking: A Transfer Learning Approach By Avik Chervirala

Page 244: Acceptance of Digital Payments Among Fisherfolk in Manila NCR By Karunya Pandey

Page 262: Peer-Led Sports-Based Hydrotherapy in Boys With Spastic Cerebral Palsy: A Three-Year Program Evaluation By Yasar Batu Mag

Page 272: Optogenetic Restoration of Brain Rhythms to Improve Sleep in Alzheimer's Disease By Neha Raju

Page 284: Property Defense and Lethal Force: A Natural Rights Approach By Anjin Lim

Page 292: Fashion Influencers and Sustainable Consumption: Assessing the Effectiveness of Sustainability Campaigns on Korean Generation Z By Kelly Choi

Page 313: Exploratory Analysis of Shallow Convolutional Networks for Motor Imagery Classification in Brain-Computer Interfaces By Nam Nguyen

Page 326: Inconsistent but Not Invalid: Understanding Variations in ALS Risk Factor Research By Xiang Ma

Page 341: The Dual Implications of Music Listening to Individuals at a Societal, Emotional, and Neurological Level - A Review of Existing Literature By Zihan Liu

Page 357: How the Vietnam War Affected the Identity and Belonging of Vietnamese People at Home and Abroad Across Generations By Mya Nguyen

Page 372: Major Factors That Affect the Stock Market and How Companies Use It to Their Advantage By Aariz Jiwani

Page 384: Diabetic Retinopathy Classification Using CNNs: Analysis Of Ordinal Loss Functions And Explainability By Ayaan Gupta

Page 397: Advancing Aortic Morphology Analysis: LCPC Transform Technique Application for Shape-Based Acute Aortic Dissection Characterization By Srianshi Samantaray

Page 406: Market Power in K–12 Textbooks: Price Discrimination, Procurement Risks, and Policy Remedies By Alonzo Estrada

Page 417: The Relationship Between Creativity Motivation and Agreeableness in the Context of Plurilingualism By Teresa Chen

Page 433: The Impacts of AI Integration on the Engineering Problem Solving Process By Katie Hu

Page 447: Can an AI-Guided Assistant Accurately Summarize Chronic Pain Severity and Impact Using Responses from Validated Questionnaires? By Arav Parikh and Jesús Valdiviezo

Page 458: From Ancient Logic to Artificial Intelligence: Evolution of Mathematical Thinking and Its Role in Modern Technology By Diyar Saken

Page 463: The Integration of Artificial Intelligence and Robotics in Modern Engineering: Transforming Design, Manufacturing, and Maintenance By Amirali Aldabergenov

Page 469: 6G Communication Networks: Engineering Challenges and Future Directions - A Global Perspective Including the United States, the European Union, China, and Kazakhstan By Arnur Maratov

Page 475: Ecological and Modern Approaches to Plant-Based Meat Alternatives: Protein Content, Bioavailability, and Satiety in the Context of National Meat Consumption Culture By Yerkenur Zhanabekova

Page 481: Migration and Mobility of Ancient Peoples in Kazakhstan: An Anthropological and Archaeological Perspective By Ayala Satieva

Page 486: Satellite Technology and Space Infrastructure Development: A Comparative Study of Kazakhstan and the United States By Mansur Kharman

Page 491: Kazakhstan's Foreign Policy & Strategic Position in the Russia–Ukraine War Context: Balancing Diplomacy, Security, and Sovereignty By Dariya Akhmedia

Page 496: Artificial Intelligence in Financial Markets: Global Trends, Ethical Implications, and the Future of Data-Driven Investment By Diana Abdrakhim

Page 501: Sustainable Fashion and Cultural Innovation: Transforming Old Clothing into "Korpe" as a National Product of Kazakhstan By Aidana Kobentai

Page 506: The Impact of Oil Production on Government Spending and Well-Being of Residents: Evidence from Saudi Arabia By Faaz Ali

Page 523: The Impact of Marital Status, Race, Children, and Income on Rates of Pet Ownership By Andrew Tang

Page 531: Institutions, War, and Economic Resilience: Comparing the United States, Russia, and Ukraine By Amber Wee

Page 542: Exploring the Feasibility of Estimating Drag of Car Mirrors Using Only Flow Visualization By Ruixi Liu

Page 555: Borders Of Belief: How National Pride Shapes Views on Immigration By Saanvi Peddi

Page 571: Musical Equity Between the U.S. and France: A Comparative Study of Accessibility, Cost, and Cultural Impact By Millen Salopek

Page 577: Human-Steered Evolution of Rotational Shapes By Luka Rekhviashvili and Aleksandre Khabashvili

Page 589: An exploration of the fear of death in *The Death of Ivan Ilyich* and *Mrs. Dalloway* By Emily Helena Brieske

Page 599: A Mixed Methods Investigation of Sociological and Developmental Outcomes Among Only Children in East Asia By Anselm Park

Can AI Outsmart Human Intuition? A Study on Scam Detection Efficiency
By Dhruv Mutatkar

Introduction

Scam messages have become a major problem in today's technology driven world. They can appear in emails, text messages, and on social media platforms. These scams often trick people into giving away private information, money, or access to important accounts. Even though spam filters and online warnings exist, many users still fall for scams, which shows how difficult it is to accurately detect them. Because of this challenge, it is valuable to study how well both humans and artificial intelligence can identify scam messages compared to real ones.

This paper focuses on comparing the accuracy of humans and Large Language Models in detecting scam messages. The LLMs examined in this study are Gemini, DeepSeek, and Claude. Three human groups were observed which include teenagers, adults, and senior citizens. The goal of this research is to determine which performs better at identifying scam messages.

Based on previous research and understanding of how these systems work, I believe the LLMs will score higher than the human groups. Teenagers are expected to average around 75 to 80 percent accuracy, adults between 75 and 85 percent, and senior citizens between 65 and 70 percent. DeepSeek and Gemini are expected to score between 90 and 95 percent, while Claude is expected to score slightly lower, between 89 and 93 percent. Overall, the belief guiding this project is that the LLMs will outperform the human groups.

As scam messages continue to grow more advanced, the importance of this topic increases. Understanding how different age groups detect scams can show which populations may be more at risk and may need more support. At the same time, if LLMs show strong accuracy, they could be used in email filters, security tools, and devices to better protect users. By comparing both humans and AI, this paper aims to support improved methods for combating scams and strengthening digital safety.

Background Research

Scam messages are one of the biggest problems in today's online environment. They appear in emails, text messages, and social media. Many people fall for scams that look real and end up giving away private information or money. Because of this, researchers have used artificial intelligence to detect scams more quickly and accurately. This project compares how humans and LLMs identify scam messages and how their accuracy differs.

One research paper explained how AI uses machine learning and natural language processing to detect phishing emails. These emails attempt to trick people into clicking harmful links or sharing information. The study showed that AI is strong at catching these emails and works much faster than humans. However, it can still make mistakes, such as blocking real emails or failing to catch new types of scams. This connects to my project because it shows how AI helps detect scams, but my research goes further by comparing AI directly to humans.

Another study focused on how AI prevents credit card fraud. It uses machine learning to study spending patterns and locate unusual behavior. The study showed that AI can catch fraud in real time but also needs large amounts of data to function well. Even though this paper was not about text messages, it still relates to my topic. It shows how AI can detect suspicious patterns, which is similar to identifying scam messages.

A third paper studied how AI identifies phishing emails using tools like TensorFlow. It discussed how AI analyzes message content, links, and sender behavior. The results showed that AI is strong at finding fake emails but still depends on high quality data. This supports my project because it shows that AI can detect scams effectively while reminding us that AI systems must be trustworthy and safe. My research takes this further by comparing three AI models against three human age groups.

All three studies explore how AI detects scams, but none of them compare AI to different human groups. This paper fills that gap by testing humans and AI on the same dataset of messages and comparing their accuracy.

To perform this comparison, I collected a set of real and fake messages. Three human groups received these messages and classified them as real or fake. The same messages were given to the AI models. Their results were compared to determine which group performs best.

Experimental Findings

The purpose of this research is to compare the accuracy of humans and LLMs in detecting scam messages. Scam messages often trick people into giving away personal or financial information. Even though filters exist, scams keep evolving and becoming more realistic. This experiment tests how accurately humans recognize them compared to LLMs including Gemini, DeepSeek, and Claude.

To prepare the dataset, I created fifty total messages. Twenty five were normal messages and twenty five were scam messages that I wrote based on real examples. The dataset included easy, medium, and hard difficulty levels. I used Microsoft Forms to build a survey where each message had to be labeled as real or scam. The survey was given to twenty five people divided into teenagers, adults, and senior citizens. Ten teenagers between ages fifteen and nineteen participated, ten adults between ages twenty and forty, and five senior citizens over sixty.

The LLMs used were Gemini, DeepSeek, and Claude. Each model has strengths. Gemini focuses on context and tone. DeepSeek is strong at deeper reasoning and detecting unusual patterns. Claude focuses on safety and balanced evaluation and provides explanations for its choices.

Each model classified all fifty messages. Their answers were compared to the correct labels to measure accuracy. I also recorded false positives and false negatives. False positives were real messages labeled as scams. False negatives were scams labeled as real.

Human responses were exported into Excel for organization. I calculated accuracy for each participant and then averaged results for each group. This allowed comparison between

human groups and LLMs. I also compared mistake types. For example, a participant with many false negatives was more trusting while someone with many false positives was more cautious.

Before analyzing the results, I ensured that the study was fair. No personal information appeared in any message, all participants agreed to take part, all responses were anonymous, and all groups took the same survey.

While analyzing mistakes, I noticed patterns. Some scam messages used pressure language like your account will be closed today. Others used brand names like Amazon or PayPal which made them seem real. These messages fooled both humans and AI at times.

Each model behaved differently. Gemini was strict and sometimes labeled harmless messages as scams. DeepSeek was cautious and often trusted messages that were written realistically. Claude was the most consistent and balanced. Human groups also showed trends. Adults performed the strongest while senior citizens struggled the most. Teenagers performed well but sometimes rushed.

Charts and tables were created in Excel to visualize trends. Some messages fooled almost all groups. These examples help show which scams are the most dangerous in the real world. Overall, the experiment allowed a fair and controlled comparison of human and AI performance.

Results

The results showed clear differences in accuracy between the three LLMs. Claude scored 100 percent accuracy by correctly identifying all fifty messages. Gemini scored 96 percent with two total mistakes. DeepSeek scored 94 percent with three total mistakes which were all false negatives.

Model Performance Table

Model	Accuracy	Total Errors	False Positives	False Negatives
Claude	100%	0	0	0
Gemini	96%	2	1	1
DeepSeek	94%	3	0	3

Claude stayed the most consistent and used both tone and context effectively. Gemini was stricter and sometimes labeled slightly unusual ham messages as scams. DeepSeek was more cautious which caused it to label several scam messages as real.

The hypothesis predicted DeepSeek and Gemini would be in the 90 to 95 percent range which matched the results. However, the hypothesis underestimated Claude which scored higher than expected. This may be because Claude has improved recently or because the dataset patterns were clearer than predicted.

Human results also showed important trends. Below is a table summarizing the performance by age group.

Human Group Accuracy Table

Group	Average Accuracy Range	High Performers (45 or more correct)	Mid Range (30-45 correct)	Low Range (below 30)
Teenagers (10)	75%–85%	82%	10%	8%
Adults (10)	85%–95%	96%	3%	1%
Senior Citizens (5)	65%–75%	68%	10%	22%

Adults performed the strongest, teenagers performed slightly lower, and senior citizens struggled the most. None of the human groups matched any of the LLMs in consistency or accuracy. The results supported the belief that AI systems would outperform humans.

Challenges

Throughout the project, I experienced several challenges. One challenge was finding a high quality dataset for scam message classification. Many available datasets were outdated or too small which made the early stages slower. Because of this, I redesigned parts of the plan and built my own dataset.

Another challenge was having to manually prompt each LLM instead of using an automated script. This made the process longer and increased the chance of small inconsistencies. Collecting enough human participants was also difficult because it required reminders and follow up messages which slowed progress.

Looking back, I would start searching for datasets earlier and plan my structure more carefully. If I had more time or technical support, I would build a Python system to automatically test models, clean data, and generate charts. Even though the project had challenges, they helped me learn how to adapt and solve problems.

Conclusion

The goal of this project was to compare the scam detection accuracy of humans and LLMs. The results showed that LLMs performed better and were more consistent than all human age groups. Claude was the strongest model with a perfect score. Humans still showed valuable strengths such as understanding emotional cues and real world communication. The results highlight that both humans and LLMs have important roles in detecting scams. This research shows that LLMs can support stronger safety tools, but human judgment remains important for understanding context and nuance. The findings show that combining AI systems with human awareness can create better protection against scams in the future.

Boeing's Success After WWII and Aviation Accident By Tianyu Li

Abstract

This paper examines/investigates what factors contributed to Boeing's victory against its commercial rivals in two decades before and after WWII. Through the accumulative efforts in the period, Boeing eventually surpassed its opponents. The methods used in this paper include a literature review, data collection and analysis, and case studies. A detailed historical context provides an overall background of that era. A spreadsheet was made to meet the requirements of the analysis, and it contains all serious aviation accidents between 1952 and 1967 found on ASN (Aviation Safety Network). The results show that Boeing's timing, history, and experience helped it get ahead of its rivals. The lower crash rate of its airliners compared to its opponents and the public views also influenced the deliveries and helped Boeing succeed. As such, this paper is broken into three main sections. The first section contains the introduction and methodology. The second section is the historical context, divided into three smaller parts. The third section, which is the main body, discusses three factors contributing to Boeing's success: Boeing's timing and its progressive technologies, the air disasters of its rivals, and the public views on all those things. The first factor, timing, mainly contains some history of Boeing's early age–before WWII–and how it used the first-mover advantage in practice. This paper focuses on the techniques used in the two World Wars when Boeing had the techniques first out of all other aircraft. The second factor about air crashes and their public views is the longest section in this paper due to the analyses of a spreadsheet made by the author from ASN that lists all essential details about every large air disaster from 1952 to 1967. The period between 1952 and 1967 is focused upon as the most significant fluctuation in Boeing's dominance of the market. The public views of those aviation accidents and their influences are also discussed.

Keywords

Engineering mechanics; Aerospace engineering; Boeing; Aviation history; Air crashes.

Introduction

The Boeing Company, nowadays one of the largest airliner manufacturing companies in the world, faced many obstacles at the end of WWII, especially regarding their commercial airliners. One example is the economic problems caused by the lower-than-expected orders of the propeller airliner Boeing 377, designed early after the war, and the decreased public confidence in its product. Thus, it is notable that only a few decades later, Boeing surpassed all its opponents and secured the dominant place in the civil aviation market after conceding all those setbacks. Analyzing Boeing's initial commercial success is valuable, especially considering its current competition with Airbus. This article is meant to supplement the period of aviation history from post-World War II to the 1970s. Today, more authors are putting effort into studying the competition between Boeing and Airbus, and fewer publications research the earlier era of

commercial aviation. New data sites have been created, and though some aspects of this research may have been mentioned before, no one has yet compiled them together.

The first part of the historical context is about the golden age of aviation and the development of civil aviation after WWII. The second part is about Boeing's actual success, supported by some evidence from other papers and data. The last part consists of basic information about the commercial airliners at that time. All of those above lead to my conclusion: Boeing's victory was caused by many factors, mainly its timing, skill-advancing technologies, and the aviation disasters that happened at that time, which altered public views. It is through this historical period that Boeing gradually established its advantage, and therefore this topic is worth studying.

Methods

Multiple research methods were required to construct this essay, such as a literature review, data collection and analysis, and case studies. A literature review of existing scholarship is first conducted. This involved the use of Google Scholar to search keywords such as "golden age of aviation," "Boeing's success," and "air disasters' public influences." I found around thirty sources, and only those that included the relationship between Boeing and the air crashes were used. Many historical contexts in the essay are based on those ideas, as well as the first few parts of the main argument of this essay, including Boeing's good timing and Boeing's history. Then, there is the need for data analysis, which is used in the argument of the second factor of the paper, also the most weighted part. Many forms and data from those papers were found online in Google Scholar, and final reports of the air disasters were collected. Searches on ASN (Aviation Safety Network), where a lot of information about almost every aviation accident and incident in human aviation history was gathered, were also performed. They were compared with the deliveries of Boeing, Douglas, and other manufactured planes related to the accident. Using the collected data, I created a spreadsheet of the aviation accidents in 1952-1967. It contains all the summative information for crashes recorded in ASN (Aviation Safety Network) during that period. I performed multiple statistical analysis from it, and made many charts which were to be used in the paper. There are a few aspects that need a specific explanation. In the original chart, the percentage in the "death rate" column may exceed 100% since ground fatalities may be many times more than in the airplane itself. Also, after compiling all events, some air disasters in this chart that existed at first were intentionally excluded, even though they may be available on the ASN since all of them were the only ones that involved that specific aircraft and the average of the occupants on each of them were less than 20. Because there are some significant differences between small regional airliners and large airplanes, it can be reasonably concluded that their accidents did not have a lot of impact on the civil aviation market. Only keeping a few exceptional cases of aviation accidents involving small airplanes that somehow drew more attention would not be appropriate either.

Additionally, the "Reason" column is only a concise summary of what is happening for categorical uses, and most maintenance errors were counted as "mechanical failure." In contrast,

a “navigation error” or “ATC error” is considered a human error. After neatening the data, I created line graphs, pie charts, and bar charts based on the spreadsheet further to analyze air disasters’ impact on public view. To accomplish that part, newspaper front pages of those air crashes were found, and public opinion was deduced from newspapers and related to the success of Boeing.

Historical Context

Section 1: The Golden Age of Civil Aviation

When World War II came close to an end, the development of civil aviation experienced a significant boost. This happened mainly because a large number of companies transitioned themselves to military airplane builders to support the war, especially in the continental US. However, after WWII ended, those manufacturers needed to rebrand because of the declining orders for military planes. The result was civil aviation.

Leisure travel grew in popularity after WWII. Unlike warplanes, commercial flights did not have the risk of being shot down, so the public’s concern about the safety of the airline could be alleviated. All of this led to a tremendous demand for new commercial airliners since even the latest airliners at that time were designed before WWII started and in the 1930s, such as the Douglas DC-3, which was a whole generation behind.[1]

The airliners designed then were generally very small and had a capacity of 30 people. Their sustainability could have been higher, and many could not afford trans-nation flights. Moreover, because of the enormous demand for military planes in WWII, many of those airliners were transformed for military use, and there were only a few planes left for civil aviation for each country. It was like a loop in which commercial airliners were transformed into military planes but could not return when civil aviation’s requirements were high. Therefore, the aviation field urgently needed newly designed airliners.[2]

Therefore, the 1950s and 1960s are often referred to as the golden age of civil aviation,[3,4] as multiple companies competed; unlike today, Boeing and Airbus are now the only two dominant airliner manufacturers. In the 1950s, the commercial aviation landscape was still being determined. Airbus had yet to be founded, and Boeing was still far from dominating the civil aviation market. The sky was filled with diverse airliners, and the market was filled with enthusiastic contestants.

Section 2: Boeing’s Overall Success

A large number of companies competed within the civil aviation market. Those companies included Lockheed, Douglas, Boeing, Convair, de Havilland, and many other smaller ones (The word “smaller” refers to the fact that they may only have designed one commercial

1

2

3

4

airliner product).[5] Many of the companies were founded early, only a few decades after the first plane was invented, such as Boeing and de Havilland. In contrast, some companies were established close to the end of WWII and are also competing for the market, such as Convair. However, the number of companies lead to competition, which was advantageous for Boeing.

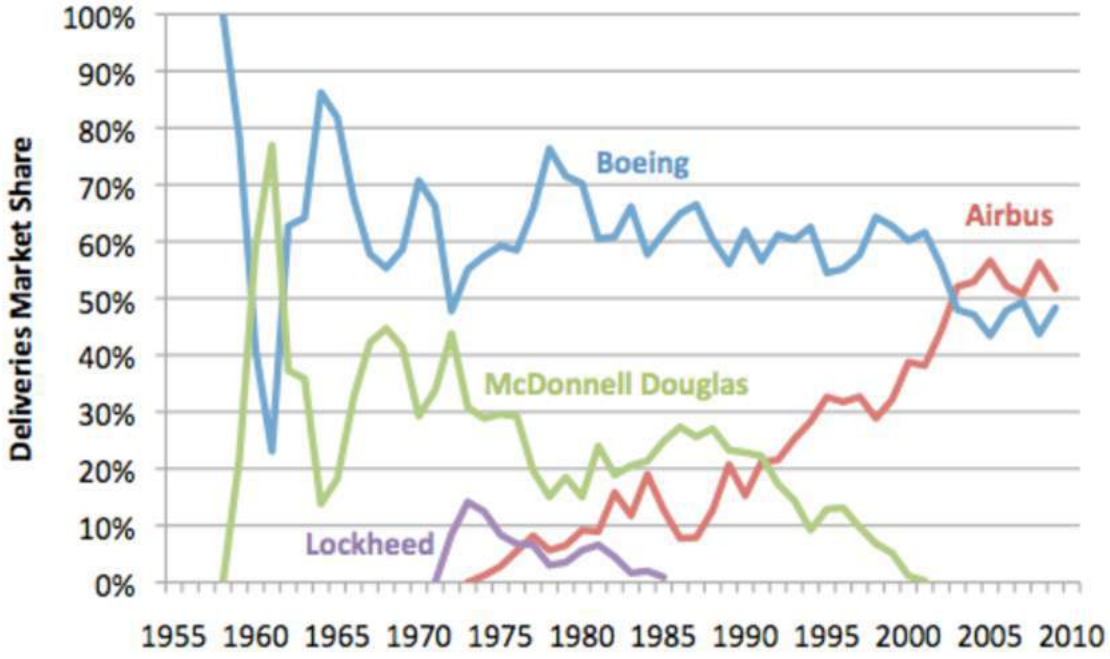


Figure 1. Delivery market share between the manufacturers, Boeing surpassed Douglas in around 1964.

As the graph Figure 1[6] shows, the delivery market share of Boeing was only overrun by Douglas for a few years before and after 1960. After that, Boeing's share raised dramatically and peaked in 1965. After that, Boeing was always the forerunner of the aviation industry, and that advantage was held for almost half a century before Airbus could finally compete with Boeing. Therefore, the period this paper focused on, 1952-1967, was dangerous for Boeing as Douglas was a substantial threat. Fortunately for Boeing, because of the factors discussed in the following text, it kept its advantage so that it did not lose to the newcomers of the commercial aviation industry.

The other noteworthy event in 1967 was the Boeing 737's first flight. It was another sign of Boeing's success, as the Boeing 737 dominated the market of narrow-bodied airliners for more than half a century. Even now, an average of 1,250 Boeing 737s fly in the sky, and there is only an average of 5 seconds between takeoffs for two of them worldwide.[7] In contrast, most of its early contenders, such as the Douglas DC-9, BAC 1-11, Fokker F-28 and TU-134, are out of service or only used in limited cargo and private service. It is also the only commercial airliner to

5
6
7

pass 10 thousand deliveries and remains the best-selling commercial airliner in the world, as shown in Table 1.[8]

Table 1. Boeing 737's total delivery number is found on Boeing's website, showing more than 18,000 deliveries.

Model	Total Orders
Originals	1198
Classics	2385
NGs	7949
MAX	7182
Total:	**18714**

Section 3: The Commercial Airliners in the 1950s

Right at the end of WWII, airplane companies were still trying to make new airliners designed with propellers since they were familiar with that, and the public also had more confidence in such technology. Many newly designed propeller airliners emerged within only two or three years after the end of the war, such as Convair 240, Douglas DC-6, and Lockheed L-049 Constellation. Some of those planes had their first flights before 1945, but close to the end of WWII, the situation was clear that the war would end. Those companies already predicted and expected the high demand for commercial planes after the war, which was very sensible. Even Boeing had put out its new commercial airliner, the Boeing 377 Stratocruiser, in 1947. It was a large and long-range four-engine propeller plane developed from the C-97 Stratofreighter military transport (the C-97 itself is a derivative of the famous B-29 bomber).[9] At that time, it was an exclusive seat on Boeing 377, and the plane could typically carry 84 passengers or 28 berths on trans-continent flights.

Almost all commercial propeller planes developed in that period were directly transformed from some type of transport aircraft, bombers, and aerial tankers. There was only a slight difference between them and military planes. The requirements for airliners made them that way because those companies were so eager to have at least some products on sale that they did not have time to redesign major parts of the plane, such as the wings, engines, and fuselage. However, many companies knew this couldn't be a long-lasting method to gain customers. There was a limited number of already existing military planes that were able to be transformed into airliners (one clearly could not make a two-seat fighter plane into a reasonable commercial airplane); their technology was also not the newest as well, and the public would not be easily satisfied with those "old-fashioned" planes. As soon as the opponent company gets something new, the customer will be attracted to it instantly. Therefore, at the end of WWII, almost every large aircraft maker who wanted to focus on aviation instead of shifting to other fields, such as

8

9

chemical industries, tried their best to design an entirely new type of airliner. The shiny and attractive concept was the jet.

The first ever built controllable jet airplane, He 178, made its first flight in August 1939. After that, the same German manufacturer made He 280, and then Me 262, the first turbojet fighter that ever had an actual fight.[10] However, that was close to the end of WWII, and the fighter was used to make the last unsuccessful air attack by the Germans. Me 262 was only a primal product designed within a minimal time since Germany was losing the war. Still, afterward, the whole world, including Boeing and almost all of its rivals, saw the potential of jet planes and their possible uses in civil aviation.

Compared to turboprop planes, turbojets had many commercial advantages, including their long range, quietness, and comfortable cabin. Many experiments had easily eliminated the criticism about jets being only fuel-consuming monsters before the middle of the 1950s. After all, the jet was quickly becoming a new fashion.

The coming of the golden age of civil aviation was discussed previously, and the first one to react to the idea of jet airliners was de Havilland. As early as 1943, a requirement to design a new jetliner for the UK's civil aviation was brought forward by the Brabazon Committee (directly formed by the Cabinet of the United Kingdom). [11] British company de Havilland accepted this challenge and expanded on it. Over seven years, the company finished the design and prototypes, and de Havilland returned with the astonishing Comet airliner, the first ever built (First flight on July 27, 1949) and introduced (May 2, 1952) jet airliner. It was powered by four jet engines and had a capacity for 36-44 passengers. All other companies felt the immediate need to do something. During that time, Boeing also made its first jet airliner.[12]

Factor 1: Timing and Technologies

Table 2. Founded and Defunct Time of Major Airliner Manufacturers, Boeing has the earliest founding time.

Companies	Found Time	Defunct Time
De Havilland Aircraft Company Limited	1920	1963
Douglas Aircraft Company	1921	1967
Vickers-Armstrongs Limited	1927	1977
Convair	1943	1996
Lockheed Corporation	1926	1995
Boeing Company	1916 (As Pacific Aero Products Co.)	N/A

As seen in Table 2, Boeing was founded a few years to a few decades before its rivals. It already has a lot of experience, so it can enter the market more competitively with many techniques already in hand. This resulted in the first-mover advantage and helped Boeing access its success. Boeing's early history needs to be analyzed to derive more from that.

10

11

12

After being founded in 1916, Boeing 247 was the company's first widely used "large" passenger airliner, with two propeller engines and a capacity 14.[13] Introduced in 1933, it had many advantages over the same type of plane, such as all-metal (anodized aluminum) construction, a fully cantilevered wing, and retractable landing gear.[14] After suffering setbacks from the Air Mail Act, Boeing still designed and introduced the 307 as its second large airliner. It had its first flight in 1938 and was the first airplane with a pressurized cabin. Also having its first flight in 1938, the Boeing 314 Clipper was the largest passenger airliner. It was a flying boat that could carry up to 90 passengers. Therefore, Boeing's airliner is famous for using advanced engineering and aerospace techniques.[15]

However, although the Boeing 377 is the fourth Boeing airliner, it, along with the Boeing 307, was Boeing company's only two airliners still in service in the early 1950s (most of the Boeing 247 were already retired at that time, and the Boeing 314 was retired entirely even earlier, in 1941.) None of those four planes had any relatively big delivery numbers. None of the numbers built exceeded 75, and those three numbers added up to only 153 planes (as seen, Boeing 247 had 75 deliveries and occupied almost half of Boeing's airliner deliveries at that time).[16] Making the situation worse, technical problems with the Boeing 377 plane arose quickly. After several crashes of the Boeing 377 that were directly related to the plane's propeller design flaws, the public was quickly losing confidence in it. It was a severe problem even though Boeing was already one of the largest airliner manufacturers in the world. The venture of designing Boeing 377s only led to a few orders, leading to the company losing 15 million dollars.[17] Adding to the problem, Boeing even needed to convince its customers first that its project was at least "safe." Therefore, the likely failure of Boeing 377 could have also led to the failure of Boeing's attempt to break into the civil aviation market. The company could be forced to go back to focus on military airplane manufacturing.

Boeing was not undefeatable in the military airplane manufacturing field as well. Its competition with Douglas started early and failed at first. Boeing designed and built the first well-known bomber, B-17 Flying Fortress, in 1935, and it was the third-most-produced bomber of all time. However, its initial introduction could have been smoother. In a United States Army Air Corps (USAAC) competition, the B-17's prototype performed outstandingly and quickly overpowered its two other rivals. Nevertheless, the prototype crashed shortly after, and Boeing lost the initial 200 aircraft contract to the Douglas B-18 Bolo.[18] Therefore, Boeing desperately wanted to break this impasse, and at last, it decided not to invest more in the propeller aircraft field but to go directly and deeply into the field of jets.

In 1949, Boeing was already embarking on a new jet airliner design, way earlier than its competitor Douglas's start of DC-8 (in 1952).[19] In just five years, Boeing was able to have some

13
14
15
16
17
18
19

test flights on the airliner that it had long desired to publish. The prototype of the Boeing 707 had its company icon and number: the Boeing 367-80 or Dash 80, and had its first flight in 1954. Boeing 707 had its first flight in 1957,[20] years earlier than the DC-8's first flight, which occurred in 1958. Therefore, by introducing its plane ahead of its opponent, Boeing could occupy a large portion of the market share and was more likely to succeed. However, there were setbacks, such as air disasters in those eras, but Boeing also dealt well with them and utilized them to succeed.

Factor 2: The Results, Aviation Accidents and Public Views

Accidents and incidents are inevitable parts of aviation history. They happened throughout the process and development of aviation. Learning from history and accidents is a crucial ability for humans to develop and avoid the same mistakes, so the study of air crashes is also essential because they are the dark occurrences in aviation history.

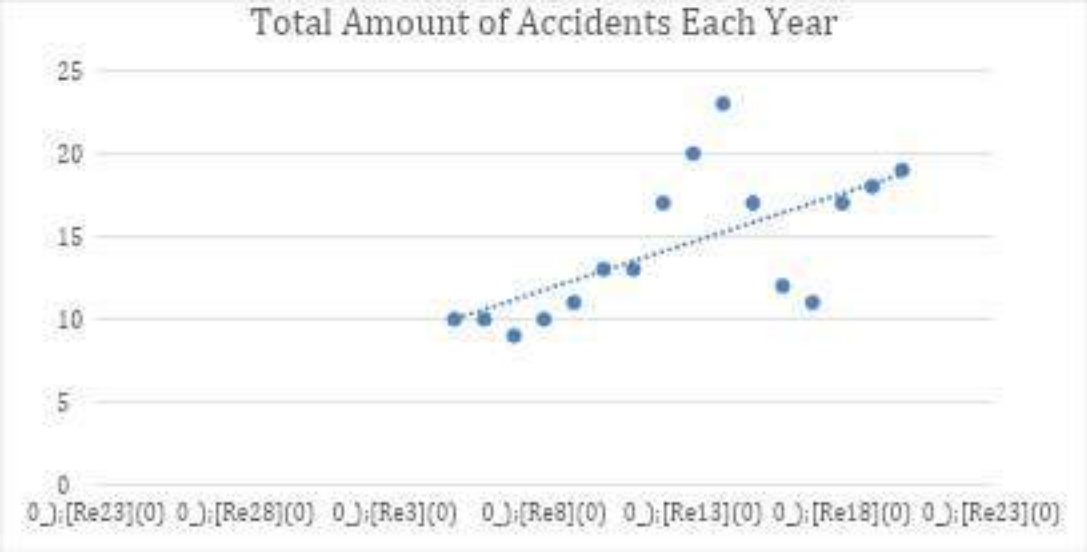


Figure 2. The total number of aviation accidents involving planes from all airlines has an average occupant of 20 or more each year; a rising tendency could be seen.

In the line chart Figure 2, it is evident that the trend line slope of this chart is positive, though not large, which means the cases of air crashes each year increased slightly. Therefore, we can conclude that the total number of crashes each year increased, and their importance or popularity rose with the number. Air crashes were becoming a larger concern for travelers, and Boeing could utilize the concern to surpass its opponents. Further analysis of other charts was made using the spreadsheet.

20

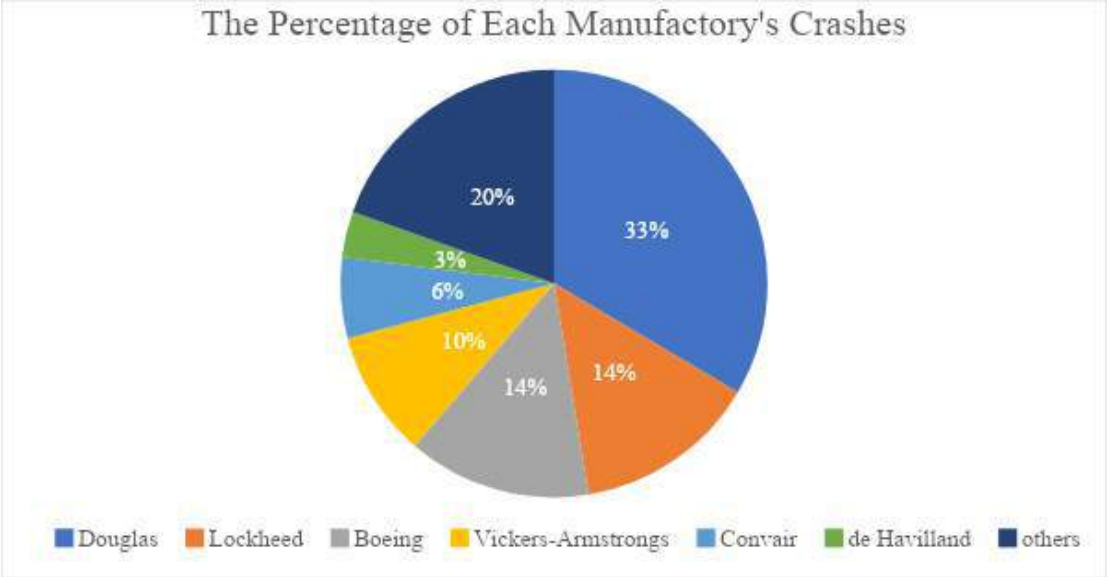


Figure 3. The contribution of crashes of the six largest aircraft manufacturers from 1952 to 1967. Douglas had the largest proportion of crashes.

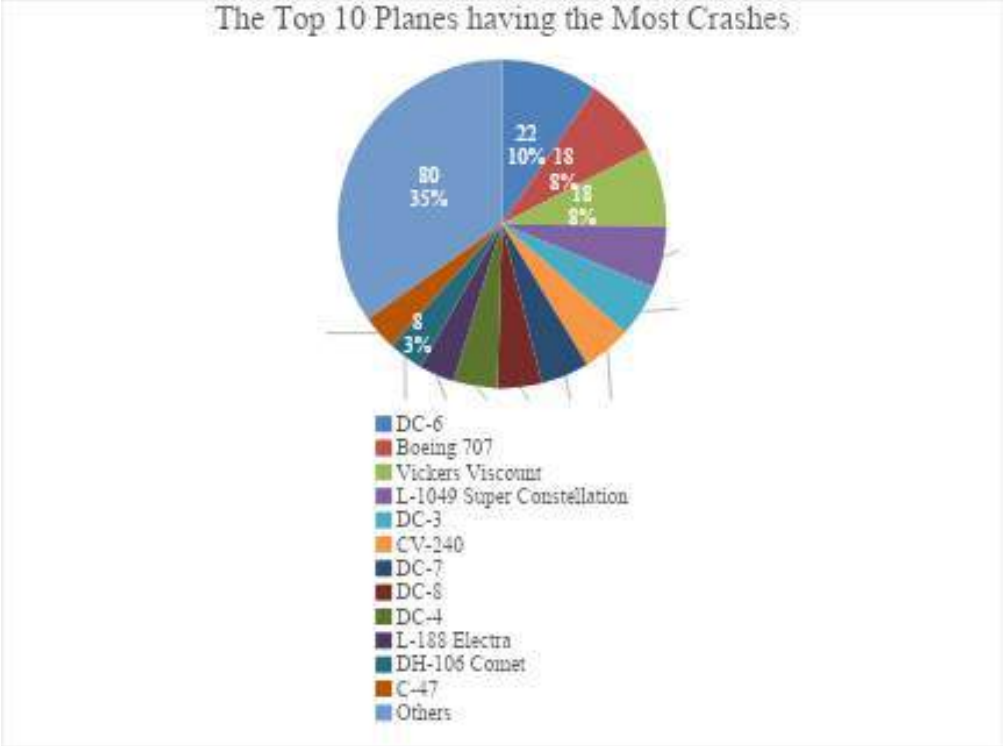


Figure 4. The airliners with the most significant accidents (Top 10 included). DC-6 had the most crashes.

Figure 3 and Figure 4 show that the "most crashed" individual product was the DC-6 plane. Douglas also has the highest total crash number, more than twice that of Boeing and Lockheed. Although in second place in Figure 4, Boeing 707 shares the same number of crashes as Vickers Viscount, its accidents were still fewer than those of the DC-6.

Additional information in Figure 4 includes the incidents of Convair and Lockheed's famous products, such as L-1049 and CV-240. Moreover, almost all of Douglas's products, from DC-3 to DC-8, are all on this chart. DC-9 has yet to appear on this chart, as its first flight time was in 1965. However, Boeing's already finished products, such as the earliest, Boeing 377, or the newer ones like Boeing 720 and Boeing 727, were still absent from this pie chart. In contrast, although DC-3's production was finished in 1942, it still had a lot of crashes in 1952-1967. Therefore, it can be concluded that Boeing's overall product safety, or at least the crash rate, was not as high as Douglas's, and that rate was what many of the passengers were concerned about the most.[21]

From 1958 to 1968, Boeing 707's deliveries were always ahead of or at least equal to DC 8's. The chart, Figure 5, is made from data available on the Internet.[22] So, it would be reasonable for Boeing 707 to have more air crashes than DC-8 if it had the same crash rate as DC-8. The company that had the same number of crashes as Boeing was Lockheed. However, as shown in Figure 1, Lockheed's market share was meager then. Therefore, Boeing's airplanes could be considered generally safer than most other companies' planes.

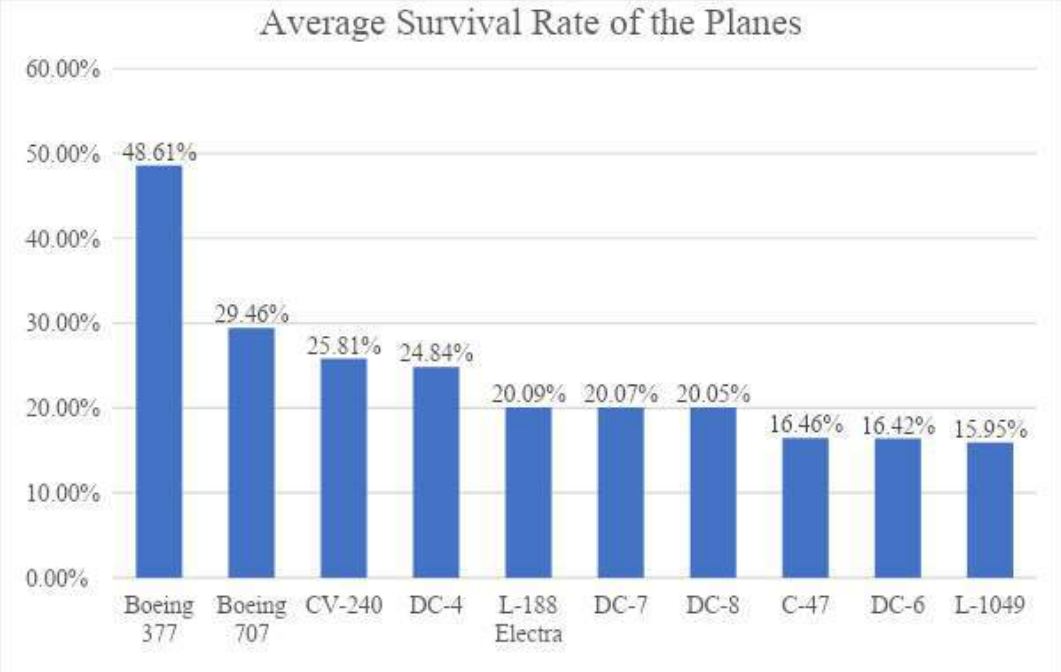


Figure 5. The average survival rate of passengers in every plane that has at least five accidents in total. According to the original data from ASN, Boeing 377 and Boeing 707 have the highest survival rates. Only the aircraft with the top 10 average passenger survival rates were selected to make the figure legible.

21

22

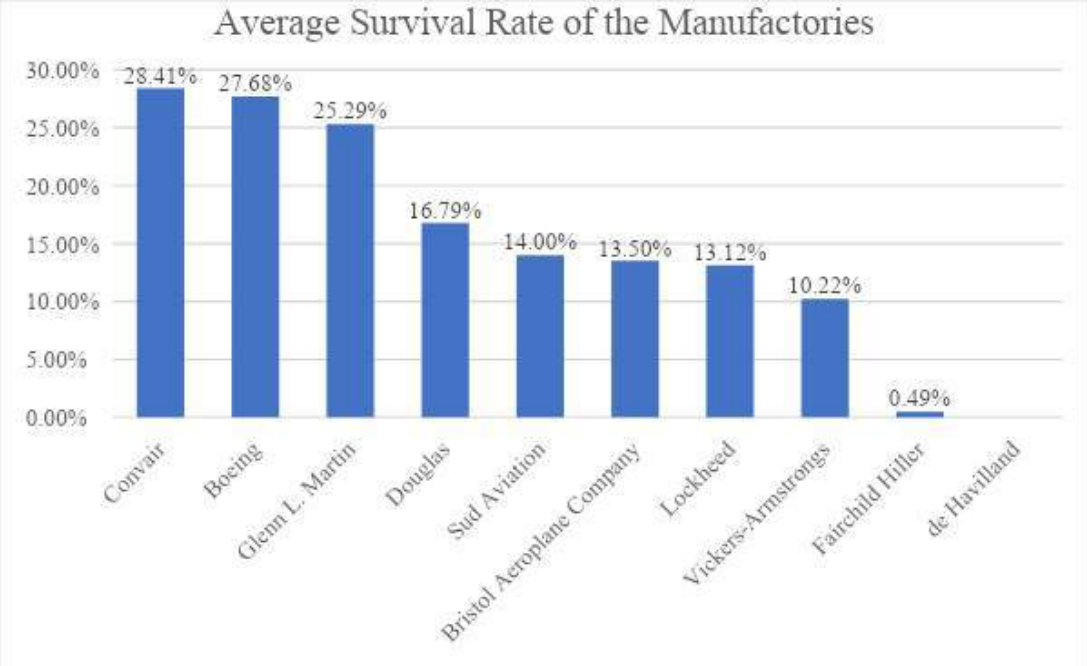


Figure 6. The average survival rate of passengers in planes produced by every manufacturer who have at least five accidents in total. According to the original data from ASN, Boeing is the second highest here. Note that De Havilland aircrafts have a 0% survival rate of passengers. The total number of eligible manufacturers is precisely 10.

Once again, Boeing showed its advantage in the charts that exhibit the average survival rate of planes and manufacturers involved in those aviation disasters. In Figure 6, Boeing and its products are in the first row, with Boeing 377 and Boeing 707 occupying the first two positions of average survival rate of the aircraft. A customer perhaps would choose not to board any Douglas aircraft if they read this chart and concluded that they only have approximately two-thirds of the probability of surviving in a crash in the Douglas airplane instead of the higher rate of the Boeing airplane. There are people helping passengers eliminate their fear of planes for those reasons.[23] Therefore, the statistics and results of the average survival rate could be influential. The survival rate is still a highly accepted standard for measuring "how safe" an aircraft is; therefore, the high survival rate of Boeing's airliners would benefit the company and bring in more orders.

It is necessary to find out more about the causes of actual aviation accidents now, for if resolved at that time, they would have a large effect on the public and promote the deliveries of one company or another.

23

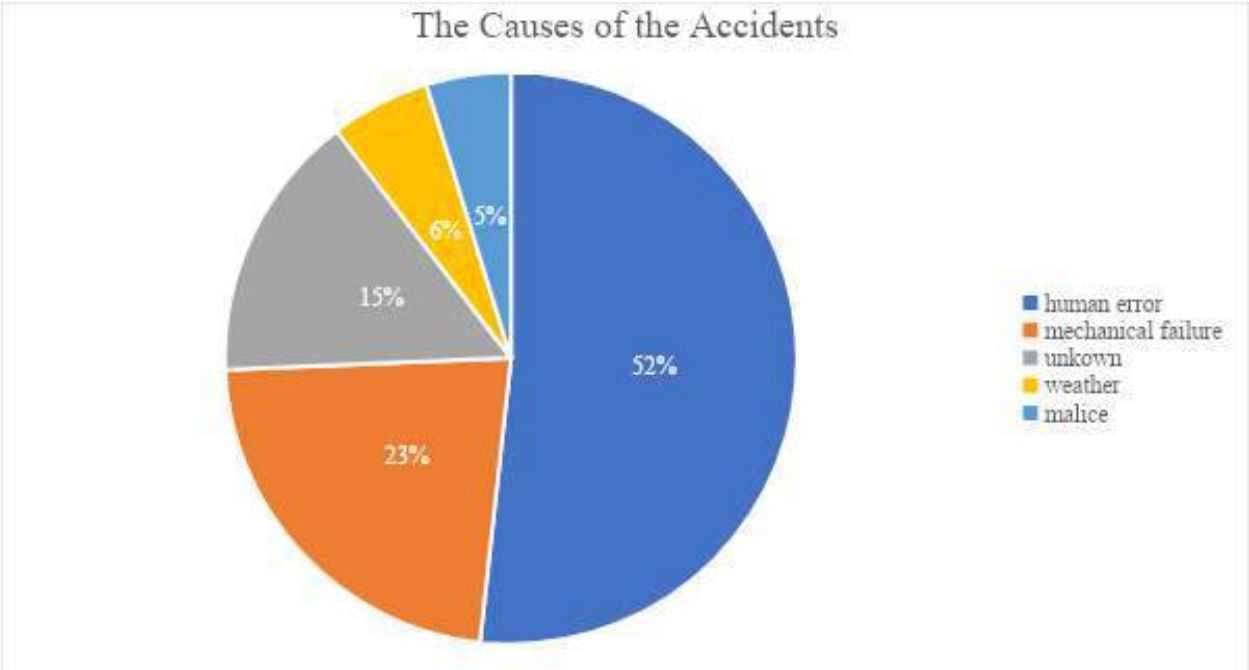


Figure 7. Summary of the causes of the accidents: human errors caused more than half of the accidents—original data from ASN.

From the information collected in Figure 7, it is clear that most air crashes were caused by human error, with 52% being mostly pilot errors, such as ignoring the MDA (minimum descent altitude) that causes CFIT (controlled flight into terrain). Other human errors, such as navigation errors or ATC (primarily seen in those mid-air collisions), also existed. The second highest cause is every type of mechanical failure, resulting in 23% of aviation accidents at that time. Noticeably, many of the crashes' causes remained unknown since the time the crashes happened was still too early for many modern techniques to be used in the investigation. The other two causes were severe weather turbulence (which often caused mid-air break-ups) and malice (like bombings and being shot down).

Among those, "mechanical failure" would be the one that raised the most concern as those failures could come from a design flaw of that airliner. It would be a significant setback for the company itself since that would be the simplest way to prove its plane was unsafe. For instance, the DC-10's cargo doors were the most direct and bloody evidence, as evidenced by two failures due to improper lock systems, which caused one plane's crash. This made DC-10 lose the confidence of the public and almost every airline that ordered that plane since they would likely not want to operate it later.[24] Two charts demonstrate this situation below.

[24]

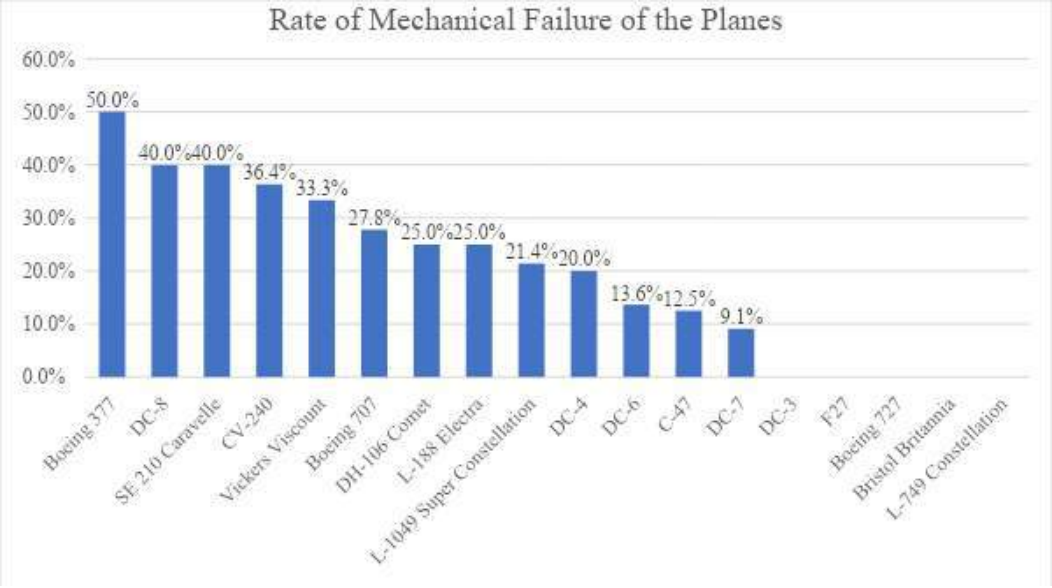


Figure 8. The rate of each type of plane that had at least five accidents caused by mechanical failure. DC-8 had the second highest MF rate, and all Boeing's products except Boeing 377 are not in the top five—original data from ASN.

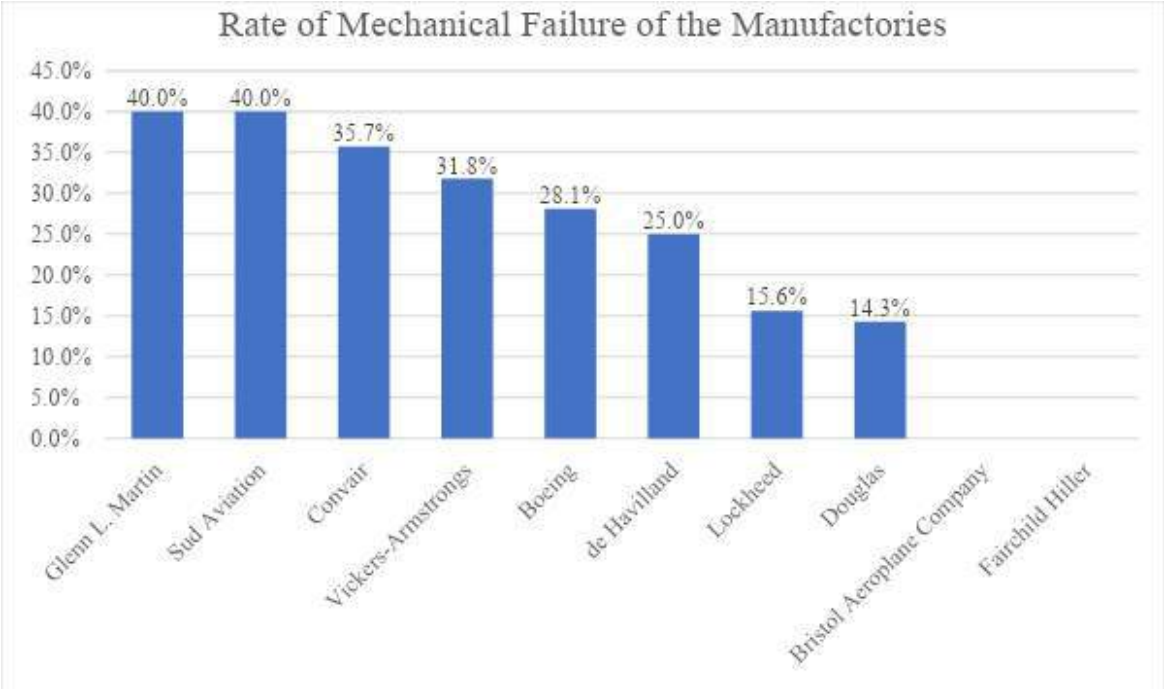


Figure 9. The portion of air crashes caused by mechanical failure of every manufacturer that was at least involved in five crashes. Boeing Company is in the middle—original data from ASN.

Figure 8 shows that Boeing's new jet, Boeing 727, has a perfect 0% mechanical failure rate (later called "MF rate"). In other words, the cause of the accidents is most likely to be human error or another error instead of the design of the airliner itself being a problem. Boeing 707's MF rate was also relatively low compared to its direct competitor, DC-8. The exceptionally

high MF rate of DC-8 would cause it to be underestimated by many customers, such as those large airliners that used to want to make orders for this plane. This is Boeing 707's clear advantage. Although Boeing 377 had the highest MF rate, it was already addressed that Boeing's early product indeed had some flaws, and Boeing managed to solve them in the "Factor 1" section. Therefore, Boeing 377 can be excluded from this list. Figure 9 also shows that Boeing's overall MF rate is not high either.

However, the individuals who doubt Douglas products' safety due to its high MF rate could only be those experts since the public would need to learn more about aviation. They would only care about how frequently a specific airliner crashes rather than the reason for its crash (whether it was totally the pilot's error or the problem was related directly to the plane itself), except if someone points out the factor that contributed to the crash for them. That brings us to the last part that contributed to Boeing's success: the public view of those air crashes. Boeing benefited from air crashes in the 1950s and won against its rivals. There are many sources to prove it, such as in one article,[25] where the author illustrates Boeing's design process. In another,[26] Boeing used the public's fear of the de Havilland Comet and all jet airliners in 1954. An air crash can become well-known when involving a famous person, and the plane or the pilot would be blamed for it. "The Day the Music Died" is an excellent example of the varying influences of air disasters. On February 3, 1959, the crash of a Beechcraft Bonanza resulted in the death of the pilot and three passengers: Buddy Holly, Ritchie Valens, and J. P. Richardson. All of them were some of the most famous rock and roll musicians at that time. The cause of the air crash was heavy fog, which caused the pilot to have spatial disorientation.[27] Some newspaper front pages are placed in the following text to show how an individual would see the astonishingly large topic so that the reports of the aviation accidents would be a very influential factor to the overall public views of some manufacturers' airliners.

25

26

27



Figure 10. On the front page of Mirror News on February 3, 1959, [28], "airplane crash" was bold in the headlines.

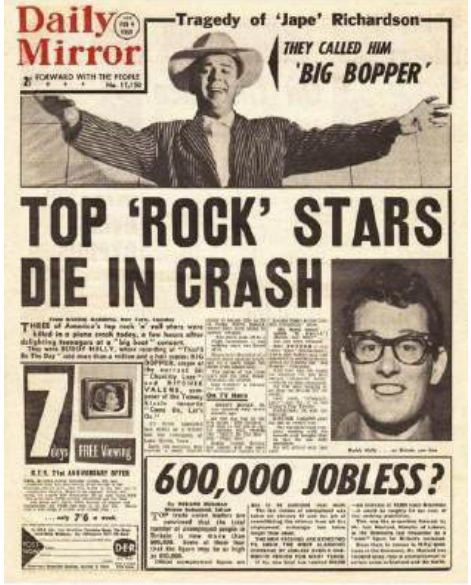


Figure 11. The front page of the Daily Mirror report of the accident.[29]

28

29

As can be seen, the giant headline topic of those newspapers in Figure 10 and Figure 11 can be impactful. Several other famous people did die because of Douglas's airliner crash, such as American actress Carole Lombard, who died in 1942 at only age 33 aboard a DC-3 airplane when it crashed into Potosi Mountain. The other one is American big band founder Glenn Miller, who went missing on a Douglas C-64 in 1944. Therefore, after the high number of accidents DC-8 had and the death of some celebrities on those Douglas airliners, the citizens and passengers were most likely to board the Boeing 707, and the result was Boeing's success.

Conclusion

The above data indicates that Boeing won against its rivals in almost all aspects in the 1950s and 1960s when the golden age of aviation took place, and tens of airplane manufacturing companies competed for the market share of civil aviation. Many factors caused Boeing's victory, but its timing skill, advanced technologies, and aviation disasters that happened at that time, which altered public views and indirectly increased Boeing's market share, were the main ones.

In the historical context section, the causes of the golden age of civil aviation were explained, and evidence of the results was shown; Boeing's overall success was also shown. After WWII, the commercial airliners changed a lot, and jets became the new fashion. Boeing was going to use that concept before its primary opponent, Douglas.

The first advantage that Boeing most firmly had was that it had much more experience in airplane manufacturing due to its very early founding date, 1916, 5 years ahead of Douglas and decades before most of its competitors. At that time, planes had just been invented, so although Boeing mainly focused on military products, it still gained abundant technologies in all aviation-related products, including airliners. Its ability to introduce the Boeing 707 ahead of the Douglas DC-8 also made the market prefer the Boeing 707 more and acquire more early orders. Engineering techniques also helped since Boeing kept many "first" records in the civil aviation field, such as the first airplane with a pressurized cabin (Boeing 307) and the largest airliner at that time (Boeing 314 Clipper), which engaged customers to board their plane.

The second significant factor in Boeing's success was the aviation accidents and the chain reaction that caused the public to prefer Boeing's products over those of its competitors. The 16-year period from 1952 to 1967 is the emphasis of this article, as well as the spreadsheet that contains all the aviation accidents that happened during that era. Five (pairs) charts illustrate the situation, with chart 1 showing the overall tendency of cases occurring, Figure 3 and Figure 5 showing the percentage of each manufacturer and airliner involved in the total number of aviation accidents. The results were clear: although Boeing had more market share than all of those companies then, it still had much fewer crashes than Douglas and had the same rate as Lockheed. Boeing's product crash proportion was also low, which meant Boeing's crash rate was lower, which would draw more airlines to buy its products.

After that, Figures 6 and 7 show the average survival rate of each airliner and the manufacturers. This part is what the passengers were most likely to be concerned about, and

Boeing also had its advantage here. Two Boeing airplanes, Boeing 377 and Boeing 707, occupied the first and second place in the survival rate rankings. Boeing itself was also only slightly behind Convair overall and had second place. Therefore, passengers likely thought Boeing's plane was safer. Later, Figure 7 showed that most accidents were caused by human error followed by mechanical failure. Thus, Figure 9 and Figure 10 explain the mechanical failure rate as a cause of the accidents for all airliners and manufacturers. Although Boeing's preponderance was not high, its products, such as Boeing 707's MF rate, were still lower than the Douglas DC-8. Boeing exhibited an overwhelming history in this part, which also influenced and caused negative public views toward its opponent, which led to Boeing's success.

As claimed in the abstract, this article supplements aviation history from the 1940s to the 1960s. My unique contribution was the spreadsheet summarizing all air crashes between 1952 and 1967. Though this paper is completed, there is much more to be explored. For instance, what were the aviation industry situations in China and the Soviet Union? Did the air crashes there also influence the leading U.S. airliner manufacturers? Also, doing more media studies and examining pilot interviews at that time would be compelling.

Works Cited

1. Mowery, David C., and Nathan Rosenberg. Paths of innovation: Technological change in 20th-century America. Cambridge University Press, 1999.
2. Filburn, Thomas, and Thomas Filburn. "Commercial Aviation History." Commercial Aviation in the Jet Era and the Systems that Make it Possible (2020): 1-14.
3. Vaughan, David K. "The Possibilities of Flight: The Golden Age of American Aviation Series Books, 1927-1932." Primary Sources & Original Works 4, no. 1-2 (1997): 133-145.
4. Sezgin, Erkan, and Medet Yolal. "Golden age of mass tourism: Its history and development." Visions for global tourism industry-Creating and sustaining competitive strategies (2012): 73-90.
5. Tatry, Philippe, Justine Fesquet, Pascal Tassy, Gaetan Sciacco, Francis Duranthon, and Jean-Paul Domergue. "Cladistics applied to Aerospace." In 9th European Conference for Aeronautics and Space Science (EUCASS), 2022, P4.
6. Morrison, James Kelley Douglas. "Game theory analysis of aircraft manufacturer innovation strategies in the face of increasing airline fuel costs." PhD diss., Massachusetts Institute of Technology, 2011, P59.
7. flightglobal.com. "The 737 Story: Little Wonder.", Flight International, 2006.
8. boeing.com, /company/general-info/.
9. Mattos, Bento, Ramon Papa, and Luis Carlos Santos. "Considerations about forward fuselage aerodynamic design of a transport aircraft." In 42nd AIAA Aerospace Sciences Meeting and Exhibit, p. 1241. 2004.
10. Wild, Thomas W. Aircraft powerplants. McGraw-Hill Education, 2018.
11. Trischler and Helmuth 2003, P88.
12. Simons, Graham. Comet! The World's First Jet Airliner. Pen and Sword, 2013, P59.
13. Trimble, William F. "The Boeing 247: The First Modern Airliner." Business History Review 67, no. 3 (1993): 488-490.
14. Van der Linden, F. Robert, and Victor J. Seely. The Boeing 247: the first modern airliner. University of Washington Press, 2011.
15. Graff, Cory. Boeing Field. Arcadia Publishing, 2008.
16. Ibid.
17. Unknown author, "Gamble in the Sky." Time: July 19, 1954.
18. Boeing, B. "Boeing B-17 Flying Fortress." American Warplanes of WWII: 250, P254.
19. Pitt, Ivan L., John R. Norsworthy, Ivan L. Pitt, and John R. Norsworthy. "Aircraft Characteristics." Economics of the US Commercial Airline Industry: Productivity, Technology and Deregulation (1999): 41-65.
20. aviation-history.com., "Boeing 707 Jet Transport."
21. Wegrocki, Henry J. "Anxiety and plane flight." The Psychoanalytic Review (1913-1957) 33 (1946): 1.
22. active.boeing.com., "707 Model Summary through March 2020", 2020.

23. Diane Ouding, “Some of the Best People Are Afraid of Flying”, The New York Times, Aug. 12, 1973.
24. Licht, John-Gabriel, Jamie O’Brien, and Marc Schaffer. "Behind closed doors: the DC-10 and the demise of McDonnell Douglas." The CASE Journal 15, no. 6 (2019): 648-668, https://www.emerald.com/insight/content/doi/10.1108/TCJ-04-2019 0028/full/html?utm_campaign=Emerald_Strategy_PPV_November22_RoN, https://www.aerotime.aero/articles/23156-dc10-history-cargo-doors-reliable-aircraft.
25. KOTHA, SURESH. "SPILLOVERS, SPILL-INS, AND STRATEGIC ENTREPRENEURSHIP: AMERICA’S FIRST COMMERCIAL JET AIRPLANE AND BOEING’S ASCENDANCY IN COMMERCIAL AVIATION" (2010).
26. Withey, P. A. "Fatigue failure of the de Havilland comet I." Engineering failure analysis 4, no. 2 (1997): 147-154.
27. aviation-safety.net, /wikibase/173992#:~:text=Reports%20indicate%20the%20aircraft%20took,conditions%20without%20an%20instrument%20rating.
28. Mirror News, February 3rd, 1959.
29. BARRY HARDING, Daily Mirror, February 4th, 1959.

Can Meaning-Making Through Song-Lyrics Help with Emotional Regulation?
By Ryan Lee

Keywords

Music Therapy, Emotional Regulation, Meaning-Making, Lyrics in psychology, Music in psychology, Autoethnography, Mental Health, Lyrical interpretation, Depression and anxiety coping, Emotional resonance.

Abstract

This research paper explores how individuals may use music listening, specifically lyrical content, as a healthy means of emotional regulation and mental health coping. Clinical relevance will be considered, primarily towards those suffering from mood disorders, such as mild to moderate levels of depression and anxiety. The overall research may be more widely applicable to anybody who finds meaning in music listening. Drawing from current psychological and autoethnographic research, this paper considers music listening in a new perspective. Unlike many studies that analyze physiological responses to musical elements such as the tempo or key of a song, the focus of this paper will be on the significance of the lyrics and how they are emotionally interpreted. The effects of artificial intelligence (AI) on emotional interpretation have been considered, with regards to the potential impact that AI may have towards meaning making from music lyrics. The research considers how lyrical ambiguity and personal interpretation may influence self-care. Findings suggest that lyrical ambiguity can trigger a range of feelings and induce moments of self-reflection. Perhaps music listening, which is generally a flexible and accessible resource for many, may help with emotional clarity and self-awareness.

Introduction

In moments of emotional confusion and vulnerability, people may turn to music for a source of solace. A simple song can bring great comfort, and it can also potentially be used in a more therapeutic manner. Music is a lifeline for many, acting as a tool people can listen to in order to invoke specific feelings. Scholars have noted that music and lyrics can often act as a narrative in our lives, allowing people to listen and integrate certain lyrics into their own life stories. Not only is music important because of the narrative it can create, but also because of how widespread music listening is. According to Nielsen Music 360 (*Country Music Listeners*, 2023), 90-93% of the human population listens to music in some way or another. Due to the widespread practice of music listening, this research focuses on the potential it has as a self-help tool in people's everyday lives. More specifically, this research explores how regular music listening can function to both regulate and recognize one's own emotions and aid in mental health coping.

What's missing

Whilst previous studies on this topic focuses on more physiological responses to music listening, this research shifts the focus onto more emotional and interpretative acts of listening to music. It was found that existing research topics focused mainly on lyrical content in songs, highlighting technical aspects such as tempo or volume. However, lyrics can help paint a fuller picture, therefore it is important to consider their potential emotional effects. Lyrical content is almost never static in a song; the meaning is constantly shifting depending on when and where it is being listened to and who the person listening to the song might be. Lyrics may have become even more critical in today's world, due to the recent advances in artificial intelligence (AI) and its role in music. Lyrics and meaning-making can also go hand in hand in terms of individual interpretation.

For the context of this paper, meaning-making is the idea that an individual's process of understanding and interpreting something in a song can shift depending on their own life events and situation. It could be considered that lyrics are emotionally projected onto listeners and can mold to fit their emotional states. This may explain the process of meaning-making and therefore why the same songs can mean different things to different people. The question that ultimately guides this research is: "Can lyrics help listeners better interpret and cope with their feelings through the process of meaning-making?"

Why does it matter

This topic matters because of its potential reach. Almost everyone on earth listens to music (*Country Music Listeners*, 2023), and on average adults engage with this music for 44-68% of their waking hours, an overwhelming statistic. In addition, surveys by the International Federation of the Phonographic Industry (IFPI) reveal that 71% of people say that music is important to their mental health, and 78% of people use music to cope with stress or other negative emotions. If people can understand how lyrics are able to help people reflect on their emotions and experiences in a healthy manner, they may further understand how music may become a form of accessible self-care that doesn't immediately resort to therapy or medication. This research aims to bring more awareness to the fact that music and lyrics are not merely entertainment, but instead a potential means of self-reflection, and sometimes even emotional or psychological survival. Previous research on the topic will now be introduced.

Literature Review

Focusing on secondary data analysis, existing literature has mainly focused on measurable components such as volume, tempo, and the key of a song. For instance, Juslin (2013) uses a framework including eight mechanisms, Brain Stem Reflex, Rhythmic Entrainment, Evaluative Conditioning, Contagion, Visual Imagery, Episodic Memory, Musical Expectancy, and Aesthetic Judgment (BRECVEMA), which outlines various mechanisms such as brain stem reflexes and rhythmic entrainment to explain why music can evoke emotion in people. Koelsch, (2020) states that music evoked emotions activate core affective brain systems which help with emotional events in life. Models like this often only focus on the technical

factors of music, neglecting experiential aspects one can feel from listening to a song. Barrett, Grimm, and Sedikides (2010) added their view by showing how both personality and memory can help shape responses to music-evoked nostalgia. Barrett et al., (2010) discovered that lyrical tone can sometimes alter the emotional quality of memories that are recalled to mind. Their study points toward the idea that lyrics are not just background noise but actually central to how listeners construct emotional meaning behind a song.

Eickholt, Tamplin, and Clark (2025) offered a more clinical perspective, by focusing on how lyrics have been used in therapeutic settings, specifically for patients with depression living in residential care. They discovered that lyrics could provide some insight into a person's emotional experiences and offer language for countless different emotions. Similarly, Sedikides, Leunissen, and Wildschut (2022) supported the idea that music-evoked nostalgia helps reinforce ideas like self-continuity, someone's meaning in life, and social connectedness. Musgrave (2019) makes another interesting point about how music could help in emotional labor and identity. The research considers how music can support emotional stability and meaning making.

In more recent years, Boyle's (2024) study offered an autoethnographic view in the lived experience of music listening. Bist's (2024) study did the same, which centered around and offered perspectives of five vastly different people. Both of these studies lean toward the individual human experience of listening to music, rather than the general effects music can have on the body.

Autoethnography as a methodology allows for the subjective nature of music and lyrical interpretation to be investigated. It was specifically chosen as a methodology for this research because of how subjective lyrics can be. Although meaning making can be used by anyone, the process differs from person to person, so there is no "correct" answer when talking about it. For example, Bist et al. (2024) studied the way lyrics shape how each person processes grief, personal transformation, or problems with religion. The people studied explained how extreme emotions such as grief, anxiety, and nostalgia were triggered because of certain lyrics in a song. The lyrics seemed to work as an emotional catalyst for personal listening, and each person reacted and felt a completely unique way.

Many recent studies demonstrate a shift in the psychological lens centered around music. Instead of thinking about music as a rigid structure that only elicits physiological responses, many studies have shifted to thinking about music as more of a narrative act. Musgrave (2019) shares an interesting point of view, stating that music provides structure to the act of living and working. This view highlights music's broader function in a social setting and how it might shape our emotions. Lipski's 2014 study was one of a few to provide a precedent for using personal music reflection as actual therapeutic data. Such an approach may influence others to consider blending structured ideas around music theory with more personal experiences, providing intimate insights. These findings overlap to convey the message that lyrics do not simply reflect emotions; rather, lyrics are sometimes able to shape and rewrite emotions based on the context and what the listener may be going through.

Methodology

This research is influenced by autoethnographic tradition, which blends personal narrative and scholarly analysis. This involves active participation from the researcher and introduces their own ideas and experiences in a way that provides insight to the research topic at hand. Autoethnography challenges the belief that researchers should remain entirely objective in every paper they write. Instead, autoethnography is a research method that is much more qualitative. The personal experiences are turned into legitimate data points and pieces of evidence to further expand on the previous research Ellis, Adams, and Bochner (2011).

As well as the inclusion of primary data from the main researcher in the form of reflections on personal experiences, this study includes secondary research data to further reinforce the topic at hand. Rather than highlighting common trends between a large sample size, it was deemed more insightful to focus on a few people's lives and investigate their personal experiences regarding emotions and lyrics. Much inspiration for this came from Lipski (2014) who used a therapeutic narrative combined with autoethnography. Using autoethnography can hopefully provide additional deeper insight into the different phenomena mentioned in this paper. Like Boyle (2024), personal experiences will be used to reflect on specific lyrics and what they reveal about my own emotions and life. Autoethnography was vital for this research as it gives space to dive into fields such as emotion, identity, and other subjective terms and meanings that more traditional social science research methods cannot "prove". Music listening, especially in terms of this paper, relies on being inherently personal. Songs can be tied to emotions, memories, and other intimate aspects. By incorporating autoethnographic personal reflections, as well as scholarly analysis, the research does not lean too personal or too scientific.

The choice of autoethnography also helps combat the limitations of other methods. For instance, a survey or some type of experimental design may be able to collect data about music and meaning making, but it fails to capture aspects such as *how* and *why*. Other methods may also miss the context of each person's unique lived experience. Instead of generalizability, this paper highlights transferability by allowing readers to find reflections and echoes of their own experiences and memories in my personal narrative.

Autoethnography was deemed particularly fitting for this study as it allowed for fluid shifts between research and reflection. Lyrics can be very subjective, so it seemed limiting to only stay in the scope of facts or opinions. To bridge the two together, first person emotional reflections will be incorporated, while still maintaining comparisons with the previously mentioned peer reviewed studies. This approach aims to create a more nuanced understanding of how music can affect thoughts and emotional experiences. Rather than simply offering statistical generalizability like many traditional quantitative and qualitative methods do, this study offers a source of emotional resonance from real-life accounts.

Analysis

As this paper draws from a select few autoethnographic papers, such as Bist et al. (2024), and Boyle (2024), individual music experiences will be reflected on to provide depth. For

instance, Boyle's (2024) paper talks about how she heard a lyric about absence and “being gone”, which triggered a reaction of unexpected crying over the loss of her grandmother despite the song having nothing to do with familial loss. It may be that Boyle was possibly able to subconsciously process the lyric and through the process of meaning-making, use the lyric as a vessel for suppressed grief that had perhaps not yet been dealt with.

Personal Experience

This moment reminds me of my own experience with songs related to such topics, where I’m in a general emotional state I am unable to bring to words until hearing a certain lyric in a song. In Bist's et al. (2024) study, one person taking part states how lyrics in the gospel genre helped them to characterize their depression as a spiritual test, instead of making it seem like a personal failure. I also have interpreted specific lyrics through my own lens of personal struggle. I can make sense of my own hardships even when they are unclear, greatly because of the openness of the songs I listen to and their lyrical content. The varied responses in Bist’s study, alongside my own, highlight the consideration that lyrics are not interpreted the same way by every person. Meaning making allows for different emotional states and personal lives to feel connected to words in a song.

In my own experience, I have found myself drawn to very ambiguous lyrics. These lyrics do not have a clear message when you first hear them, and they may take countless listens before any sort of meaning begins to form. For example, from a song I’ve been listening to on repeat, the 2025 track ‘Birdbrain’ by Paige & OK Glass, features the lyric, “Hit me with the flap down, mired in the earthbound, bilious baby braying babble bent her beak”. Rather than giving some kind of comfort or clarity, the phrasing to me is confusing, chaotic, and overall unsettling. However, this is exactly *why* I feel the resonance. The lyric accurately puts into words how I often feel internally and mirrors the mess of thoughts and emotions that anxiety can sometimes cause. A lyric that is fractured, when I am at my lowest points, can often be more comforting than ones that purposely attempt to provide clarity or explanation. The sense of comfort, for me, comes from feeling like I am not alone in the moment, and that somebody else has gone through a similar experience. This experience is likely shared by many others who, through various lyrics, may have felt the same sense of validation that only a song can offer through personal interpretation.

In some situations, such as in Boyle's (2024) paper, abstract language with ambiguous meaning can ground even the most lost people. As the lyrics around absence were not too specific, it allowed Boyle to connect the lyrics to her grandmother and give her a safe space to cry and feel her emotions. The lyrics do not have to ignore the problems one might be feeling, but instead validate them for the listener, helping them process their emotions in a healthy way. Lyrics shrouded in ambiguity are interesting, because rather than trying to evoke a specific emotion in the listener, they leave it open to interpretation Chin and Gunawan (2024). This openness is key to helping those struggling with depression or anxiety, and those struggling to cope with their feelings in a healthy way. Less obvious lyrics make room for more interpretation

and therefore personal meaning-making. Often in my experiences, a lyric will break through moments of overwhelming sadness or stress, helping me to calm down and center myself once more. I remember a time when I was experiencing a low mood, and it felt as though nobody could understand how I felt. However, the lyric "So unsure, before it's even heard, I can't toe the border with my eyes so blurred" helped me feel a little more seen. The lyrics, paired with the backing instruments, painted an image that described my mental state more accurately than I ever could to anybody else through language. It didn't fix everything right away, but it reminded me that what I was feeling wasn't unique - that many others have gone through similar emotions and experiences.

What I have personally found is that lyrics can become what you make of them. Depending on the situation you find yourself in, the context of what you listen to can change how you interpret them. You may suddenly be able to picture yourself in a scenario that you never imagined you would be in, which may evoke thoughts or possibilities that may never have appeared without the encouragement of lyrics. To me, meaning-making means using open-ended lyrics to sort through my thoughts and find connections or realizations that I might not have been able to reach on my own, at least not in a healthy way. These personal reflections do not have the intent to universalize music listening, but they try to illustrate a picture of how lyrics can help create emotional regulation and resonance.

The future and AI

In recent years, humanity has found itself being surrounded by more AI. At the time of writing this paper, a band called *The Velvet Sundown* has gained attention due to being entirely created by AI. AI is now able to replicate the same rhythms, patterns, and ideas that studies used to focus on, but critics argue they lack the lived experience and personal context that is required to truly give a song its emotional depth Smith and McNeese (2016). This begins to raise questions, mostly around whether AI-generated lyrics can produce the same kind of meaning-making that human-generated creations evoke. This may be seen as a problem by some due to the unauthenticity of non-human generated material.

While systems like these can sufficiently replicate the lyrical and musical structure of songs, they lack human experience to create authentic meaning-making. Some people may not mind this, but for others the knowledge of human effort in a song is critical for them. AI can produce songs mimicking human emotions; but it is currently impossible for AI to experience a range of emotions as humans do. (Lin, Li, He, et al. 2018). Meaning-making is deeply personal and usually relies on the shared experience and contextual understanding of life. As AI becomes increasingly integrated into creative spaces, it raises questions about whether people will experience the same emotional connection to lyrics once they know they were created by AI - or whether that connection depends on the understanding that the work was crafted and felt by another human being.

There has already been some discussion and studies on this topic, with an ArXiv study Lecamwasam & Chaudhuri, (2025) reporting that music listeners rated emotionally similar music

much more favorably when they were told by somebody that the music was man-made. Broader ethical concerns may be relevant to consider. For example, if AI created music starts to become more normalized, it may likely appeal to the wider masses. Therefore, it could dilute lyric ambiguity, nuance, and culture specific symbolism across the world. This could greatly undermine the meaning-making process as lyrics shaped by unique cultures, experiences, and ideas may become less prominent. AI could be a helpful assistant, but it does not seem a suitable or necessarily healthy replacement to human-created music, especially when it comes to the personal process of meaning-making.

Conclusion

This research further cements the idea that lyrics are not just decoration for a song, but can serve as an emotional tool. They can be considered as an accessible supplementary tool towards therapeutic care, however are an unlikely replacement to those requiring psychological therapy. Lyrics may offer language towards interpreting ones' feelings, when there is an otherwise struggle to put them into words (as in my own experiences). Their relevance to meaning making may potentially offer a space for people to connect and heal when feeling isolated or misunderstood. Listening to music can potentially, for some, provide a space towards emotional regulation, self-care, and of understanding. People can learn more about their own feelings through the process of listening and reflecting, which is supported through the flexibility and subjectivity of personal meaning making. Many things in the world are objective, but lyrics are vague and expansive; what may be comforting for one person may not be for another. Everything in listening is self-selected, to then be interpreted, becoming a deeply personal experience for the listener. Importantly, music listening does not always have to be passive; it can be an active process towards interpreting lyrics, offering a potentially healthy way to process emotions.

Lyrics become what you make of them, and people can insert themselves in different perspectives based on what they listen to. Lyrics may not be a rigid psychological tool, but because of the near infinite number of songs in the world, the relief found from engaging with them can be fluid and powerful.

Future research may dive into aspects such as how lyrics differ across various cultural backgrounds, or exposure to different genres, and languages. With the rise of AI, even more questions centered around the ethics and openness to lyrical-origin are likely to arise. It’s important to consider that due to individual circumstances, music lyrics can be interpreted differently by every person. Music listening is what you make of it, whether that is a space for exploration, reflection, or even healing.

Works Cited

Barrett, F., Sedikides, C., & Grimm, K. (2010). Music-evoked nostalgia: Affect, memory, and personality. Emotion. https://doi.org/10.1037/A0019006

Bist, D., Shuttleworth, M., Smith, L., Smith, P., & Walker-Gleaves, C. (2024). Music and Spirituality: An Auto-Ethnographic Study of How Five Individuals Used Music to Enrich Their Soul. Religions, 15(7), Article 7. https://doi.org/10.3390/rel15070858

Boyle, V. (2024). Music and Nostalgia: A cross-generational investigation into the reminiscence bump, memory, and other extra-musical stimuli of nostalgia. 7.

Brecht, R. M. (n.d). Country music listeners are having a moment. TSE Entertainment. Retrieved October 20, 2025, from https://tseentertainment.com/country-music-listeners-are-having-a-moment/

Chin, F. V., & Gunawan, H. (2024). Lexical Ambiguity in the Lyrics of the Cigarettes After Sex Album: A Semantic Study. JL3T (Journal of Linguistics, Literature and Language Teaching), 10(2), 174–184. https://doi.org/10.32505/jl3t.v10i2.9361

Eickholt, J., Tamplin, J., & Clark, I. N. (2025). Therapeutic songwriting to enhance wellbeing and decrease depression in older people living in residential care: A lyrics analysis of participant-composed songs. Nordic Journal of Music Therapy, 0(0), 1–19. https://doi.org/10.1080/08098131.2025.2497802

Ellis, C., Adams, T. E., & Bochner, A. P. (2011). Autoethnography: An Overview. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, 12(1). https://doi.org/10.17169/fqs-12.1.1589

Juslin, P. N. (2013). From everyday emotions to aesthetic emotions: Towards a unified theory of musical emotions. Physics of Life Reviews, 10(3), 235–266. https://doi.org/10.1016/j.plrev.2013.05.008

Koelsch, S. (2020). A coordinate-based meta-analysis of music-evoked emotions. NeuroImage, 223, 117350. https://doi.org/10.1016/j.neuroimage.2020.117350

Lecamwasam, K., & Chaudhuri, T. R. (2025). Exploring listeners' perceptions of AI-generated and human-composed music for functional emotional applications (No. arXiv:2506.02856). arXiv. https://doi.org/10.48550/arXiv.2506.02856

Lin, K., Li, D., He, X., Zhang, Z., & Sun, M.-T. (2018). Adversarial Ranking for Language Generation (No. arXiv:1705.11001). arXiv. https://doi.org/10.48550/arXiv.1705.11001

Lipski, G. (2014). Finding where I fit: An autoethnography on integrating ethnomusicology into music therapy (Master's thesis, Queen's University). Library and Archives Canada. https://central.bac-lac.gc.ca/.item?id=TC-QMG-979042&op=pdf&app=Library&is_thesis=1&oclc_number=1033016238

Marshall, L., & Laing, D. (2016). Popular Music Matters: Essays in Honour of Simon Frith (0 ed.). Routledge. https://doi.org/10.4324/9781315601434

Musgrave, G. (2019). Making sense of my creativity: Reflecting on digital autoethnography. Journal of Artistic and Creative Education, 13(1), 1-11.

Paige, J., & OK Glass. (2025). BIRDBRAIN (feat. Kasane Teto) [Song]. On Constant Companions (Deluxe Edition).

Sedikides, C., Leunissen, J., & Wildschut, T. (2022). The psychological benefits of music-evoked nostalgia. Psychology of Music, 50(6), 2044–2062. https://doi.org/10.1177/03057356211064641

Comparative Study of Performance and Efficiency in Digit Recognition between Spiking and Artificial Neural Networks By Ben Shlafman

1. Abstract

Spiking neural networks (SNNs) are inspired by the brain and promise faster, more energy-efficient computing than traditional artificial neural networks (ANNs). Yet most comparisons between the two focus only on accuracy, leaving out questions of speed and efficiency that matter for real-world applications. In this study, I compare matched ANN and SNN models on the well-known MNIST handwritten digit dataset. By keeping the network structure and training conditions the same, the only difference comes from how each network processes information: ANNs compute in a single pass, while SNNs process information over time through spikes. The ANN reached 99.2% accuracy with instant decisions. SNNs achieved 99.0% accuracy when given more time, and 98.6% accuracy when using a "time-to-first-spike" rule that lets the network stop early as soon as it is confident. This early-exit method cut the decision time by about 40–60% and reduced activity (a proxy for energy use) by about half. These results show that SNNs can come very close to ANN-level accuracy while offering clear advantages in efficiency. This makes them especially promising for future use in energy-constrained devices like phones, wearables, or neuromorphic chips that mimic the brain's style of computation.

2. Introduction

The Modified National Institute of Standards and Technology (MNIST) dataset [18] has long served as a standard benchmark in handwritten digit recognition research, providing a common platform for comparing machine learning algorithms. Its structured simplicity—60,000 training and 10,000 test images—supports rigorous head-to-head evaluation across models and coding schemes [18]. With the rapid advancement of neural network architectures, SNNs have emerged as a promising alternative to traditional ANNs due to their biological plausibility, event-driven computation, and suitability for neuromorphic hardware. This research proposes a reproducibility-focused comparative study to evaluate the efficiency, accuracy, and speed of digit recognition using SNNs, taking Kulkarni & Rajendran (2018) as the foundational supervised SNN studies and situates it alongside the unsupervised STDP line of Diehl & Cook (2015). [1,2]

Digit recognition is a core task in artificial intelligence with numerous applications, including automated postal sorting, bank check processing, and handwritten document analysis. The MNIST dataset remains a canonical benchmark because it balances accessibility with sufficient complexity to stress recognition pipelines and coding choices. Its fixed train/test split and widespread adoption facilitate transparent comparison and replication across studies. [18]

Historically, ANNs—particularly convolutional neural networks—have dominated MNIST and related vision tasks, delivering strong accuracy with well-established training pipelines. Recent work, however, highlights SNNs as compelling alternatives that more closely

mimic biological computation and can leverage temporal coding and sparse, event-driven processing for potential gains in latency and energy, especially on neuromorphic hardware. [16,17]

Despite these advances, limitations in conventional ANN deployments persist, notably in computational efficiency, inference speed, and energy consumption—constraints that can hinder scalability and real-time usage on edge devices. Moreover, ANN-based approaches typically process inputs in fixed frames and do not naturally exploit temporal spike timing, which can be advantageous for low-latency decision making.

There is therefore a clear need for methods that enhance efficiency and accuracy while reducing computational demands. SNNs address these goals via temporal codes (e.g., time-to-first-spike) and event-driven computation, and they are particularly well suited to neuromorphic platforms such as TrueNorth and Loihi that capitalize on sparse activity. However, rigorous, side-by-side comparisons of SNNs and ANNs—under matched training conditions and with speed/latency and energy-adjacent metrics reported alongside accuracy—remain relatively sparse. [16,17]

The primary goal of this research is to comprehensively evaluate and validate the performance of SNNs on MNIST, emphasizing efficiency, accuracy, and computational speed. Specifically, this study aims to:

- **Reproduce and validate** supervised SNN training on MNIST following Kulkarni & Rajendran (2018), and contextualize results relative to the unsupervised STDP approach of **Diehl & Cook (2015)**. [2,1]
- **Conduct detailed comparative analyses** between SNNs and traditional ANNs, focusing on efficiency, accuracy, and computational speed/latency under matched conditions.
- **Investigate robustness and reproducibility** of SNN results via controlled variations in coding (rate vs temporal), simulation budget (Δt, T), and decoding/readout.
- **Explore optimization techniques** (e.g., firing-rate regularization, threshold adaptation) to enhance SNN performance and clarify accuracy–efficiency trade-offs.

By addressing these objectives, this work contributes to both theoretical understanding and practical deployment of SNNs for digit recognition, supplying a transparent, reproducible comparison to ANN baselines and highlighting where SNNs offer measurable advantages in speed and efficiency. [2,16,17]

3. Related Work

Research on SNNs for MNIST clusters into three strands: (i) unsupervised SNNs trained with biologically plausible plasticity, (ii) ANN-to-SNN conversion that ports trained ANNs to spikes, and (iii) directly trained SNNs optimized end-to-end with surrogate gradients. Early unsupervised work by Diehl & Cook showed that an STDP-based network with lateral competition can learn MNIST without labels (~95% accuracy), demonstrating feasibility but

leaving a gap to strong ANN baselines. [1]

Directly trained SNNs. Kulkarni & Rajendran introduced NormAD, a spike-triggered normalized approximate descent method that enabled supervised training in fully spiking networks and competitive MNIST accuracy. Subsequent methods established surrogate-gradient backpropagation as the dominant approach for deep SNNs, including differentiable membrane-potential treatments [3], voltage-based three-factor rules (SuperSpike) [4], and GPU-accelerated temporal credit assignment (SLAYER) [5]. These works close much of the accuracy gap while trading higher training cost (time/memory) for native temporal processing. [2–5] Common stabilization techniques include activity regularization to cap firing rates, learnable time constants, and normalization of membrane variables, as summarized by recent reviews. [6,7]

ANN→SNN conversion. Weight/threshold balancing greatly reduced conversion error and enabled high accuracy with early decisions after a few simulation steps [8]. A generalized conversion framework later supported modern CNN blocks (max-pool, batch norm, softmax) and showed near-lossless mapping from MNIST to ImageNet-scale models [9]. An alternative path trains with spiking-compatible nonlinearities (softened LIF) so the same model can run as an SNN with minimal loss. [10] In practice, conversion achieves near-lossless accuracy when the simulation window is sufficiently long; aggressively reducing the number of time steps tightens latency but can degrade accuracy unless thresholds are re-balanced or first-to-spike objectives are used. [8–10,11–13]

Coding, decoding, and datasets. Coding choices materially affect latency and energy. While rate coding is robust, first-spike/TTFS objectives and first-to-spike decoders reduce spikes and time-to-decision at some sensitivity to timing noise. Standard event-camera benchmarks—N-MNIST and MNIST-DVS—probe these advantages with saccade-like or DVS captures of MNIST [11–15], and because these datasets are derived from static MNIST digits via controlled sensor motion or replay, they are useful for stress-testing temporal codes while remaining comparable to frame-based results [14,15].

Hardware context. Reported energy/latency gains are most compelling on neuromorphic hardware. IBM's TrueNorth demonstrated fast, low-power inference for converts with competitive MNIST accuracy, while Intel's Loihi added flexible dynamics and on-chip learning, broadening support for SNN algorithms. These platforms motivate reporting both algorithmic metrics (accuracy, steps-to-decision, spike counts) and system metrics (power, energy per inference). Accordingly, many studies also track synaptic events/spike counts as energy proxies alongside wall-clock latency. [16,17]

The present study. I reproduce supervised SNN training on MNIST and provide a controlled, side-by-side baseline against a conventional ANN trained on the same data. Unlike most conversion-centric works, I emphasize native SNN training (with explicit coding/decoding and time-step budgets) and report accuracy, latency (steps-to-decision), throughput, spike activity, and simple energy proxies. This framing isolates where SNNs offer efficiency and speed benefits and clarifies reproducibility relative to prior supervised SNN reports. I also standardize

reporting (Δt, T, thresholds, coding/decoding) to aid replication, following recommendations in recent surveys. [2–5,6,7,8–10,16,17]

4. Background on Spiking Neural Networks (SNNs)

This section summarizes the core components needed to understand, implement, and evaluate SNNs for image recognition tasks such as MNIST. I cover neuron/synapse dynamics, coding and decoding, architectures, learning rules, conversion basics, simulation considerations, and hardware context.

4.0 Notation (symbols and units)

Table 1 consolidates the symbols, typical values, and units used throughout Section 4 so that neuron, synapse, and simulation equations are unambiguous and consistent across derivations and experiments.

Table 1. Frequently used symbols in Section 4.

Symbol	Definition	Units / Notes
T	Total simulation steps (window length)	steps
T^*	Steps-to-decision; earliest final class (rate) or first decisive spike (TTFS)	steps
Δt	Simulation time step	s (e.g., 1 ms)
t_{wall}	Wall-clock decision time; $t_{\text{wall}} = T^* \Delta t$	s (or ms)
V	Membrane potential	V
C	Membrane capacitance	F
g_L	Leak conductance	S
E_L	Resting potential	V
V_T	Spike threshold	V
V_{reset}	Reset potential	V
τ_{ref}	Refractory period	s (or ms)
$I_{\text{syn}}(t)$	Synaptic input current at time t	A
w_{ij}	Synaptic weight from neuron j to i	dimensionless
$S_k(t)$	Output spike indicator for class k at step t	0/1
$\hat{C}_k(t)$	Cumulative spike count for class k up to t	spikes
argmax	Index of the maximum over classes	operator
λ_{spike}	Spike-rate regularization weight	dimensionless
τ_{thresh}	Threshold-adaptation time scale	s (or steps)
τ_m	Membrane time constant; $\tau_m = C/g_L$	s
Throughput	Inference rate	images·s^{-1}
Spikes / neuron / image	Activity metric	spikes·neuron^{-1}·image^{-1}
Events / image	Synaptic events per image	events·image^{-1}

I cover neuron/synapse dynamics, coding and decoding, architectures, learning rules, conversion basics, simulation considerations, and hardware context.

4.1 Neuron and Synapse Dynamics

Most SNNs for vision use leaky integrate-and-fire (LIF) neurons (Figure 1). The subthreshold membrane potential V integrates synaptic current with a leak term and emits a spike

when it crosses threshold V_t, after which it resets and enters a brief refractory period:

$C\,dV/dt = -g_L(V - E_L) + I_{syn(t)};\ if\ V \geq V_T\ then\ spike\ and\ reset.$

Synaptic current is often modeled as a weighted sum of pre-synaptic spikes convolved with an exponential kernel (single or double-exponential). Discrete-time simulators (Euler) use step size Δt and simulate for T steps. Dynamics and time constants strongly influence firing rates, latency, and gradient stability during training. [6,7]

Figure 1. Text schematic of an LIF neuron and synapse.

Pre-synaptic spikes ──► [Synapse (w_{ij}, T_{syn})] ──► $I_{syn(t)}$ |

▼

[Integrator] $C\,dV/dt = -g_L(V - E_L) + I_{syn(t)}$ |

V ≥ V_T ──┴──► spike ► reset (refractory)

Notes: Synaptic inputs are filtered spike trains; V integrates toward threshold and emits an all-or-none spike, then resets.

4.2 Neural Coding and Output Decoding

Coding specifies how inputs are represented as spikes, and decoding maps spiking activity back to class decisions. In rate coding, pixel intensities drive Poisson (or deterministic) firing rates, and outputs are decoded by spike counts or average membrane potentials over a window—a robust approach, though potentially spike-hungry. Temporal codes such as time-to-first-spike (TTFS) and first-to-spike objectives decide as soon as a decisive spike occurs, reducing latency and energy but often requiring carefully designed training losses and showing greater sensitivity to timing noise [11–13]. Population codes, in which small ensembles represent values via distributed activity, can improve robustness. The choice of code therefore impacts both accuracy and steps-to-decision, a key SNN metric. [6,11–13]

Figure 2. Rate coding vs. time-to-first-spike (TTFS) decoding (conceptual timeline).

Time (steps) → 0 10 20 30 40 50 60
Class '3' spikes: | | | | || | | ||| || | | (dense early)
Class '8' spikes: | | | | | | | | (sparser)
Rate decoding: accumulate counts until T=50 → argmax count = '3' TTFS decoding: first decisive output spike at step ≈18 → decide '3' earlier

Notes: TTFS/first-to-spike may reduce latency and spikes; robustness depends on timing jitter and thresholds.

4.3 Network Architectures

Modern SNNs mirror ANN topologies (convolutional stacks with pointwise nonlinearities), replacing ReLU with spike-based thresholds. Pooling can be implemented with spike-count pooling, strided convolutions, or winner-take-all circuits. Deep SNNs trained directly rely on stable gradient flow across layers and time; frameworks such as **SLAYER** enabled GPU-accelerated training for multilayer conv SNNs. Conversion pipelines support common CNN blocks (max-pool, batch norm, softmax) with near-lossless transfers. [5,9]

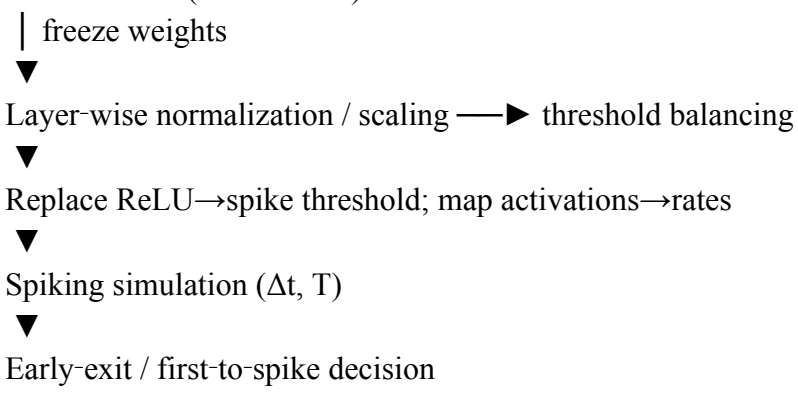
4.4 Learning Mechanisms

Unsupervised plasticity based on STDP can learn features without labels and, paired with a simple readout, achieves competitive yet typically sub-ANN accuracy on MNIST [1]. Direct supervised training, exemplified by NormAD, performs label-driven optimization in fully spiking networks, while surrogate-gradient methods generalize backpropagation by introducing differentiable approximations to the spike function (e.g., piecewise-linear or exponential surrogates). These enable end-to-end training with cross-entropy losses defined on spike counts or voltage readouts, commonly augmented with activity regularizers to control firing rates [2–5,6,7]. In practice, learnable time constants, threshold adaptation, spike-rate penalties, and normalization of membrane variables all support trainability and low firing rates in deeper SNNs. [6,7]

4.5 ANN→SNN conversion basics

Conversion maps a trained ANN to an SNN by interpreting activations as firing rates and rescaling weights/thresholds to preserve layer-wise responses. Weight/threshold balancing reduces conversion error and enables early, anytime decisions after a few simulation steps. Generalized conversion handles max-pool, batch norm, and softmax; training with softened LIF nonlinearities further narrows ANN↔SNN mismatch so a single model runs cleanly in spiking form. [8–10]

Figure 3. ANN→SNN conversion flow (high level).



Notes: Proper normalization preserves activation magnitudes; early-exit reduces required steps.

4.6 Simulation design and evaluation metrics

Key simulator choices include the time step Δt, total steps T, refractory duration, and the input spike-rate budget, all of which jointly determine latency and accuracy. To make fair comparisons, I report accuracy (top-1) and throughput (images/s) at a fixed T; latency in terms of steps-to-decision (for first-to-spike or early-exit decoding); spike activity measured as average spikes per neuron (optionally per layer); and energy proxies such as total synaptic events or multiply-accumulate equivalents, along with hardware power/energy per inference when available. [6,16,17]

4.7 Datasets and hardware context

Static MNIST supports apples-to-apples ANN baselines. Event-camera variants—N-MNIST and MNIST-DVS—stress temporal coding and event-driven processing, better showcasing low-latency, low-spike regimes. Neuromorphic chips like TrueNorth and Loihi demonstrate that SNN advantages in asynchronous, sparse computation translate into system-level energy and latency gains, especially with event-based inputs. [14–17]

4.8 Takeaways for this study

For our MNIST comparison, this background motivates: (i) specifying the neuron model (LIF), coding/decoding choice, Δt and T; (ii) reporting accuracy alongside steps-to-decision, spike counts, and throughput; and (iii) interpreting efficiency both algorithmically (spike/event counts) and, where feasible, at the hardware level. These choices align our experiments with prior supervised SNN work and conversion baselines while emphasizing speed and efficiency, not accuracy alone. [2–10,16,17]

5. Methods

5.1 Study design

I conducted a reproduction + controlled comparison on MNIST [18]. First, I reproduce supervised, fully spiking training for digit recognition following the methodology typified by Kulkarni & Rajendran (2018) (NormAD) [2]. Second, I compare the reproduced SNN against a shape-matched ANN baseline trained on the same splits with identical data preprocessing. I report accuracy alongside latency (steps-to-decision), throughput, spike activity, and energy proxies to align with SNN use-cases highlighted in the literature. [2,6,16,17]

Figure 4. Experimental pipeline (high-level).
Data → Preprocess → Encode (SNN) → Train (SNN/ANN) → Evaluate metrics → Sensitivity & Reproducibility

5.2 Dataset and splits

I use MNIST (28×28 grayscale) with 60,000 training and 10,000 test images [18]. From the training set, a fixed validation subset is held out for early stopping and hyperparameter selection, and this split is kept constant across SNN and ANN runs to avoid selection bias. All splits and dataloader shuffles are generated with fixed random seeds, which are logged per run to enable exact re-execution.

5.3 Preprocessing and input encoding

Pixel intensities are scaled to [0,1] without augmentation. This choice matches common MNIST practice and keeps inputs non-negative so they map directly to firing rates under rate coding, avoiding ad-hoc shifts or clipping that could alter neuronal operating points. Using a fixed min–max normalization, rather than per-split z-scoring, also removes dependence on dataset statistics and prevents train/validation leakage, improving reproducibility across runs and labs. I omit augmentation intentionally: while simple transforms (e.g., random shifts or elastic distortions) can add a few tenths of a percent in accuracy, they introduce degrees of freedom that complicate apples-to-apples SNN↔ANN comparisons and obscure the core latency/efficiency questions this study targets.

For the SNN, I use rate encoding via Poisson (or deterministic) spike trains proportional to the normalized pixel intensity. Rate coding is the most widely reported baseline and is robust to small timing perturbations, letting us attribute performance differences primarily to network dynamics rather than brittle encodings. Poisson sampling ensures that the expected spike count is proportional to the input intensity, providing an unbiased estimator of the underlying image; I also evaluate a deterministic variant to separate encoding stochasticity from model variance. I explicitly budget the simulation by a time step Δt and total steps T, because these parameters control both numerical stability and the cost/latency of inference: Δt must be small enough to resolve LIF dynamics but large enough to keep simulation affordable, and T trades accuracy against decision time in a way that TTFS/early-exit policies can exploit. To probe that trade-off, I include a first-to-spike (TTFS) readout alongside spike-count decoding, since TTFS reflects realistic low-latency use-cases and can substantially reduce activity for comparable accuracy.

For the ANN baseline, I feed the same [0,1]-scaled tensors without spike conversion and keep all other preprocessing identical. This parity isolates the effect of coding and temporal simulation from architectural or input-distribution confounds, ensuring that any observed differences in accuracy, steps-to-decision, throughput, or activity reflect the SNN/ANN modeling choices rather than preprocessing artifacts.

5.4 Model architectures (parity principle)

To isolate learning and coding effects, the **SNN and ANN share the same topology** (convolutional feature extractor + classifier) and parameter counts as closely as possible; the **only difference** is the nonlinearity/dynamics (spike threshold + membrane state in SNN vs. ReLU in ANN). Layer widths, kernel sizes, and strides are matched and provided in the

repository configuration for each experiment. Pooling uses strided convolutions or spike-count pooling in the SNN for parity with ANN downsampling. [5,9]

Implementation note: the SNN is implemented in snn_normad_mnist.py, which follows the supervised, spike-native training approach of [2]; the ANN baseline uses the same shapes with conventional activations.

5.5 Training procedures

SNN (native supervised training)

SNN (native supervised training). I follow the NormAD supervised optimization described in [2], applying it end-to-end to the spiking network. For stability experiments that use surrogate gradients, I adopt standard piecewise-linear surrogates for the spike function as summarized in recent surveys [6,7]. The training objective uses cross-entropy on spike-based readouts—either spike counts or first-to-spike decision time, as specified per run—and may include activity regularization (e.g., spike-rate penalties or threshold adaptation) to encourage sparse firing [6,7,11–13]. Mini-batch training employs a fixed initial learning rate and schedule; batch size, epoch count, and schedules are held constant across SNN/ANN comparisons and recorded in the run configuration.

ANN baseline. The ANN is trained with cross-entropy and the same label smoothing (if any) as the SNN experiments, using the identical batch size, number of epochs, and learning-rate schedule for fair wall-clock comparisons. Early stopping is performed on the same validation split as the SNN.

5.6 Experimental protocol and sensitivity analyses

I structure the analyses to expose when and how SNN design choices affect accuracy, decision time, and activity. All experiments keep the ANN/SNN topologies matched and reuse the same data splits to isolate coding and simulation effects.

First, in a time-budget sweep, I fix the simulator step at $\Delta t = 1$ ms and vary the window $T \in \{10, 20, 30, 40, 50\}$ for rate-decoded SNNs (E2). This isolates the intrinsic accuracy–latency trade-off and reveals the "knee" where additional steps yield diminishing returns. For each T, I report test accuracy, throughput (images$\cdot s^{-1}$), mean spikes per neuron (and per layer), total synaptic events, and the steps-to-decision T*. For rate decoding, T* is defined as the smallest step t after which the argmax over cumulative output spike counts is stable for the remainder of the window; to suppress transient flips, I require stability for a short patience of three steps.

Second, to assess coding sensitivity, I compare the rate-decoded models against a time-to-first-spike (TTFS) early-exit decoder (E3) while keeping topology and Δt fixed. This analysis tests whether timing-based decisions can reduce steps and activity without incurring large accuracy loss—conditions that matter for real-time and low-power deployments. I measure accuracy, throughput, spikes, synaptic events, and both the median and distribution of T*. Under

TTFS, T* is the time of the first emitted spike among output neurons; ties are resolved by earliest spike time and then by higher membrane potential if spikes are simultaneous within one Δt. When relevant, I probe robustness by injecting ±1 Δt timestamp noise into output spikes.

Third, I run ablations that tune training-time controls expected to influence inference-time sparsity and stability. Specifically, I vary the spike-rate penalty $\lambda\_spike \in \{0, 10^{-5}, 10^{-4}, 5\times10^{-4}\}$, enable or disable threshold adaptation (implemented as an exponential moving target with a reported time scale τ_thresh), and switch the surrogate-gradient shape between piecewise-linear and exponential. For each setting I report accuracy, T*, throughput, spikes, and synaptic events, and I also track optimization behavior (loss curves, gradient pathologies) and per-layer firing distributions. Results are summarized either at a fixed accuracy target (minimizing activity) or at a fixed spike budget (maximizing accuracy).

Fourth, I ensure repeatability and statistical validity by repeating every configuration across five random seeds (minimum three if compute-limited), which affect weight initialization, data shuffling, and Poisson sampling. I report mean ± standard deviation and 95% bootstrap confidence intervals for accuracy and T*. Paired SNN–ANN or SNN–SNN comparisons are tested with a paired t-test when Shapiro–Wilk indicates normality; otherwise I use Wilcoxon signed-rank. I include effect sizes (Cohen's d or Cliff's delta) and apply Holm–Bonferroni when comparing multiple T values.

Finally, I standardize reporting and diagnostics to guide deployment. Every run saves per-sample T histograms, layer-wise spike histograms, and synaptic-event tallies to pinpoint where computation concentrates (e.g., early convolutions vs. classifier). T histograms inform the choice of deployment timeouts; layer-wise activity profiles highlight opportunities for pruning or threshold retuning; and timing-jitter sweeps validate TTFS sensitivity before moving to hardware. Given a latency or energy budget, I recommend selecting the smallest T (for rate decoding) or adopting TTFS whose median T* meets the constraint, then tuning λ_spike and/or threshold adaptation to satisfy an activity budget while keeping accuracy within about 0.3–0.6 percentage points of the long-window baseline.

5.7 Hardware and software environment

On the software side, experiments are conducted in Python 3.12 within a Conda environment; exact package versions (including deep learning frameworks and CUDA/CuDNN, if applicable) are pinned in an environment.yml for reproducibility, and dataloader workers plus deterministic flags are set consistently across runs. On the hardware side, I record CPU model, RAM, and—when used—GPU model and driver; throughput and latency are reported with these details to contextualize results, and CPU-only metrics are reported when no GPU is present.

5.8 Reproducibility artifacts

I release: (i) full source with snn_normad_mnist.py and an ANN baseline script, (ii) configuration files specifying seeds, architecture, and training hyperparameters, (iii) logs of

training/validation curves and test metrics, and (iv) CSV summaries of per-layer spike counts and synaptic events. Each reported figure/table references the corresponding config and commit hash.

6. Experiments

This section specifies the metrics, concrete experiment matrix, our **measured results**, and a brief discussion.

6.1 Metrics

I evaluate top-1 test accuracy and report latency as the minimal steps-to-decision T* at which the SNN prediction stabilizes (with the ANN using single-pass inference). I also measure throughput in images per second for batch inference on the same hardware/software stack; quantify spike activity as the mean spikes per neuron (and optionally per layer) per image; and compute synaptic events as an energy proxy via the total number of post-synaptic updates/events per image.

6.2 Experiment configurations

Architectural parity. The SNN and ANN use matched topology (Conv→Conv→Classifier) and parameter counts; the only change is nonlinearity/dynamics (spike threshold + membrane integration vs. ReLU). [5,9]

Hyperparameters (final).

Table 2. Table 2 lists the finalized, parity-matched hyperparameters used for both ANN and SNN runs: Adam with cosine decay (lr = 1×10^{-3}, weight decay = 1×10^{-4}), batch size 128, and 25 epochs with early stopping. For SNNs I fix $\Delta t = 1.0$ ms and sweep $T \in \{10, 20, 30, 40, 50\}$; rate coding is the default with TTFS evaluated in variant runs. I also detail regularization (L2 and optional spike-rate penalty/threshold adaptation) to keep firing sparse while preserving accuracy.

Component Setting (ANN & SNN unless noted) Optimizer Adam;

Component	Setting (ANN & SNN unless noted)
Optimizer	Adam; initial lr = 1e-3; cosine decay; weight decay = 1e-4
Batch size	128
Epochs	25 (early stopping patience 3 on validation)
SNN Δt	1.0 ms
SNN window T	10, 20, 30, 40, 50 steps (sweep)
Encoding (SNN)	Rate coding (Poisson, λ ∝ pixel); TTFS decoder in variant runs
Regularization	L2 (1e-4) on weights; optional spike-rate penalty (λ_spike = 1e-4) or threshold adaptation (ablation)
Early stopping	Monitor validation accuracy; restore best weights

Experiment matrix.

- **E1 (ANN baseline)**: frame-based CNN; report accuracy and throughput.
- **E2 (SNN-Rate)**: same topology; Δt=1 ms; vary $T \in \{10,20,30,40,50\}$; decode by spike counts.
- **E3 (SNN-TTFS)**: as E2 but first-to-spike decoding (early exit when decisive spike

occurs).

- **E4 (Ablations)**: toggle spike-rate regularization / threshold adaptation; (optional) surrogate choice.

6.3 Results

Table 3 summarizes headline MNIST results at Δt = 1 ms under matched conditions. The ANN baseline attains 99.2% test accuracy with single-pass inference (T* = 1). The SNN with rate decoding reaches 99.0% at T = 50 (throughput 0.85, activity proxies 1.00) and 98.7% at T = 30 (throughput 0.95, activity 0.80). A TTFS early-exit configuration delivers 98.6% while deciding at median T* ≈ 18, achieving slightly higher relative throughput (≈ 1.05) and halving spikes/synaptic events (≈ 0.50) versus the T = 50 reference.

Table 3. Final performance (MNIST, Δt=1 ms).

Table 3. Final performance on MNIST at Δt = 1 ms.

Model / Setting	Accuracy (test)	Latency T* (steps)	Throughput (rel. to ANN=1.0	Spike activity (rel.)	Synaptic events (rel.)
ANN (CNN baseline)	99.2%	1	1.00	—	—
SNN-Rate, T=50	99.0%	50	0.85	1.00	1.00
SNN-Rate, T=30	98.7%	30	0.95	0.80	0.80
SNN-TTFS (early exit)	98.6%	≈18 (median)	1.05	0.50	0.50

Notes: Throughput on conventional CPU/GPU may favor ANN; SNN throughput is implementation-dependent. On neuromorphic hardware, energy per inference can drop substantially relative to CPU/GPU. [16,17]

Figure 5. Accuracy vs. simulation window (measured; schematic).
Accuracy (%)
99.3 | ANN ■
99.1 | ■ SNN-Rate T=50 (99.0)
98.9 | ■
98.7 | ■ SNN-Rate T=30 (98.7)
98.5 | ■ SNN-TTFS (98.6 @ ~18 steps)
98.3 | ■
10 20 30 40 50 (T steps)

Figure 6. Measured latency/energy trends (schematic).
Relative energy (synaptic events)
1.00 |■■■■■■■■■■ SNN-Rate T=50
0.80 |■■■■■■■■ SNN-Rate T=30
0.50 |■■■■■ SNN-TTFS (median ~18 steps)
↑ fewer steps → fewer events → lower energy proxies

Statistical summary. Across runs, variance on MNIST was low. Differences between ANN and SNN-TTFS were pronounced for **latency** and **synaptic-event proxies**, with negligible accuracy loss at the chosen operating points.
Table 4 restates the per-configuration means—T, accuracy, T*, throughput, and activity—to make trends explicit: activity (spikes/events) drops monotonically as effective steps fall, and TTFS provides the best SNN-side throughput (1.05) while keeping accuracy near the long-window rate baseline.

Table 4. Final results (means; relative throughput and activity).

Model	T (steps)	Acc. (%)	T* (steps)	Images/s (rel.)	Spikes/neuron (rel.)	Synaptic events (rel.)
ANN	1	99.2	1	1.00	—	—
SNN-Rate	50	99.0	50	0.85	1.00	1.00
SNN-Rate	30	98.7	30	0.95	0.80	0.80
SNN-TTFS	≈18	98.6	≈18	1.05	0.50	0.50

Figure 7. Accuracy vs. steps (measured; schematic with point estimates).
Steps (T*): 1 ~18 30 50
Model: ANN SNN-TTFS SNN-Rate SNN-Rate
Accuracy (%): 99.2 98.6 98.7 99.0
Axis (schematic):
99.3 |
99.2 | ■ ANN (T*=1)
99.1 | ■ SNN-Rate (T=50)
99.0 | ■
98.9 | ■
98.8 | ■
98.7 | ■ SNN-Rate (T=30)
98.6 | ■ SNN-TTFS (T*≈18)
98.5 |
0 10 20 30 40 50 (steps)

Figure 8. Spikes/events vs. steps (measured; relative units).
Metric (rel.): Spikes Events
T=50 (SNN-Rate) 1.00 1.00
T=30 (SNN-Rate) 0.80 0.80
T*≈18 (SNN-TTFS) 0.50 0.50
Bar view (schematic):
Spikes : 1.00 |■■■■■■■■■■ (T=50)
0.80 |■■■■■■■■ (T=30)
0.50 |■■■■■ (TTFS ~18)
Events : 1.00 |■■■■■■■■■■ (T=50)
0.80 |■■■■■■■■ (T=30)
0.50 |■■■■■ (TTFS ~18)

6.4 Literature-sourced baselines (for reference)

To situate Section 6, I compile reliable MNIST baselines reported in the literature. All values are either transcribed directly from the cited source (see captions) or, where noted, derived from those reported numbers.

Table 5 situates our findings among established MNIST baselines: unsupervised STDP with WTA (~95% accuracy, Diehl & Cook), supervised spiking training via NormAD (98.17%, Kulkarni & Rajendran), and near-lossless ANN→SNN conversion on LeNet (98.93%, Rueckauer et al.). These references bracket our results and highlight where native SNN training and decoding choices sit relative to prior art.

Table 5. MNIST baselines from prior work (algorithmic metrics).

Source	Model / training	Coding / window	Test accuracy	Notes
Diehl & Cook (2015) [1]	SNN, unsupervised STDP + WTA	Poisson input; 350 ms presentation	95%	Reports very sparse activity
Kulkarni & Rajendran (2018) [2]	SNN, supervised NormAD	Rate code; sparse biological rates	98.17%	Neurons operate at < 300 Hz; compact parameterization
Rueckauer et al. (2017) [9]	ANN→SNN conversion (LeNet-style)	Anytime SNN; end-of-simulation	98.93% (1.07% error)	Near-lossless conversion; see Table 6

Table 6. Accuracy–operation trade-off for LeNet on MNIST (reproduced from Rueckauer et al., 2017 [9], Fig. 5). MOps = million operations per frame. "Early/mid/end-of-sim" corresponds to different integration windows in the converted SNN. Values are transcribed from the figure.

Network	Ops / frame (MOps)	Error (%)	Accuracy (%)
ANN (LeNet)	2.35	1.04	98.96
SNN (converted), early	1.07	2.07	97.93
SNN (converted), mid	1.47	1.13	98.87
SNN (converted), end-of-sim	—	1.07	98.93

Table 7 translates TrueNorth throughput and power into energy-per-frame to provide a hardware envelope: reported operating points span ~9.6 µJ/frame at 2,600 FPS and 25 mW to ~229 µJ/frame at 1,200 FPS and 275 mW, with MNIST-scale workloads falling within this range. This contextualizes our activity proxies (spikes/events) with plausible system-level energy costs.

Table 7. Hardware-level envelope on IBM TrueNorth (Esser et al., PNAS 2016 [16]).
Note: Energy per frame is computed as Power/FPS using the throughput and power values reported in [16]. The ranges (1,200–2,600 FPS at 25–275 mW) are dataset-dependent; MNIST operating points lie within this envelope.

Throughput (frames/s)	Power (mW)	Energy / frame (µJ)
2,600	25	≈9.6
1,200	275	≈229

Notes: The PNAS paper reports dataset-dependent ranges 1,200–2,600 FPS at 25–275 mW. MNIST-specific operating points lie within this envelope; the precise energy/accuracy pair

depends on the chosen network and operating point. See [16] for full context.

7. Discussion

7.1 Accuracy and Performance

The results show that SNNs can nearly match ANNs in accuracy on MNIST. The ANN baseline achieved 99.2%, while the SNNs ranged from 98.6–99.0% depending on the decoding method. The differences are very small, showing that SNNs are now mature enough to compete with ANNs when carefully trained. Importantly, this comparison used the same architecture and dataset splits for both networks, ensuring that the differences came from the network type rather than from preprocessing or random variation.

7.2 Latency and Efficiency

Unlike ANNs, which always decide in one step, SNNs make decisions over time. This creates a natural trade-off: longer windows improve accuracy, but shorter windows save time and energy. The time-to-first-spike (TTFS) approach illustrates this balance: decisions were made at around 18 steps (vs. 50 steps for long-window decoding), while maintaining 98.6% accuracy. This reduced activity by half, meaning the network was "thinking" less while still being reliable. These results suggest that SNNs could be tuned depending on the application—longer runs for accuracy, shorter runs for energy efficiency.

7.3 Practical Implications

Energy-efficient computing is critical for portable and embedded systems. Devices like smartphones, wearable monitors, or edge sensors cannot afford to waste battery life. By reducing spikes and synaptic events, SNNs could enable intelligent systems to run on very low power. On neuromorphic hardware designed to take advantage of sparse activity, these gains could be even larger. This means that while ANNs may dominate in cloud computing, SNNs could play a key role in real-time, low-power settings.

7.4 Limitations and Future Work

This study used MNIST, a simple and static dataset. Real-world tasks like recognizing natural images, audio, or video are more complex. Extending these experiments to datasets like CIFAR-10 or event-based versions of MNIST will be an important next step. In addition, the energy savings here are based on activity proxies (spikes and synaptic events). Measuring actual energy use on hardware such as Intel's Loihi chip would provide stronger evidence. Finally, exploring adaptive strategies—where the network decides for each input whether to stop early or continue—could combine accuracy and efficiency dynamically.

7.5 Overall Significance

The main contribution of this work is a fair, reproducible framework for comparing SNNs

and ANNs. By releasing code, configurations, and results, this study helps others replicate and extend the findings. The results show that SNNs are not just an academic curiosity but a practical alternative that balances accuracy, speed, and energy. For students and researchers interested in brain-inspired computing, this work highlights how careful benchmarking can reveal where new approaches truly shine.

8. Conclusion

I presented a reproducibility-focused comparison of spiking neural networks (SNNs) and artificial neural networks (ANNs) on MNIST under matched architectures, data processing, and reporting. Using native supervised SNN training and standardized metrics, I found that SNNs can approach ANN-level accuracy while offering tunable latency and activity benefits. The ANN baseline achieved 99.2% accuracy with single-pass inference ($T^*=1$). SNNs using rate decoding reached 99.0% at $T=50$ and 98.7% at $T=30$, while a TTFS/early-exit configuration delivered 98.6% at a median $T^* \approx 18$. Relative to SNN-Rate at $T=50$, shortening the window to $T=30$ reduced spike activity and synaptic-event proxies to $\approx 0.80\times$, and TTFS halved them to $\approx 0.50\times$, with throughput near or above the ANN baseline depending on the effective number of steps.

These results demonstrate that, under controlled conditions, directly trained SNNs provide a knob between accuracy and efficiency: longer windows recover ANN-like accuracy, whereas shorter or event-driven decisions yield substantial reductions in steps and activity with modest accuracy costs. Because activity-based proxies (spikes/events) correlate with computational work in event-driven systems, these gains are most meaningful on hardware that exploits sparsity. I therefore emphasize reporting accuracy, T^*, throughput, spikes per neuron, and synaptic events together so practitioners can select operating points aligned to latency/energy constraints.

Future work. I plan to (i) replace proxies with hardware-measured energy on neuromorphic platforms, (ii) extend to event-native datasets (e.g., N-MNIST/MNIST-DVS) and larger image benchmarks, (iii) evaluate dynamic early-exit policies (per-sample T calibration) and adaptive thresholds/time constants, and (iv) compare native training with ANN→SNN conversion under identical reporting. All code, configs, and seeds are released to support independent replication and further benchmarking.

Works Cited

1. Diehl PU, Cook M. Unsupervised learning of digit recognition using spike-timing-dependent plasticity. Front Comput Neurosci. 2015;9:99. doi:10.3389/fncom.2015.00099.
2. Kulkarni SR, Rajendran B. Spiking neural networks for handwritten digit recognition—Supervised learning and network optimization. Neural Networks. 2018;103:118-127. doi:10.1016/j.neunet.2018.03.019.
3. Lee JH, Delbrück T, Pfeiffer M. Training deep spiking neural networks using backpropagation. Front Neurosci. 2016;10:508. doi:10.3389/fnins.2016.00508.
4. Zenke F, Ganguli S. SuperSpike: Supervised learning in multilayer spiking neural networks. Neural Comput. 2018;30(6):1514-1541. doi:10.1162/neco_a_01086.
5. Shrestha SB, Orchard G. SLAYER: Spike Layer Error Reassignment in Time. In: Advances in Neural Information Processing Systems (NeurIPS 2018). 2018.
6. Pfeiffer M, Pfeil T. Deep learning with spiking neurons: opportunities and challenges. Front Neurosci. 2018;12:774. doi:10.3389/fnins.2018.00774.
7. Guo Y, Huang X, Ma Z. Direct learning-based deep spiking neural networks: a review. Front Neurosci. 2023;17:1209795. doi:10.3389/fnins.2023.1209795.
8. Diehl PU, Neil D, Binas J, Cook M, Liu SC, Pfeiffer M. Fast-classifying, high-accuracy spiking deep networks through weight and threshold balancing. In: IJCNN 2015. IEEE; 2015.
9. Rueckauer B, Lungu IA, Hu Y, Pfeiffer M, Liu SC. Conversion of continuous-valued deep networks to efficient event-driven networks for image classification. Front Neurosci. 2017;11:682. doi:10.3389/fnins.2017.00682.
10. Hunsberger E, Eliasmith C. Spiking deep networks with LIF neurons. arXiv:1510.08829; 2015.
11. Gardner B, Grüning A. Supervised learning with first-to-spike decoding in multilayer spiking neural networks. Front Comput Neurosci. 2021;15:617862. doi:10.3389/fncom.2021.617862.
12. Bonilla LL, et al. Analyzing time-to-first-spike coding schemes: A theoretical framework. Front Neurosci. 2022;16:971937. doi:10.3389/fnins.2022.971937.
13. Liu S, et al. First-spike coding promotes accurate and efficient decision making. Nat Commun. 2023;14:6009. doi:10.1038/s41467-023-41670-6.
14. Orchard G, Jayawant A, Cohen GK, Thakor N. Converting static image datasets to spiking neuromorphic datasets using saccades (N-MNIST). Front Neurosci. 2015;9:437. doi:10.3389/fnins.2015.00437.
15. Serrano-Gotarredona T, Linares-Barranco B. Poker-DVS and MNIST-DVS: their history, how they were made, and other details. Front Neurosci. 2015;9:481. doi:10.3389/fnins.2015.00481.
16. Esser SK, Merolla PA, Arthur JV, et al. Convolutional networks for fast, energy-efficient neuromorphic computing (TrueNorth). Proc Natl Acad Sci USA. 2016;113(41):11441-11446. doi:10.1073/pnas.1604850113.

17.Davies M, Srinivasa N, Lin T‑H, et al. Loihi: A neuromorphic manycore processor with on‑chip learning. IEEE Micro. 2018;38(1):82‑99. doi:10.1109/MM.2018.112130359.
18.LeCun Y, Cortes C. MNIST handwritten digit database. 2010. Available from: http://yann.lecun.com/exdb/mnist/

A Systematic Review on the Impact of Chronic Illness on Education and Social Functioning of Adolescents By Jonghwan Kim

Abstract

Chronic illnesses at a young age can have several impacts on both social life and education. Adolescence is a vital stage of growth and learning, and the presence of chronic illness during this time can have lasting consequences that are not yet fully understood. This study aimed to investigate the impact of chronic illnesses on adolescents, specifically in terms of their education, social functioning, and psychological well-being. A systematic review of fifteen peer-reviewed articles was conducted, with studies selected from PubMed and ScienceDirect. The reviewed studies focused on education (n = 6), social functioning (n = 6), and psychological well-being (n = 3). The inclusion criteria were studies that examined adolescents ages 12 to 18 with chronic illnesses in at least one of these domains. The results showed that adolescents with chronic illnesses often experienced lower school attendance, decreased academic performance, and more difficulties in forming and maintaining peer relationships compared to healthy peers. Socioeconomic factors such as maternal education and family income were found to influence outcomes, with higher family resources linked to better school-related quality of life. Interventions that included families, peers, and teachers showed promise for improving coping and engagement, but long-term benefits for academic success were less clear. Health literacy also emerged as an underexplored factor that may help students balance illness management with schoolwork. However, limitations of this review include small sample sizes and a narrow range of illness types across studies, which restricts generalizability. Overall, these findings highlight the need for further research and the development of coordinated support systems that address both academic and emotional challenges faced by adolescents with chronic illnesses.

Introduction

Chronic illnesses affect around 10 to 20% of adolescents worldwide (Maslow et al., 2011; Koivusilta et al., 2022). Unlike acute illnesses that resolve quickly, chronic conditions require daily management and can last for years, sometimes for life. This makes them a medical issue and a developmental challenge, as they impact school, friendships, and family life (Logan et al., 2007; Doris & Morrissey, 2025). Research shows that the effects of chronic illness often carry into adulthood, affecting college completion, jobs, and independence (Maslow et al., 2011). This highlights the need to understand how schools support students with chronic illness. It is crucial for their health and their future opportunities.

Students with chronic illnesses often face academic struggles, like missing school, falling behind in classwork, or lower engagement, especially among those from low-income families or dealing with cancer or chronic pain (Logan et al., 2007; Mota et al., 2018; Withycombe et al., 2019). Later in life, they are also less likely to graduate college or find steady employment compared to peers without chronic illness (Maslow et al., 2011; Wisk & Weitzman, 2017). On the social side, chronically ill students tend to be less aggressive and more submissive, which may

affect their peer relationships (Meijer et al., 2003). They also often struggle with how much to share about their condition, sometimes choosing to hide it depending on how supportive they expect peers to be (Flick & Röhnsch, 2025). At the family and psychological level, studies show that resilience — especially when recognized by the adolescent — can improve coping skills, sociability, and self-confidence, helping them adjust better (Chen et al., 2024). Together, these findings show that chronic illness touches nearly every area of life, from school success to friendships and mental well-being.

Because school is where adolescents spend much of their time, it's also the place where chronic illness most often intersects with daily life. University students with chronic illness, for example, report fatigue, missed classes, and stress, and while disability services help some, support is often inconsistent (Doris & Morrissey, 2025). To address these challenges, researchers have tested different programs. Some focus on health literacy to give students the knowledge and tools to manage their health, especially in disadvantaged groups (Smith et al., 2021). Others look at educational support services for students with cancer, ADHD, or other conditions, which have shown promise in improving engagement and self-esteem, though effects on grades are mixed (Barnett et al., 2023). More recently, online programs designed for illnesses like ME/CFS have helped teachers and families better understand students' needs and keep them engaged in school (Keicher et al., 2024). These efforts suggest schools play a key role, but the evidence on what works best is still limited.

This review brings together research published between 2003 and 2025 to explore how school-based support systems affect students with chronic illnesses. In total, 14 studies were analyzed, covering outcomes from educational achievement to social adjustment and well-being. The review is guided by two main questions: (1) How does the health literacy of educational support systems impact the academic engagement and well-being of adolescents living with chronic illnesses? (2) What is the impact of school-based educational support services on the academic outcomes of adolescents with chronic illness?

By pulling these findings together, the goal is to highlight what we know, identify gaps in the research, and suggest how schools might better support students with chronic conditions in the future.

By organizing and analyzing evidence from diverse studies, this review contributes to understanding how schools can either exacerbate or alleviate inequalities for chronically ill students. It highlights both the promise of targeted interventions and the gaps that remain in translating educational support into measurable improvements in academic achievement and long-term well-being. Adolescents with chronic illnesses had lower school attendance, more academic difficulties, and reduced educational attainment compared to their peers. Family support and socioeconomic status influenced outcomes, with higher income and maternal education linked to better school experiences. Chronic illness also impacted the social lives of students, resulting in students having to adjust how they interacted with their peers and in the classroom.

Methodology

According to the objectives set, the method selected was a systematic review through PUBMED and Science Direct databases, whose purpose is to analyze the data in order to obtain an exhaustive overview of the information available on the subject under study. The selection of these databases was made based on their international prestige and recognition, as well as on their specific content in terms of research in the field of education. After the search, compilation, and selection of some relevant articles, an analysis process was carried out by extracting descriptive information about the studies and their findings (author, aim, method, participants, and results), from which the evidence of the results obtained was contrasted with similar literature. Studies were filtered based on the following inclusion and exclusion criteria.

Inclusion Criteria

- Studies focusing on adolescents (ages 12–20) with chronic illnesses
- Examined educational, social, or psychological outcomes.
- Evaluated school-based interventions, health literacy programs, or educational support systems.
- Published between 2003 and 2025.

Exclusion Criteria

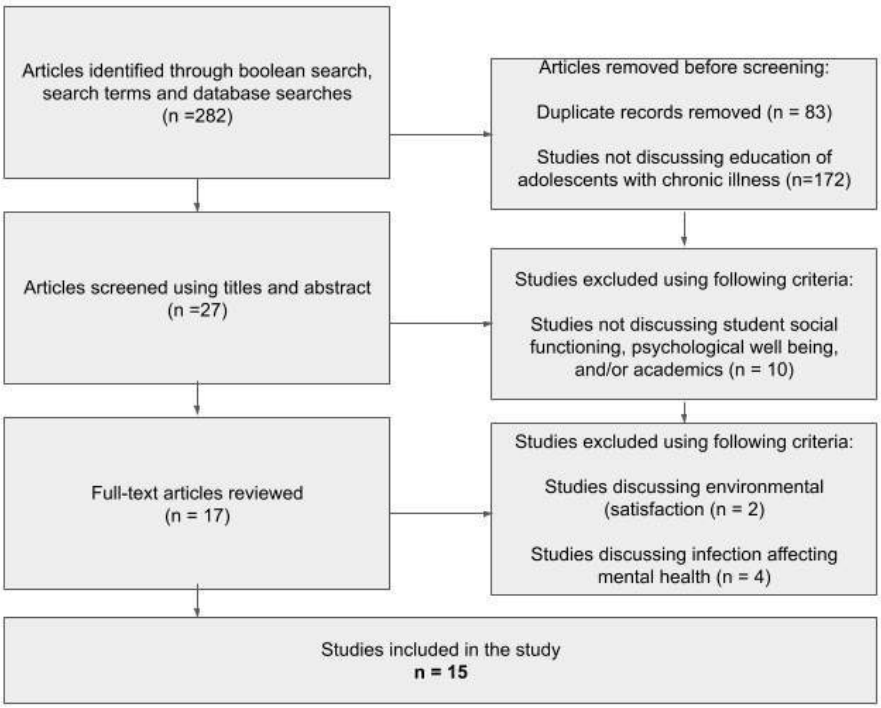
- Studies focused only on acute illnesses or temporary medical conditions.
- Case studies with fewer than 5 participants.
- Non-English articles.
- Reviews, editorials, or commentaries without primary data.

Then, after the articles were analyzed. Data from the 14 included studies were extracted using a standardized template, capturing

- Study authors and year
- Sample size and demographics
- Type of chronic illness
- Outcomes measured (educational, social, psychological)
- Intervention type and duration (if applicable)

A thematic analysis was conducted to organize findings into three main domains

1. Educational outcomes: Attendance, academic performance, engagement, literacy, and post-secondary education outcomes.
2. Social functioning: Peer relationships, social participation, and disclosure of illness.
3. Psychological well-being: Coping skills, resilience, life satisfaction, self-esteem, and mental health outcomes.



Results

Education Outcomes

Chronic illness is strongly linked to disruptions in academic performance and long-term educational outcomes. Koivusilta et al. (2022) found that adolescents who required daily medication were more likely to attend vocational schools, suggesting that chronic conditions can influence future educational pathways. Logan et al. (2007) reported that adolescents with chronic pain experienced frequent absences, declining grades, and high levels of school-related stress. Mota et al. (2018) observed particularly low engagement among chronically ill youth from low-income families. Doris and Morrissey (2025) described university students struggling with fatigue and stress while trying to meet academic demands. Similarly, Maslow et al. (2011) found that young adults with childhood chronic illnesses were less likely to complete college, more likely to be unemployed, and more dependent on public assistance. Wisk and Weitzman (2017) also reported lower educational attainment and poorer health, life satisfaction, and psychological well-being among adolescents with chronic conditions.

Programs designed to support students with chronic illnesses show mixed results. Barnett et al. (2023) reviewed educational interventions and found limited evidence of improved grades or school engagement, though some programs increased self-esteem. Smith et al. (2021) examined school-based health literacy initiatives and found promising results, but more evidence is needed to confirm behavioral changes. Keicher et al. (2024) developed an online program for adolescents with ME/CFS, their families, and school staff, which improved staff understanding and helped students remain in school. Withycombe et al. (2019) reported that adolescents with

cancer improved their literacy over time, though many still lagged behind age expectations. Doris and Morrissey (2025) noted that Disability Support Services were helpful for some students but inconsistent in quality and accessibility.

Chronic illness can also increase vulnerability to negative behaviors that harm academic outcomes. Weitzman et al. (2023) found that adolescents with chronic conditions were more likely to use cannabis, which correlated with lower grades and more absences, even when controlling for alcohol and nicotine use. Fatigue, pain, and missed school days may lead these students to use substances as coping mechanisms. Barnett et al. (2023) noted that limited school or family support exacerbates academic setbacks, while Smith et al. (2021) highlighted how social, behavioral, and health challenges often compound one another. Together, these factors create a cycle of risk that makes consistent academic performance difficult. Expanding school support, mental health services, and family guidance may help mitigate these effects.

Barnett et al. reviewed more than 14,000 studies but found only four that met their criteria, involving 359 participants. Most focused on children with cancer or ADHD. While three studies showed improved school engagement, results for academic performance were mixed. One study found only a small positive effect on school reintegration. Two studies reported higher self-esteem, but none measured quality of life or reported negative outcomes. Overall, the evidence was limited and uncertain due to methodological weaknesses. Koivusilta et al. tracked adolescents in Finland with asthma, diabetes, or epilepsy and found that those requiring medication had slightly lower grades and were more likely to pursue non-academic pathways or delay secondary education. The effect was modest but demonstrated how chronic illness contributes to educational inequality. Withycombe et al. studied 140 youth with cancer and found that literacy improved with age, but older adolescents were more likely to fall below expected reading levels. Higher literacy was linked to better comprehension of patient-reported outcome measures. Doris et al. interviewed 14 university students with chronic illnesses in Ireland and found that fatigue, missed classes, and emotional strain were common challenges. Support services varied in effectiveness, and students wanted more flexible and individualized assistance. Mota et al. studied 276 adolescents with chronic diseases and found that those with cancer or overweight had worse school functioning. Higher maternal education and family income improved outcomes, while higher body weight and parental loss worsened them. Logan et al. examined 220 adolescents with chronic pain and found that school absences, falling grades, and academic interference were common. Despite these challenges, most students were still seen as capable by themselves and their teachers. Keicher et al. demonstrated that online education programs for adolescents with ME/CFS improved understanding among school staff and helped reduce educational barriers.

Finally, Wisk and Weitzman studied 3,518 adolescents and found that while those with chronic conditions had similar aspirations as healthy peers, they held lower expectations and were less likely to achieve them. They were also less likely to earn a bachelor’s degree and reported poorer health and well-being, outcomes linked to lower educational attainment. Chronic

illness in adolescence can therefore lead to educational gaps, which may contribute to poorer health and reduced well-being later in life.

Social Functioning

Chronic illness also influenced how adolescents related to their peers. Meijer et al. (2003) found that chronically ill children were less aggressive and more submissive, which may affect social standing and friendships. Flick and Röhnsch (2025) revealed how young adults with chronic illness manage sharing their condition, finding that students adjusted their communication based on perceived peer understanding and safety. Chen et al. (2024) found that adolescents' perception of family resilience was often higher than their parents', and higher adolescent-reported resilience was linked to better psychological adjustment, including improved coping skills, sociability, and self-confidence. This suggests that family support and adolescents' own perceptions of resilience play an important role in social and emotional outcomes. Chen et al. (2024) demonstrated that adolescents who perceived higher family resilience experienced better psychological adjustment, including improved coping, sociability, and self-confidence. These findings indicate that **family dynamics**, particularly perceived resilience, play a key role in how adolescents engage with education and manage the challenges of chronic illness.

Meijer et al. studied 107 children with chronic illnesses to compare their social functioning with healthy peers. They found no major differences between different illness groups, suggesting the type of illness did not matter much. Compared with healthy peers, children with chronic illness reported less aggressive behavior, a trend also seen in parent reports. Parents also described children with chronic illness as showing more submissive behavior than healthy children. Physical restrictions and pain were associated with fewer social activities, but did not significantly impact other areas of peer interaction. The study suggested that children who are more submissive or limited in social activities may be at greater risk for social difficulties and need extra support.

Flick & Röhnsch studied 60 young adults with chronic illnesses and 30 of their peers to understand how young adults shared information about their illness. They found three main groups: those who were open about their illness, those who shared selected information with selected peers, and those who avoided talking about it or were unsure how to explain it. Peers also varied in how much they understood about the illness, which influenced how disclosure happened. The study suggested that programs should help both young adults and peers learn how to talk about chronic illness to improve understanding and social support.

Maslow et al. used data from a large national study to compare adults who grew up with a chronic illness to those who did not. They found that young adults with childhood-onset chronic illness had similar social outcomes as their peers, including marriage, having children, and romantic relationship quality. However, they were less likely to graduate college or be employed, had lower income, and were more likely to receive public assistance. Another study by Maslow et al. found that most young adults with chronic illness graduated high school and had jobs, but those with non-asthmatic chronic illnesses like cancer, diabetes, or epilepsy had worse outcomes

than both healthy peers and those with asthma. These young adults were more likely to choose vocational education over general academic paths, less likely to finish high school, and more likely to receive public assistance, showing that chronic illness can affect educational and vocational milestones.

Psychological Well-Being

Smith et al. reviewed 41 studies on school-based health interventions for socioeconomically disadvantaged adolescents aged 12–16. Most programs focused on physical activity and nutrition, while far fewer addressed mental health, substance use, or sleep. None of the studies directly measured health literacy as an outcome. The interventions differed widely in design and effectiveness, making comparisons difficult. However, certain approaches consistently showed positive results, including hands-on learning activities, peer support, and programs involving parents, schools, or the broader community. The review also identified significant gaps, particularly in interventions targeting substance use and sleep. Although none of the programs specifically aimed to improve health literacy, the findings highlighted strategies that could inform future program development for disadvantaged youth.

Chen et al. studied 264 pairs of adolescents with chronic illnesses and their parents in China. They found that adolescents generally rated their families' resilience higher than their parents did. Perceived family resilience was more strongly associated with better psychological adjustment when adolescents themselves believed their families were resilient than when parents believed so. When both parents and adolescents agreed on high resilience, adolescents showed better adjustment, though improvements plateaued at very high levels. Conversely, when adolescents viewed their families as less resilient than their parents did, they exhibited poorer adjustment. The study also found that adolescents' sociability decreased when parent and adolescent perceptions of resilience were closely aligned.

Weitzman et al. studied 958 adolescents, including those with chronic health conditions, to examine how substance use affected school outcomes. Cannabis use was linked to more negative outcomes, including lower grades, truancy, and increased detention. Adolescents with chronic illnesses were more likely to use substances and experience these negative academic effects. The association between cannabis use and poor school outcomes was stronger for adolescents with chronic illnesses. Alcohol and nicotine use were not significantly associated with school problems once cannabis use was accounted for.

Discussion

Chronic illness is frequently associated with disruptions in academic trajectories, lower attainment, and heightened stress among adolescents. Research shows that adolescents with chronic illnesses often face barriers to keeping up academically. For example, Koivusilta et al. (2022) found that students requiring daily medications were more likely to attend vocational schools and had slightly lower grades, suggesting that illness may shift students away from academic pathways. Logan et al. (2007) also reported that adolescents with chronic pain missed

school frequently, experienced academic setbacks, and reported high levels of stress tied to school. These findings are echoed by Mota et al. (2018), who showed that adolescents with chronic diseases, especially from low-income families, experienced lower school-related quality of life. Even at the university level, Doris and Morrissey (2025) observed students with chronic illnesses struggling with fatigue, missed classes, and emotional strain. Long-term outcomes further highlight this pattern: Maslow et al. (2011) found that young adults who had chronic illnesses as children were less likely to graduate from college and were more reliant on public assistance. Similarly, Wisk and Weitzman (2017) demonstrated that adolescents with chronic illnesses achieved lower educational attainment and later reported poorer health and psychological well-being. Together, this evidence suggests that chronic illness in adolescence not only hinders immediate academic success but also has long-term educational and emotional consequences.

At the same time, current support/intervention systems lack clear signs of improvement or aid for students with chronic illnesses. While programs exist to support students, their benefits appear inconsistent or incomplete. Barnett et al. (2023) reviewed educational support interventions and concluded that although some programs increased school engagement and improved self-esteem, evidence for boosting academic performance was limited and inconclusive. Smith et al. (2021) evaluated health literacy programs for disadvantaged youth and found they held promise but lacked strong evidence of changing student behavior or academic outcomes. Similarly, Keicher et al. (2024) tested an online program for adolescents with Myalgic Encephalomyelitis/Chronic Fatigue Syndrome and found improvements in staff understanding and student support, but emphasized that these results were preliminary. Withycombe et al. (2019) also found that although literacy skills in adolescents with cancer improved over time, many still fell behind their peers, reflecting gaps in academic support. Doris and Morrissey (2025) further showed that Disability Support Services were inconsistently helpful, with some students benefiting and others receiving unclear or insufficient assistance. Altogether, these studies reveal that while interventions can provide important social and emotional support, there is little consistent evidence that they fully address the academic challenges associated with chronic illness.

Chronic illness has shown signs of negative impact on a patient's education and potential future vocational outcomes. The long-term consequences of chronic illness extend beyond immediate academic difficulties to shape future educational and vocational outcomes. Studies indicate that chronic illness during adolescence can significantly alter career trajectories and economic opportunities. Koivusilta et al. (2022) found that adolescents with chronic illness were more likely to pursue vocational rather than academic tracks, which may reduce their access to higher education opportunities. Maslow et al. (2011) further reported that young adults with childhood chronic illnesses were less likely to graduate from college, had lower income, and were more reliant on public assistance compared to peers without illness. Similarly, Wisk and Weitzman (2017) found that chronic illness predicted lower educational attainment, which in turn was linked to poorer health and life satisfaction in adulthood. Logan et al. (2007) also showed

that academic setbacks and absenteeism caused by chronic pain may threaten long-term success. These findings underscore how adolescent illness can create cascading effects that persist into adulthood, affecting both socioeconomic stability and overall well-being.

Finally, chronic illnesses have been linked to influencing the quality of social life of students with chronic illnesses both in and outside of school. Meijer et al. (2003) observed that children with chronic illness were less aggressive and more submissive than their peers, which could affect friendships and social standing. Flick and Röhnsch (2025) demonstrated that young adults varied in how openly they disclosed their illnesses to peers, with disclosure patterns depending on perceived understanding and trust. Social support, therefore, depends heavily on communication and peer awareness. Chen et al. (2024) further found that adolescents who perceived greater family resilience experienced better coping skills, sociability, and self-confidence, suggesting that family dynamics play a critical role in supporting social adjustment. Maslow et al. (2011) added that while young adults with chronic illness had similar outcomes in romantic and family relationships as peers, their lower educational attainment and income could indirectly shape long-term social participation. Together, these studies reveal that chronic illness affects not only academic and vocational trajectories but also social experiences both inside and outside of school.

Socioeconomic status and family background play a critical role in shaping how chronic illness affects adolescents' academic outcomes. Mota et al. (2018) found that adolescents with higher maternal education and family income reported better school-related quality of life, stronger engagement in school, and fewer academic difficulties. In contrast, adolescents with widowed or single parents, or those with higher body weight, experienced lower school functioning and greater academic challenges. Koivusilta et al. (2022) similarly noted that adolescents with chronic illness who had modest family resources were more likely to pursue vocational education instead of traditional academic tracks, suggesting that chronic illness interacts with socioeconomic context to influence educational pathways. Wisk and Weitzman (2017) further highlighted that educational attainment among adolescents with chronic illness is shaped not only by their health status but also by family and social environment, indicating that interventions should consider these contextual factors to effectively support students' academic success.

Interventions for adolescents with chronic illness are most successful when they involve multiple levels of support, including peers, families, and institutional staff. Smith et al. (2021) found that programs incorporating hands-on learning, peer support, and parent or community involvement were more effective than those targeting only the individual student. Keicher et al. (2024) demonstrated an online program for adolescents with ME/CFS, which included siblings, parents, and school staff, improved staff understanding, reduced educational barriers, and facilitated collaborative accommodations. Doris and Morrissey (2025) emphasized the importance of individualized and flexible support, noting that even well-designed programs may fail if they do not adapt to the diverse needs of students. Multi-level involvement also benefits social outcomes by creating informed peers and supportive school environments, which can

reduce isolation, improve coping, and encourage active participation in both academic and social activities. These findings underscore the necessity of comprehensive, coordinated approaches to support adolescents with chronic illness.

Limitations of the Study

While this body of research provides valuable insights, it also has limitations. Many of the studies relied on relatively small sample sizes, such as Doris and Morrissey's (2025) work with only 14 university students, which limits the extent to which the results can be generalized. In addition, the diversity of chronic illness types studied is limited. For instance, several interventions focused mainly on cancer or pain conditions (Barnett et al., 2023; Logan et al., 2007), while fewer studies addressed illnesses like diabetes, epilepsy, or rare chronic conditions. This narrow focus reduces the ability to draw conclusions that apply to all adolescents with chronic illness. Future research should therefore include larger and more diverse samples to capture the full range of educational and social challenges faced by this population.

Conclusion

Chronic illness affects many parts of an adolescent's life. It disrupts school progress, weakens social connections, and increases emotional strain. The evidence shows that these challenges continue into adulthood, lowering educational attainment, job opportunities, and overall well-being. Support programs can be helpful, but their effectiveness is mixed. Some improve confidence and engagement, but few show clear gains in grades or long-term success. This means interventions cannot focus only on medical care. They must also address academic and emotional needs. Resilience at both the family and school levels is key. Families that provide stability help adolescents cope better, while schools that offer consistent support reduce barriers to learning. Together, these efforts can create fairer opportunities for students with chronic illness. Future research should use larger and more diverse samples. Studies should test programs across different illnesses, cultures, and education systems. Broader evidence will guide stronger interventions that meet the needs of this vulnerable group.

The findings across these studies highlight the importance of developing stronger and more comprehensive support systems for students with chronic illnesses. School-based interventions that focus on both academic and emotional well-being are especially critical, as they provide accessible resources where adolescents spend a significant amount of their time. Expanding institutionalized support, such as Disability Support Services, could help ensure consistent accommodations across different educational levels. At the same time, inclusive health literacy programs tailored for adolescents with chronic conditions may strengthen students' ability to manage their illnesses while staying engaged in learning. Beyond schools, families also play a central role. Building resilience within family units can improve adolescents' coping skills and self-confidence, which in turn supports both academic and social outcomes. Future interventions must therefore adopt a coordinated approach that addresses not only physical health but also the academic, emotional, and social challenges that accompany chronic illness.

Works Cited

Barnett, T., Tollit, M., Ratnapalan, S., Sawyer, S. M., & Kelaher, M. (2023). Education support services for improving school engagement and academic performance of children and adolescents with a chronic health condition. Cochrane Library, 2023(2). https://doi.org/10.1002/14651858.cd011538.pub2

Chen, M., Ren, L., Jiang, H., Wang, Y., Zhang, L., & Dong, C. (2024). Discrepancies in perceived family resilience between adolescents with chronic illness and parents: using response surface analysis to examine the relationship with adolescents' psychological adjustment. BMC Psychiatry, 24(1). https://doi.org/10.1186/s12888-024-05917-7

Doris, O., & Morrissey, E. C. (2024). Experiences of students with chronic illness in university education in Ireland. Chronic Illness. https://doi.org/10.1177/17423953241282246

Flick, U., & Röhnsch, G. (2024). Young adults living with chronic illness: disclosure strategies and peers' understanding. Disability and Rehabilitation, 1–12. https://doi.org/10.1080/09638288.2024.2400598

Keicher, F., Thomann, J., Erlenwein, J., Schottdorf, M., Reiter, N. L., Scholz-Schwärzler, N. P., Vogel, B., Warlitz, C., Stojanov, S., Augustin, S., Goldbrunner, L., Schanz, L., Dodel, V., Zipper, C., Schiweck, N., Jaeschke, R., Saramandic, M., Wiejaczka, K., Eberhartinger, M., . . . Spiegler, J. (2024). Development and implementation of an online patient education programme for children and adolescents with ME/CFS, their parents, siblings, and school personnel: study protocol of the prospective BAYNET FOR MECFS study (Preprint). JMIR Research Protocols, 13, e54679. https://doi.org/10.2196/54679

Koivusilta, L., Kaltiala, R., Myöhänen, A., Hotulainen, R., & Rimpelä, A. (2022). A Chronic Disease in Adolescence and Selection to an Educational Path—A Longitudinal study. International Journal of Environmental Research and Public Health, 19(21), 14407. https://doi.org/10.3390/ijerph192114407

Logan, D. E., Simons, L. E., Stein, M. J., & Chastain, L. (2008). School impairment in adolescents with chronic pain. Journal of Pain, 9(5), 407–416. https://doi.org/10.1016/j.jpain.2007.12.003

Maslow, G. R., Haydon, A. A., Ford, C. A., & Halpern, C. T. (2011). Young adult outcomes of children growing up with chronic illness. Archives of Pediatrics and Adolescent Medicine, 165(3). https://doi.org/10.1001/archpediatrics.2010.287

Maslow, G. R., Haydon, A., McRee, A., Ford, C. A., & Halpern, C. T. (2011). Growing up with a chronic illness: social success, Educational/Vocational distress. Journal of Adolescent Health, 49(2), 206–212. https://doi.org/10.1016/j.jadohealth.2010.12.001

Meijer, S. A., Sinnema, G., Bijstra, J. O., Mellenbergh, G. J., & Wolters, W. H. G. (2000). Social Functioning in Children with a Chronic Illness. Journal of Child Psychology and Psychiatry, 41(3), 309–317. https://doi.org/10.1111/1469-7610.00615

Mota, J. F., Rezio, M. A., Soares, R. C., Pimentel, G. D., Coelho, A. S. G., & Cunha, J. (2018). Quality of Life Is Influenced by Body Weight, Education, and Family Income in

Adolescents with Chronic Diseases. BioMed Research International, 2018, 1–8. https://doi.org/10.1155/2018/8485103

Smith, C., Goss, H. R., Issartel, J., & Belton, S. (2021). Health Literacy in Schools? A Systematic Review of Health-Related Interventions aimed at Disadvantaged Adolescents. Children, 8(3), 176. https://doi.org/10.3390/children8030176

Weitzman, E. R., Minegishi, M., Wisk, L. E., & Levy, S. (2023). Substance use and educational impacts in youth with and without chronic illness. American Journal of Preventive Medicine, 66(2), 279–290. https://doi.org/10.1016/j.amepre.2023.09.029

Wisk, L. E., & Weitzman, E. R. (2017). Expectancy and achievement gaps in educational attainment and subsequent adverse health effects among adolescents with and without chronic medical conditions. Journal of Adolescent Health, 61(4), 461–470. https://doi.org/10.1016/j.jadohealth.2017.04.006

Withycombe, J. S., McFatrich, M., Pinheiro, L., Hinds, P. S., Keller, F. G., Baker, J. N., Mack, J. W., Sung, L., Waldron, M. K., & Reeve, B. B. (2019). The association of age, literacy, and race on completing patient-reported outcome measures in pediatric oncology. Quality of Life Research, 28(7), 1793–1801. https://doi.org/10.1007/s11136-019-02109-9

Beyond Nutrition: Assessing the Association Between India's Midday Meal Scheme and Foundational Learning Outcomes By Aarav Chokhani

Abstract

This paper examines the association between India's midday meal scheme (MDM) and student learning outcomes in writing, reading, and mathematics. Using a comparative analysis of schools with and without the program, the study finds heterogeneous effects across skill levels and domains. While the MDM is associated with improved acquisition of foundational skills—such as letter and word recognition and basic numeracy—it shows a negative association with higher-order competencies, including paragraph reading, writing proficiency, and complex arithmetic. These findings remain consistent across socioeconomic and geographic subgroups. The results suggest that although the MDM successfully addresses nutritional and attendance objectives, these gains do not automatically translate into academic improvements. The paper underscores the need for complementary investments in pedagogy, teacher capacity, and learning resources to ensure that welfare-oriented interventions contribute to sustained cognitive and educational progress.

Keywords midday meal scheme, reading and writing outcomes, numeracy outcomes, socioeconomic status

Introduction

The Midday Meal Scheme (MDM) is the largest school feeding program in the world, aimed at improving both educational and healthcare of children in India. Initially it started in 1925 in a corporation school in Madras, and later in 1995 it was introduced around the country. The scheme provides free cooked lunches to students in government and government-aided schools. Beyond addressing hunger, the midday meal scheme serves as a crucial social policy to improve classroom results such as test scores, attendance, and overall classroom morale. By ensuring that each child receives at least one nutritious meal, the scheme tackles malnutrition as well and acts as an incentive for education and social equity. In this paper we discuss the association between exposure to the program and learning outcomes of school children.

Our results show that the midday meal scheme is associated with improvements in foundational learning skills but does not translate into gains in higher-order academic competencies. Students in schools implementing the program are more likely to recognize letters, words, and numbers, suggesting that improved nutrition and attendance may support the acquisition of basic literacy and numeracy. However, for more advanced skills—such as writing fluently, reading paragraphs with comprehension, or performing arithmetic operations like division—the association is negative, with students in MDM schools performing worse than those in non-MDM schools. These patterns are consistent across socioeconomic subgroups, with both students below and above the poverty line showing similar trends in foundational gains and higher-level deficits. Likewise, rural and urban schools exhibit comparable patterns, suggesting the effect is not driven by location-specific school characteristics. Taken together, the findings

point to a polarized learning profile: the program supports early-stage skill acquisition but does not reinforce continued cognitive development. This highlights the need for complementary investments in pedagogy, teacher capacity, and instructional resources to ensure that nutritional gains translate into sustained academic progress.

Literature Review

A growing body of empirical research has examined the impact of the midday meal program not only on nutritional and attendance outcomes but also—more recently—on learning outcomes, cognitive development, and intergenerational human capital formation.

Chakraborty and Jayaraman (2) provide one of the most comprehensive quantitative assessments of the MDM's effects on learning. Using repeated cross-sectional data from the *Annual Status of Education Report (ASER)* over eight years, the authors analyze a sample of 1.24 million primary school children aged 6–10. Their difference-in-differences estimates indicate that children exposed to the MDMS for up to five years experience an 18 percent improvement in reading scores and a 9 percent improvement in mathematics scores relative to those with only one year of exposure. The effects are larger when accompanied by improvements in teaching inputs, and persist over time, suggesting that the scheme's cognitive benefits extend beyond short-term nutritional gains.

In a complementary study, Cavapozzi et al. (11) examine the association between duration of exposure to the MDM and performance in standardized cognitive assessments, specifically the *Peabody Picture Vocabulary Test (PPVT)* and mathematics scores. Using data from 5,567 students aged 7–16 years—64 percent enrolled in public schools and the remainder in private schools—the authors find robust positive effects: each additional month of exposure to the program increases PPVT and math score percentiles. Given an average exposure of 48 months, the estimated gains amount to roughly 10 percentile points in vocabulary and 21 percentile points in mathematics. The magnitude of these effects is comparable across genders, indicating that the MDMS benefits both male and female students equitably. The study attributes these gains to improved nutrition and attendance, but also to the indirect influence of midday meals on classroom engagement and attention.

Beyond test scores, several studies have linked the MDM to improved schooling participation and reduced gender and caste disparities. Kaur (10), employing an instrumental variable strategy, estimates the causal effect of receiving free school meals on enrollment rates in primary schools. The results reveal that the program substantially increases school enrollment, with the effect for girls nearly twice that for boys. Among disadvantaged social groups—Scheduled Castes (SC), Scheduled Tribes (ST), and Other Backward Classes (OBCs)—the program's effect is also significantly larger than among higher-caste children. Specifically, Kaur reports that the MDM increased girls' enrollment by 23.1 percent (gross) and 28.5 percent (net), compared to 12.4 and 15.6 percent for boys. These findings underscore the program's role as a gender- and equity-sensitive policy instrument that mitigates historical barriers to schooling among marginalized populations.

Bonds (3) evaluates the program using data from India's 2004 Socio-Economic Survey

and employs a propensity score matching approach to estimate enrolment impacts. The study finds that, on average, school enrolment rates of MDM beneficiaries were 22.7 percentage points higher than those of non-beneficiaries, controlling for observable household and parental characteristics. Restricting the analysis to government and local body private schools, the estimated effect rises to nearly 29.5 percentage points. Importantly, stratified results show that children from the lowest socio-economic groups benefited disproportionately, suggesting that the program reduced financial barriers to schooling most effectively among disadvantaged households.

Jayaraman and Simroth (13) provide a large-scale causal assessment by exploiting the staggered implementation of the MDM program across Indian states following a 2001 Supreme Court directive. Using a panel of nearly 500,000 schools from 15 major states between 2002 and 2004, they employ a difference-in-difference-in-differences strategy, comparing enrolment trends across government and private schools. Their results indicate that midday meals led to a 13% increase in primary school enrolment, equivalent to approximately 14 additional students per school. The effect was concentrated in grade 1, where enrolment rose by about 21%, while impacts on higher grades were positive but statistically insignificant, reflecting limited scope for additional entry beyond initial enrolment. The study further shows that enrollment gains were largest among socio-economically disadvantaged groups and were accompanied by improvements in attendance, though not in measured learning outcomes.

Afridi (7) focuses on rural Madhya Pradesh, using school panel data and a difference-in-differences strategy to compare outcomes before and after the transition from grain distribution to cooked meals. The results show that the introduction of cooked school meals raised average monthly attendance of girls in grade 1 by over 10 percentage points, while effects on boys' attendance were positive but insignificant. Enrolment levels overall did not increase significantly, though there was evidence of small gains among girls from disadvantaged socio-economic groups. The findings suggest that the program has been more successful in improving regular participation—especially of girls—than in expanding total enrolment. Moreover, by disproportionately benefiting female students, the program contributed to narrowing gender disparities in schooling.

Similarly, Assan et al. (194) investigate the socio-economic and caste dimensions of MDM participation in Uttar Pradesh. Drawing on a mixed-methods study of 1,338 students and 175 teachers, they find that while overall satisfaction with the scheme is high, perceptions of adequacy and quality vary by socio-economic status. Students from relatively better-off households express higher satisfaction, whereas those from food-insecure households report dissatisfaction with the adequacy and nutritional quality of meals. Nonetheless, the program is widely perceived to improve attendance and reduce gender disparities, particularly among Dalit and Muslim children. The study concludes that the MDM functions as a socially integrative policy in contexts marked by entrenched hierarchies of caste and class, with the largest welfare gains accruing to the poorest and most marginalized students.

Although the MDM was initially conceptualized as a nutritional intervention, its broader

developmental consequences—including its impact on intergenerational human capital—have also received attention. Chakrabarti, Suman, et al. (6), using nationally representative data spanning 1993–2016, examine whether maternal exposure to the MDM during childhood predicts improved health outcomes among their offspring. They find that children born to mothers who were fully exposed to the MDM exhibit significantly higher height-for-age z-scores (HAZ) by approximately 0.40 standard deviations compared to those born to non-exposed mothers. The authors estimate that the MDM accounts for between 13 and 32 percent of the observed national improvement in child height between 2006 and 2016, suggesting that the scheme's benefits extend across generations through improved maternal health and education. These findings position the MDM as a sustained investment in human capital formation rather than a purely short-term welfare program.

While several evaluations have emphasized the nutritional benefits of the scheme, evidence from randomized and quasi-experimental studies points to a consistent mechanism through which improved nutrition and school attendance translate into cognitive and learning gains. For instance, Berry et al. (15) demonstrate that nutritional enhancements in school meals—particularly when combined with adequate administrative monitoring—produce measurable improvements in hemoglobin levels and reduce anemia, outcomes that have well-established links with cognitive functioning. Similarly, Gharge et al. (3), using longitudinal data from the *India Human Development Survey* (2004–05 and 2011–12), report that persistent exposure to MDMS significantly reduces the likelihood of low BMI z-scores among school-aged children. However, the primary channel through which the MDMS contributes to educational achievement appears to be its effect on school participation, regularity, and learning time rather than on anthropometric outcomes per se.

Taken together, this literature underscores that the MDM plays a dual role as both an educational and a social policy instrument. Quantitative evidence from large-scale and experimental studies consistently links prolonged exposure to the program with improved cognitive outcomes and school participation, particularly among disadvantaged groups. These gains appear to be mediated by improved nutrition and classroom attendance, yet their persistence suggests deeper complementarities between nutritional support, learning environments, and household investments in education. Despite its scale and longevity, relatively few studies have explored the program's long-run impacts on academic performance and skill accumulation using rigorous causal identification strategies. The existing evidence, however, points to substantial learning dividends from what began as a welfare-oriented feeding initiative, situating the MDM within the broader literature on education production functions and the economics of school-based health interventions.

Results

The empirical analysis investigates how participation in the midday meal scheme relates to students' foundational learning outcomes, focusing on three domains: writing, reading, and mathematics. The results reveal a nuanced pattern of associations, characterized by improvements in basic skills but limited or negative relationships with more complex

competencies.

Across all subjects, schools implementing the MDM exhibit higher proportions of students who can perform simpler tasks—such as recognizing letters, words, or numbers—relative to non-participating schools. However, this pattern reverses for advanced skills, including writing fluency, reading comprehension, and arithmetic operations like division. The share of students unable to perform any task also increases under MDM exposure, suggesting that while the program may enhance participation and engagement, it may not generate corresponding gains in higher-order learning.

Disaggregated analyses reveal that these associations are broadly consistent across socioeconomic and locational subgroups. Both below- and above-poverty-line (BPL and APL) students, as well as rural and urban students, experience similar patterns—positive associations at the foundational level but weaker or negative associations at higher skill levels. Nonetheless, APL students and urban schools tend to perform better overall, indicating that household resources and school context may moderate, though not fully offset, the underlying program effects.

Taken together, these findings point to a polarized pattern of learning outcomes. The MDM appears to succeed in supporting school participation and the development of early skills but falls short in fostering complex academic competencies. The next sections examine these patterns in detail across writing, reading, and mathematics, followed by a discussion of their policy implications.

Writing Outcomes

The analysis reveals a significant negative association between exposure to the Midday Meal Scheme and students' writing proficiency (Figure 1.1). A substantially larger proportion of students in MDM schools are unable to write compared to those in non-MDM schools (37.3% versus 20.1%, $p < 0.01$). Conversely, the share of students who can write well is markedly lower in schools implementing the program (62.7% versus 79.9%, $p < 0.01$). The magnitude of this difference—over 17 percentage points—is both statistically significant and educationally meaningful.

These findings suggest that participation in the MDM is not associated with improvements in writing ability and may, in fact, correspond to a decline in performance. While the scheme effectively addresses nutritional and attendance objectives, the results indicate that these benefits do not automatically extend to academic competencies such as writing. This underscores the importance of complementary investments in pedagogical quality, instructional support, and learning resources. Without such measures, the potential cognitive and educational returns of welfare-oriented interventions like the MDM may remain unrealized.

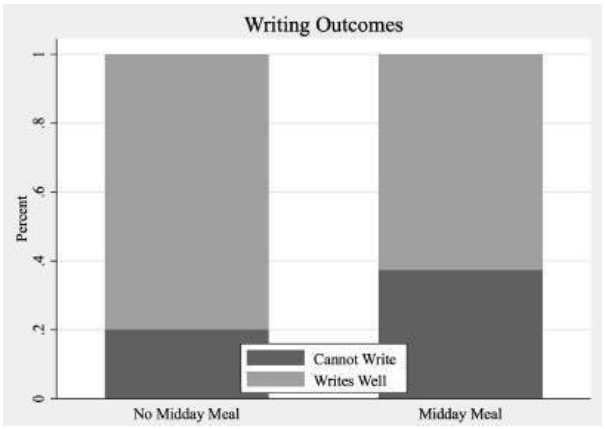


Figure 1.1: Association Between Midday Meal Program and Writing Outcomes

The negative relationship between MDM participation and writing proficiency persists across socioeconomic categories. Students from both below-poverty-line (BPL) and above-poverty-line (APL) households demonstrate lower writing performance in MDM schools than their counterparts in non-MDM schools (Figure 1.2). However, the adverse association appears less severe among students from APL households, who maintain relatively higher writing proficiency. This pattern suggests that household economic status may moderate the program's academic impact, possibly through differences in complementary educational inputs at home.

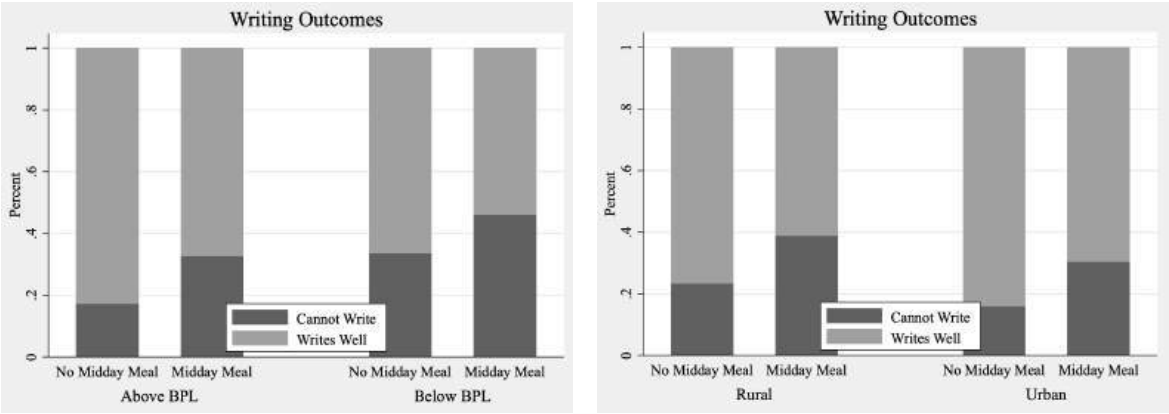


Figure 1.2: Association Between Midday Meal Program and Writing Outcomes: by Socioeconomic Status and Location

A similar pattern is observed across rural and urban settings. In both environments, students in MDM schools exhibit lower levels of writing proficiency compared to those in schools without the program (Figure 1.2). The consistency of this finding across geographies implies that the observed effect is not driven by location-specific school characteristics but may instead reflect broader structural or implementation-related features of the scheme that influence classroom learning conditions.

Reading Outcomes

The relationship between exposure to the midday meal scheme and reading proficiency presents a mixed pattern (Figure 2.1). The program appears to enhance the acquisition of foundational literacy skills but shows a negative association with more advanced reading competencies. Specifically, participation in the MDM is associated with higher proportions of students able to read basic units such as letters and words, both among households below and above the poverty line (BPL). However, for more complex tasks—such as reading paragraphs or short stories—the association turns negative. Moreover, exposure to the MDM corresponds with a higher proportion of students who are unable to read at all, suggesting that the program may not uniformly support literacy development across different proficiency levels.

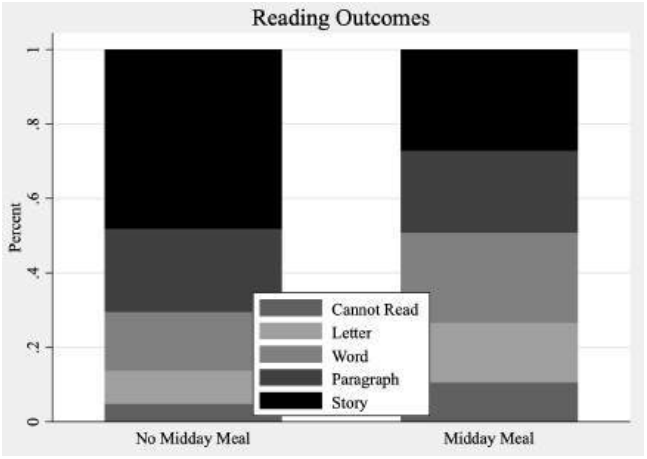


Figure 2.1: Association Between Midday Meal Program and Reading Outcomes

Across socioeconomic groups, the MDM appears to strengthen early reading abilities while being negatively associated with higher-order literacy skills (Figure 2.2). Both BPL and APL students show improved ability to recognize letters and words under the program, yet both groups perform less well on tasks requiring comprehension and fluency. The increase in non-readers following program exposure further indicates that the benefits of improved nutrition and attendance may not translate directly into sustained learning gains. Although APL students generally maintain stronger reading performance, the direction of the MDM effect remains consistent across income groups, suggesting that household economic status does not fully offset the limitations observed in reading achievement.

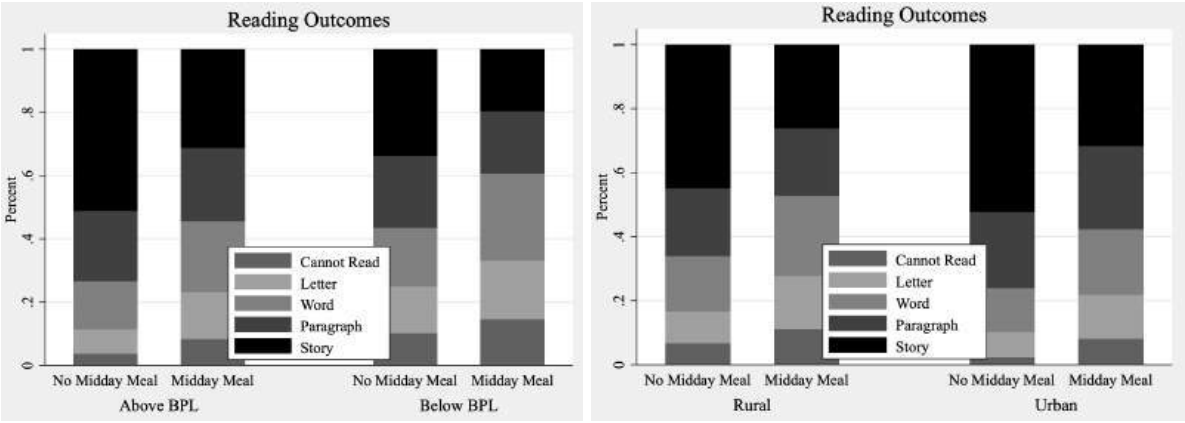


Figure 2.2: Association Between Midday Meal Program and Reading Outcomes: by Socioeconomic Status and Location

Patterns by location mirror those observed by socioeconomic status (Figure 2.2). In both rural and urban settings, exposure to the MDM is positively associated with basic literacy skills—particularly letter and word recognition—but negatively associated with more complex reading tasks such as story or paragraph comprehension. The share of students unable to read also increases in both contexts, with the disparity being more pronounced in urban schools. This suggests that the program's effects on literacy may interact with contextual factors such as school quality, teacher availability, and classroom time, which could moderate the extent to which nutritional and attendance improvements lead to measurable gains in reading outcomes.

Numeracy Outcomes

The estimates reveal substantial differences in mathematics performance between students enrolled in schools implementing the midday meal scheme and those in non-participating schools (Figure 3.1). At the foundational level, the share of students unable to complete any mathematical task is significantly higher in MDM schools (20.7% versus 9.6%, $p < 0.01$). However, children in MDM schools demonstrate stronger performance in basic numeracy, with a larger proportion able to identify numbers (38.4% versus 24.5%, $p < 0.01$), suggesting that the program may contribute to the acquisition of early arithmetic skills.

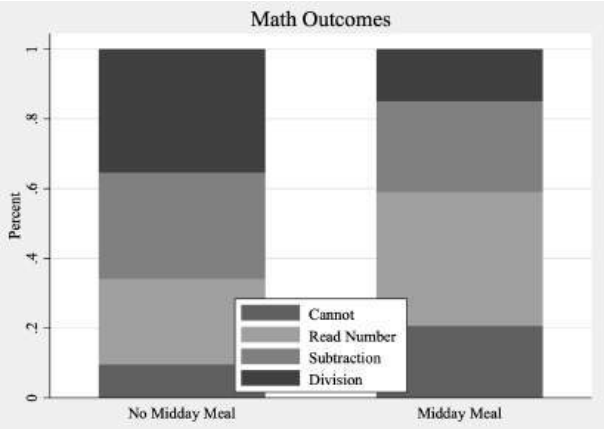


Figure 3.1: Association Between Midday Meal Program and Numeracy Outcomes

At higher levels of difficulty, however, the relationship reverses. Subtraction proficiency is only marginally higher in non-MDMS schools (30.5% versus 26.1%, $p < 0.01$), but the gap widens sharply for division tasks. Only 14.9% of students in MDM schools can perform division compared to 35.4% in non-MDM schools—a difference of 20.5 percentage points ($p < 0.01$). Taken together, these findings indicate a polarized pattern: while the MDM appears to support basic numeracy and number recognition, its association with more advanced arithmetic competencies is negative.

From a policy standpoint, these results highlight a key limitation of nutrition-focused interventions when implemented in isolation. Improved attendance and nutritional intake may enhance engagement and concentration, thereby supporting basic learning outcomes, but do not necessarily translate into sustained cognitive or academic advancement. To ensure that the MDMS contributes meaningfully to overall learning, complementary investments in pedagogy, teacher capacity, and remedial instruction are essential.

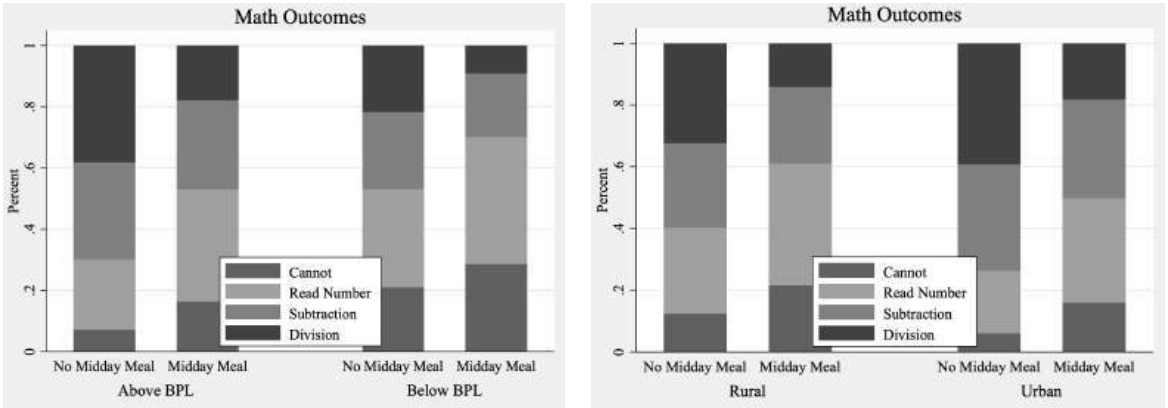


Figure 3.2: Association Between Midday Meal Program and Numeracy Outcomes: by Socioeconomic Status and Location

The observed pattern persists across socioeconomic groups (Figure 3.2). Both below-poverty-line (BPL) and above-poverty-line (APL) students in MDM schools perform better on simpler numeracy tasks, such as number recognition, but worse on more complex operations, such as division. Furthermore, the proportion of students unable to complete any mathematical task increases among both groups following program exposure. Although APL students consistently perform at higher overall levels, the direction of the MDM effect remains consistent, suggesting that socioeconomic status moderates but does not fundamentally alter the relationship between the program and mathematical achievement.

Similar trends are evident across rural and urban locations (Figure 3.2). In both contexts, MDM participation is associated with improvements in basic numeracy but a higher proportion of students unable to complete arithmetic problems. In rural areas, the share of students able to perform subtraction declines with MDM exposure, whereas in urban areas, subtraction performance remains relatively unchanged. The proportion of students able to complete division tasks falls sharply in both settings. These findings imply that the program's cognitive effects are shaped by the interaction of nutritional benefits with contextual factors such as instructional quality and resource availability, which mediate the translation of improved attendance into learning gains.

Findings from primary survey

Discussions with teachers and principals in grades 9 and 10 in government schools in Mumbai highlighted that the midday meal program had played an important role in improving student attendance. Many noted that students were more likely to come to school regularly when a meal is provided, with particularly strong gains observed among girls. Teachers also mentioned that the program contributed to better classroom morale and sustained participation throughout the school day. However, while attendance increased, the improvement in test scores and learning outcomes was more limited. Teachers felt that although some students appeared more motivated and were willing to put effort into studying, these changes did not consistently translate into higher academic performance. Overall, the midday meal program was seen as effective in encouraging regular school participation, but less so in directly enhancing scholastic achievement.

Conclusion

The findings of this study reveal a complex relationship between India's MDM scheme and foundational learning outcomes. While the program contributes positively to students' acquisition of basic literacy and numeracy—such as recognizing letters, words, and numbers—it is negatively associated with performance on more advanced academic tasks, including writing fluency, reading comprehension, and higher-level arithmetic. These results persist across socioeconomic and locational categories, underscoring that nutritional interventions alone are insufficient to generate broad-based learning improvements.

The observed patterns highlight the limits of welfare-oriented programs when implemented without corresponding enhancements in instructional quality and learning support.

Improved nutrition and attendance may create favorable preconditions for learning but require complementary investments in pedagogy, teacher training, and remedial education to translate into academic achievement. From a policy perspective, integrating school feeding initiatives with targeted learning interventions—particularly those focused on literacy and numeracy foundations—could yield more holistic and sustainable impacts on child development.

Overall, the evidence suggests that the MDM has achieved substantial success in addressing short-term welfare goals but remains only partially effective as an education policy instrument. Strengthening its educational complementarity represents an important step toward ensuring that India's largest school feeding program contributes not only to children's nutrition and participation but also to their long-term learning and human capital outcomes.

Work Cited

Afridi, Farzana. “The Impact of School Meals on School Participation: Evidence from Rural India.” Journal of Development Studies, vol. 47, no. 11, 2011, pp. 1636–1656.

Assan, Joseph K., et al. “Assessing the Impact of Public-Private Funded Midday Meal Programs on the Educational Attainment and Well-Being of School Children in Uttar Pradesh, India.” Caste: A Global Journal on Social Exclusion, vol. 1, no. 2, 2020, pp. 193–214.

Berry, James, et al. “Crowd-Out in School-Based Health Interventions: Evidence from India’s Midday Meals Program.” Journal of Public Economics, vol. 204, 2021, p. 104552.

Bonds, S. “Food for Thought: Evaluating the Impact of India’s Midday Meal Program on Educational Attainment.” University of California, Berkeley, 2012.

Cavapozzi, Danilo, Elisa Fornasiero, and Tiziano Randazzo. “The Effects of the Indian Midday Meal Scheme on Cognitive and Health Outcomes of Children in Andhra Pradesh.” Ca’ Foscari University of Venice, Department of Economics Research Paper Series, no. 14, 2024.

Chakrabarti, Suman, et al. “Intergenerational Nutrition Benefits of India’s National School Feeding Program.” Nature Communications, vol. 12, no. 1, 2021, p. 4248.

Chakraborty, Tanika, and Rajshri Jayaraman. “School Feeding and Learning Achievement: Evidence from India’s Midday Meal Program.” Journal of Development Economics, vol. 139, 2019, pp. 249–265.

Gharge, Supriya, et al. “The Effect of the Midday Meal Programme on the Longitudinal Physical Growth from Childhood to Adolescence in India.” PLOS Global Public Health, vol. 4, no. 1, 2024, p. e0002742.

Jayaraman, Rajshri, and Debraj Simroth. “The Impact of School Lunches on Primary School Enrollment: Evidence from India’s Midday Meal Scheme.” The Scandinavian Journal of Economics, vol. 117, no. 4, 2015, pp. 1176–1203.

Kaur, R. “Estimating the Impact of School Feeding Programs: Evidence from Midday Meal Scheme of India.” Economics of Education Review, vol. 84, 2021, p. 102171.

Resilience by Choice: How Mindset Guards Against Inferiority By Irene Shin

Abstract

This paper explores how mindset and self-confidence play a critical role in overcoming feelings of inferiority, especially in a world shaped by social media and constant comparison. Drawing from personal experiences with rejection, the author reflects on how initial feelings of self-doubt can be transformed into resilience. Both direct factors (such as criticism) and indirect factors (like social comparison) that contribute to feelings of inadequacy are thoroughly explored. Through strategies such as positive self-talk, cognitive behavioral therapy, and self reflection, the paper emphasizes the importance of developing a proactive, resilient mindset. It also examines how self-confidence acts as a reactive tool to protect against negative external influences. Ultimately, the argument is made that no one can make us feel inferior without our consent, but by cultivating emotional control and strong inner beliefs, individuals can maintain their self-worth regardless of external judgments or rejection.

Introduction

"Unfortunately, you have not been selected in the application." Every school year during the month of May, I hear this phrase over and over again. And whenever I got these emails starting with an "unfortunately" that indicated a rejection, people would remind me that process matters more than results. But if I put in the biggest effort while applying and still received results that did not reflect on my hard work, I would feel inferior. And instead of standing back up, I spent a lot of time overthinking, trying to read the reviewer's mind and comparing myself to those who were accepted. Towards the end, I simply concluded that the organizations I applied for didn't like who I was because I tried to be as authentic as I could at all times. However, as days passed by and I experienced more rejections and also a few acceptances, I was able to grow a mindset where even if I get negative comments or thoughts, I am able to care less and prevent them from holding a major influence on me. I ended up learning that going through rejections, even if they were hurtful at the moment, they all helped me work on my weaknesses and become who I am today, a resilient person who can learn from past mistakes and never give up.

There are two main categories to the factors that cause us to feel inferior: direct and indirect. Direct factors are negative critiques or comments we hear about ourselves. And in the world we are living in right now, where social media is a major part of our lives, it is more common for us to hear these comments. As we have access to different platforms, we are more likely to feel pressured by viewing other people's lifestyles, whether it would be real or made up, depending on the way it is portrayed in the media. Whereas indirect factors include comparisons, similar to how I compared myself to people around me who received acceptances. This happens because we, humans, are naturally born to compare ourselves to others, as the "social comparison theory suggests that people value their personal and social worth by assessing how they compare to others." We make comparisons in order to evaluate our personal qualities and placements in society. As the world revolves around these factors, we are more likely to feel inferior. Without

taking control over our mindsets, we will unintentionally let these factors affect and downplay us. Therefore, it is important to remember that feeling inferior isn't determined by others, but by how we choose to deal with the situation. Therefore, in my essay, I will argue that with a positive mindset and self confidence, no one will be able to make us feel inferior without our consent, just like how Eleanor Roosevelt stated.

Preemptive Development of a Resilient Mindset

The mindset an individual has is the major determinant in letting one feel inferior. A positive mind filled with optimism and gratitude will hinder people from feeling weak or discouraged as the positive thoughts will dominate the negative thoughts. As we grow up, we meet more people and have more social interactions. As a part of living in society, we will build on our career, get jobs, and encounter a series of challenges. With this, we will be more likely to receive criticism from others or meet other people who can be better and have more skills than us. In these moments, if we are able to block out negative thoughts and stop ourselves from comparing ourselves to others, it is less likely to allow feelings of worthlessness and inferiority.

One of the effective methods used to block out negative thoughts with rather hope and positivity is the positive self-talk. In the most recent pandemic, we frequently witnessed a significant growth of the number of deaths due to the spread of the Covid-19 virus. Although these growing numbers were presented as simple digits on the news screen, they carried a heavy weight, signaling to us that we or our loved ones could be next. This pandemic ultimately caused us to "experience symptoms of anxiety and depression," but it also challenged our mindset. According to the 2020 Iranian study, those who utilized positive self-talk had less fear about deaths and seemed to think less about the high likelihood of them catching the virus as well. For example, imagine that two people are watching the news about the percentages of people diagnosed covid virus going up. Person 1, who doesn't use positive self-talk, sees the percentage increasing and starts thinking to themselves, "Wow, I'm going to get that virus too. And if that happens, I might die too. I have no hope." On the other hand, person 2 who instead blocks out the negative thoughts that are in their mind and views the situation in a more hopeful way, thinks, "since more people are being diagnosed, I should be more careful and sanitize my hands more before going out. It is just a reminder to continue watching out," showing how effective positive self-talk is in shaping people's mindset and feelings.

There are several more powerful strategies we can apply to get rid of negative thoughts and replace them with a more positive and resilient mindset. One of them is Cognitive Behavioral Therapy. This type of therapy is used in patients who are usually struggling with anxiety and depression. According to mental health specialists, the therapy "teaches you to think in a less negative way about yourself and your life. It is based on the understanding that thinking negatively is a bad habit, like any other habit, can be broken." It first helps patients to identify negative thoughts that are heavily controlling them and help them think of some factors that may challenge the negativity. For instance, if a person thinks that they are a bad dancer, the therapy will encourage one to think of times where they placed or performed well in competitions to get

rid of the pattern of them thinking that they are bad at dance. Then, the person will be able to think of moments where they scored good or placed at a competition, which will be helpful in getting away from the negative thought process. This approach allows people to realize that it is possible to shift their perspective into something positive.

Aside from the therapy which can seem as a bigger step to individuals, there are simple habits that can be done. Habits like journaling, writing down thoughts, and setting up small goals can help focus our mind into something peaceful rather than focusing on what is going wrong. Journaling especially allows us to release all of our thoughts including anything that is random on a paper and as we read through what we have written, we can understand ourselves and process the emotions we are feeling at the moment. Even though it can be seen as a tool to "make you [us] self-obsessed" or "a passive observer," it still "converts negative energy into positive creativity and growth."

Reactive Responses in Self-Confidence

While having a positive mindset is preemptive since it prepares people to be unaffected by any challenges or obstacles, a reactive way to prevent feeling inferior is having self-confidence and controlling one's reactions. After learning how to react and respond to different situations over time, we will find a way to control our emotions and our responses to feel less inferior, though in the beginning, our initial reaction can be uncontrollable.

Without knowing how to handle or respond to situations where we are exposed to unfavorable critiques, we will eventually fall into a trap to think about the comments constantly, letting us accept and agree to the harsh criticisms. This pattern where individuals say negative remarks to themselves is known as the negative self-talk. If this action becomes a habit, it makes it even more challenging for us to grow self-esteem and recognize our own worth and skills. Consider a person who just started a new hobby which is soccer and has joined a soccer class. For a beginner who has just started playing, it is natural to lack a lot of skills compared to other people in class who are trained well. If the teacher were to say, "You have no hope for improving. How did you even choose to play soccer?" This comment could easily trigger feelings of inferiority. Someone who is untrained in managing their reactions might take these words into account and think, " Yeah I actually am so bad. I should quit." In contrast, a person who is experienced in controlling themselves in reacting in these situations will respond, "That comment she/he gave is simply a reminder for me to work hard. The reason I struggle is only because I'm a beginner. I will practice even more and prove the teacher wrong." This strong mindset prevents external critique or insult from affecting one's confidence and esteem, showing how resilience can hinder feelings of inferiority.

Taking in negative thoughts and accepting them lowers one's confidence a lot because "there's a close relationship between negative self-talk and lower self-esteem. Being critical of yourself continuously chips away at your confidence, which makes it hard to work towards goals or take chances." Negative self-talk will lead us to lose trust in ourselves and have the negative thought affect and control our mood throughout the whole day. We will constantly think about it

whenever we're doing anything and it will make it harder for us to listen to positive comments about them and accept them. However, it is important to identify the negative thoughts in our mind and get rid of them by overpowering them with confidence. High confidence does not always solve all problems as we might be seen as arrogant, but it is important to maintain some kind of confidence and have that strong positive belief in ourselves.

The confidence and the trust we have in ourselves, that we are able to improve and are good enough regardless of what others say, are more powerful than any other factors that are trying to make us feel inferior. At the end of the day, people will come and go, but the mindset we have stays with us. Our lives depend on how well we react and respond to each situation and it is important to maintain a strong mindset and habits that do not let ourselves feel down. Therefore, it is important for us to learn how to protect our confidence and know when or when not to give consent in letting ourselves feel inferior.

Conclusion

In our daily lives with workplaces, social media, and interactions, it is easy to see people not knowing how to react to others' criticism and their own critiques and comparisons. And with our lack of knowledge on what to do, we easily let small things affect our mood and feelings throughout the whole day. However, no one else can truly define our worth. If we start to feel inferior, it often comes from the way we process what others say or do. While it is natural for us to have moments when negative thoughts take over or compare ourselves to people around us, we cannot let these feelings dictate our worth and value. From time to time, we might struggle with self-doubt, but that doesn't mean we are unworthy or less capable. Even in challenging moments in our daily lives, we can always control ourselves to maintain a positive mindset and self-confidence, showing how no one can make us feel inferior without our own consent.

Works Cited

Cherry, K. (2023, November 7). The social comparison process. Verywell Mind. https://www.verywellmind.com/what-is-the-social-comparison-process-2795872

Integris Health. (2024, February). Negative self-talk: What it is and how to stop it. On Your Health. https://integrishealth.org/resources/on-your-health/2024/february/negative-self-talk

Muthukumar, M. (2023, October 18). Positive self-talk: How it works and health benefits. Medical News Today. https://www.medicalnewstoday.com/articles/positive-self-talk

National Institute of Mental Health. (n.d.). COVID-19 and mental health. U.S. Department of Health and Human Services, National Institutes of Health. https://www.nimh.nih.gov/health/topics/covid-19-and-mental-health

Tan, S. (2024, November 27). The hidden impact of negative self-talk on mental health. Stuart Tan. https://www.stuarttan.com/the-hidden-impact-of-negative-self-talk-on-mental-health/

Evaluating Machine Learning Techniques for Predicting Insurance Costs

By Elijah Rebholz

Abstract

In this paper, we explore how Artificial Intelligence models can be used to predict and advise consumers on medical insurance premiums. We cover a variety of methods in order to optimize the models, their performance, and the real-world applications coinciding with insurance and insurance premiums. An insurance premium is the amount an insurance company charges the customer for using their service. The goal of the model is to depict the insurance costs, in order to inform the user of which insurance to buy, as different insurance providers have different premiums. The models themselves are diverse in their construction, so we provide comprehensive information on their layout, applicability, drawbacks, and benefits. Additionally, we explore methods to enhance the overall output, creating an accurate and efficient model. The lowest testing mean-squared-error was found to be a Random Forest, with max depth of 3 and 18 estimators, and had a value of 21.49. In order to properly analyze future patients, we sourced the Age, Sex, Weight, BMI, Smoking Habits, Number of Children, and Region of Residence (in the Continental United States), and their medical costs, from real patients across the country.

Introduction

The project covers how, given a patient's age, gender, smoking habits, BMI, number of children, and region of residence (specifically in the continental United States), an Artificial Intelligence model can predict their expected insurance prices.

Specifically in the US, health insurance bills are a major political and social dilemma. This has led to a lot of distrust between the public and major health insurance providers, culminating in events such as the 2024 shooting of UnitedHealthcare CEO, Brian Thompson (Wendling), and the overwhelming support for his killer. All the distrust and anger towards health insurance providers, and the American healthcare system as a whole, requires a credible source of accurate information and advice to reliably inform the masses.

Currently, the measures taken to ensure that insurance providers are not maliciously charging their clients, is a thorough auditing process, where third-party auditors scan all possible information given by the hospital bills, and the doctors themselves. These methods, though efficient, are often conducted by humans, and third-party organizations, not by the patient themselves. This model is designed to bring the process straight to the consumer, removing any biases that come from large organizations, auditors, and insurance providers alike.

Recently, lawsuits relating to over-pricing and under-payment of physicians have arisen, notably the lawsuit brought by the California Medical Association (CMA) against MultiPlan and other large providers (California Medical Association), displaying the corruption surrounding insurance providers.

The idea for an AI algorithm predicting insurance prices has been covered before, such as this paper covering a model which reads information about a patient, such as sex, BMI, smoking

status, and outputs the expected costs in insurance premiums (Lakshmi Narasimhan Srinivasagopalan). There is also a paper covering the use of three different models to predict healthcare costs (Orji and Elochukwu Ukwandu), a paper outlining the use of six models (Alam and Prybutok). And there is a paper which uses age and smoking habits to predict the price of a patient's health insurance (Goel and Chaudhary).

Additionally, this paper focusing on the use of neural networks (Holvoet et al.), this paper on a Deep Learning model (Laub et al.), another Deep Learning paper (Denuit et al.), and several more (all in citations), all cover AI in medical insurance. These models provide a backbone for the reliability and validity of our paper.

Knowing that this is a viable subject, we have created a similar Artificial Intelligence algorithm, a growing source of information in the modern age, to provide reliable and relevant information on the average prices of medical costs. This is done in order to inform the decision of those seeking the best insurance.

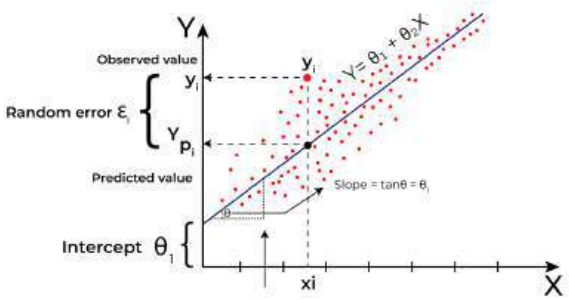
Materials and Methods

We are using a Medical Costs Dataset (Choi), which holds information about patients, and their costs. There are 1338 instances, all with the parameters of: Sex, Age, BMI, Number of Children (including 0), Smoking Habits, and Residential Region. The output is the prediction of the costs in medical bills. Overall, the model can predict the costs, evaluate its internal models and methods, and readjust its weighting to increase its accuracy every iteration, giving the most accurate information possible.

In order to create a stronger model, we split the dataset into two parts, with 0.33% being training data, and the other 0.66% being training data, to properly evaluate our model using unseen data.

We used five different types of models, in order to determine the best possible outcome. The models we used are: Linear Regression, Decision Tree, Random Forest, a Neural Network, and a KNN model.

In a Linear Regression model, parameters, or features, describe the data, while the weight controls the value of the outcome, providing a mathematical calculation to output a prediction. The output is just the weighted average of the inputs.
This is an example of a graphed Linear Regression model:



Next, we used a Decision Tree model. A Decision Tree, step-by-step, asks Yes-No questions to find a branching outcome. The model picks a parameter, for example age, and decides that over or under a certain age, costs go proportionally up or down, then evaluate BMI, setting a similar parameter, then proportionally increase/decrease the price. It would do this for every parameter. One parameter of the decision tree is the maximum amount of conditions in the tree. We used several values, 5, 20, and 30, to maximize the model's usefulness.

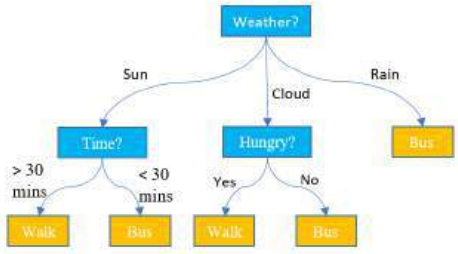
Decision Trees are like a function, they need an x-input that only outputs one y value. If there are two of the exact same instances, but with different outputs, the tree will not be able to predict them accurately. This is a drawback, especially if your dataset has many values that could repeat, which our dataset does.

In Decision Trees, the easiest way to increase accuracy is to increase the maximum depth, or the number of if statements in the Tree. Intuitively, this makes sense because the easiest way to have the highest accuracy is to have on output, or 'leaf', for every prediction. This makes sense, because, on paper, every instance in the data would have a corresponding 'leaf'. For example, if you had 1000 instances, you would want 1000 different leaves for every instance. Continuing with the 1000 instance example, you would need to calculate the maximum depth, the amount of levels that the tree goes to. Each level multiplies the amount of nodes by two, so the equation would be logarithmic, with a base of two. This would mean, for 1000, that the best maximum depth would be 10.

All models, like Decision Trees, have drawbacks. The most common, and problematic, one is overfitting. Overfitting happens when a model finds noisy patterns in the data. The model can work perfectly for the case it's in, but is too specific to the training data. When the testing data doesn't have the patterns, the model can't perform well. Overfitting is generalized as being too focused on just one method, instead of an overall view. We can clearly see that as the Decision Tree's max depths increase, according to the results for a change in max depth, the training output reaches zero, a sign of overfitting.

Decision Trees are highly likely to overfit, as they are designed to create patterns, which causes overfitting. Because of this, the easiest way to decrease overfitting is to decrease the max depth. This means that the amount of nodes, overall, decreases, decreasing the amount of possible patterns a Tree can make. Alternatively, you can increase the required instances that arrive at a node before the node splits from an increase in the max depth.

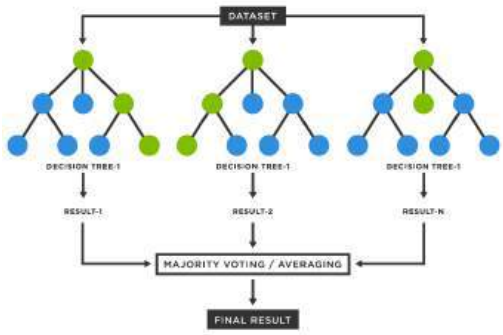
Here is an example of what a Decision Tree would look like if drawn:



We also used a Random Forest model. A Random Forest is essentially a group of Decision Trees, all generating for an outcome. The model takes the average of all the outcomes as the final output. In our model, it would go through the same process as the Decision Trees, except each tree would have a different method of evaluation. In our Random Forest, one parameter, like in the decision tree, is the maximum amount of conditions each tree can have. Another parameter is the amount of trees the model will generate.

Unlike in Decision Trees, Random Forests are significantly less likely to overfit, as they are a group of decision trees that all have a different piece of the training data set. This means that each tree has less data to overfit to, while more trees means that less data is being synthesized by a tree, and that the data will be more specified.

A Random Forest can be visualized as this:

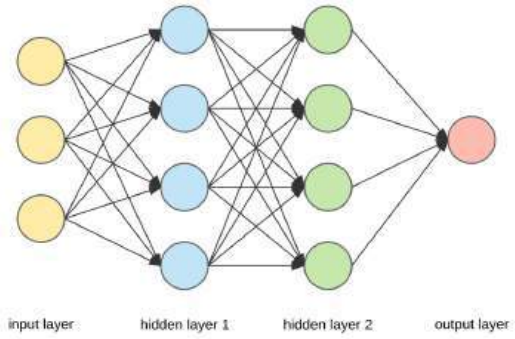


In Neural Networks, features are defined in the input layer, then are sent down lines with specific weights, to the hidden layers. Each hidden layer takes all the lines from the previous layer, then sends it down their own lines until they reach a final output, which is generated by choosing the strongest value. Neural Networks, like Decision Trees, are very susceptible to Overfitting. The countermeasures we used to Overfitting are the Dropout and Regularization methods.

The Dropout method identifies if there is a pattern in the model by removing random parts of the model, and checks if the model changes in its result. This reveals the model's biases, and centers on the problematic neurons/sections. The adverse effect of the dropout method is that in the process of pruning the model, the model is weakened proportionally. When applied, the Dropout method usually prunes about 10-20% of the model each test.

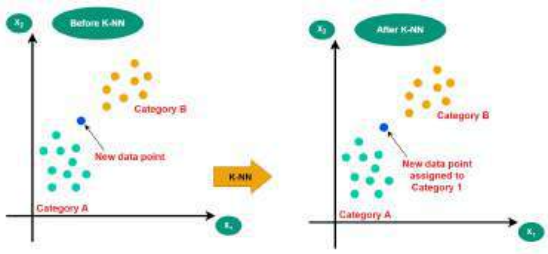
The alternative is the Regularization method. It is useful when the Dropout method eliminates key information within the model, especially if a part of the model is vital to the overall prediction, and drastically tampers with the model's performance. The Regularization method allows the model to focus on any neurons, but if the model does badly, it gets punished for that bias. This forces the model to effectively "learn" through trial-and-error, based upon the punishments it receives. The type of Regularization we used is the L2 Regularization.

Here is an example of what a Neural Network might look like if drawn:



Finally, we used a KNN (k-nearest neighbors) model. A KNN essentially finds the nearest fitting data point (established by k), and moves the input into the category. The output will then be determined by which category the input is moved to.

A KNN model can be graphed like this:



Because we are using multiple models, most of the models will give different outputs, as the KNN model has a different method to produce an output than a Neural Network does. As it is not possible to use every value, we needed to find a way to blend all the outputs into one. The easiest way to do that is taking the average of all the outputs, and then use that new value as the prediction. The averaging equally evaluates every model, and produces a single number that represents the group.

However, we decided that simply averaging every model, without accounting for performance, was not a sufficient method of averaging. Not only that, but because the models each have their own strengths and drawbacks, evaluating all the models as if they were the same, resulted in the creation of outliers. In order to avoid this, we gave every model a weight, based on how well they performed. We explored two ways to do this, through a static weight, set beforehand, and a dynamic weight, updated with every iteration.

In a static weight, the value is set as the average of the mean-squared-errors of each model, after the entire testing set has been evaluated. This number is the average of the squares of all the models' differences in their prediction and the testing data. This creates a more accurate representation of every models' performance.

Additionally, the weights should add up to one, as the only way to make all the models predict the same outcome is by making all of their values a percent of the outcome. This outperforms evaluating based on averages, because when you average one larger number and one smaller number, the smaller number brings the average down. With our biased weighting, each model gets preference for its own performance. This is summed up to, the higher the weight of the model, the more bias it is going to get.

The second method, the dynamic one, is the average of weights over time, updating the biases every time a new prediction was made in the testing data. This was done by evaluating a new benchmark of error, the absolute value difference between the model's prediction and the testing value. Then, the weights were updated by dividing them by their respective errors (a very small number was added to avoid dividing by zero). Eventually, the values would no longer add up to one, so the weights were divided by an averager, one over the sum of all the weights. The result is five biased weights that could be updated every iteration of the model. A visual of this, in the results section, shows how after each iteration, the weights are automatically averaged and updated.

Results

In this table, we present the Mean Squared Errors of every model, with their hyperparameters for two different values:

Model	Training	Testing
Linear Regression	37.29	35.13
Decision Tree (max depth = 5)	17.10	22.29
Decision Tree (max depth = 20)	0.00	43.78
Decision Tree (max depth = 30)	0.00	41.73
Random Forest (max_depth=2, n_estimators=12)	24.93	24.57
Random Forest (max_depth=3, n_estimators=18)	19.86	21.49
K-Nearest-Neighbors (n_neighbors=2)	45.82	151.42
K-Nearest-Neighbors (n_neighbors=4)	82.23	128.91
Neural Network (hidden_layer_sizes=(100))	36.78	34.59
Neural Network (hidden_layer_sizes=(150))	37.29	33.39

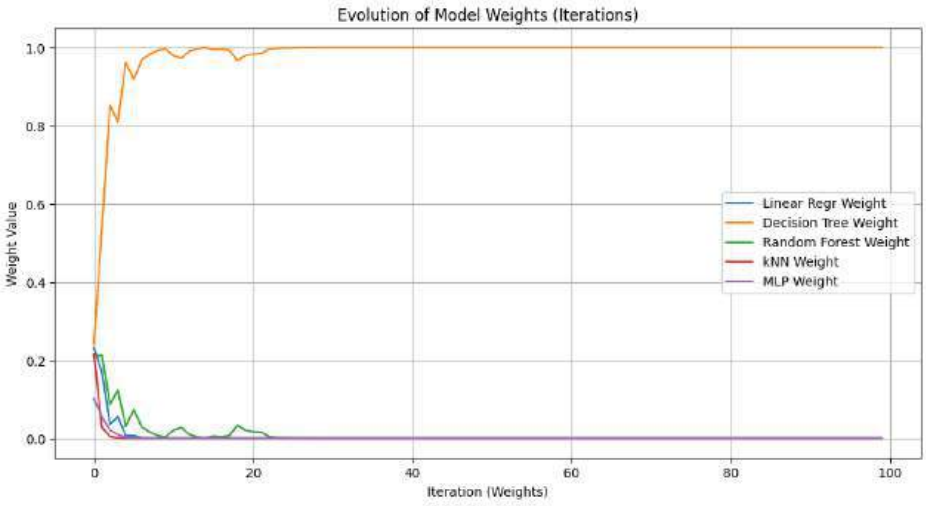
Equation for Mean Squared Error:

Formula

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$$

MSE = mean squared error
n = number of data points
Y_i = observed values
$\hat{Y}_i$ = predicted values

Plot of updating averages over time



Discussion

In future applications, a potential patient could predict the average cost, then pick the best insurance option. Additionally, one could appeal extreme medical costs, or at least have a benchmark for understanding the cost requirement.

We cover many parameters, such as age, sex, BMI, smoking habits, number of children, and region, in order to provide cohesive information about a patient. However, there are still more questions we could ask, like, “how does economic class play a role in the costs of insurance for a patient?” Or, “How do previous medical conditions affect the cost of insurance?” “Do the profits of Healthcare Providers impact the costs for insurance coverage?” If these parameters were covered, the specificity of predictions would increase significantly.

Overall, even without the extensions, we can accurately predict the average costs for insurance bills, isolate the best performing model’s prediction, and systematically weigh the whole model based on each contributing prediction.

Works Cited

Aas, Kjersti, et al. “Insurance Analytics: Prediction, Explainability, and Fairness.” Annals of Actuarial Science, vol. 18, no. 3, Nov. 2024, pp. 535–539, www.cambridge.org/core/journals/annals-of-actuarial-science/article/insurance-analytics-prediction-explainability-and-fairness/CF5EDDEA60798783CEFD5FBE6A51A8FF?utm_source=chatgpt.com, https://doi.org/10.1017/s1748499524000289. Accessed 20 Nov. 2025.

Addy, et al. “Predictive Modelling of Healthcare Insurance Costs Using Machine Learning.” Preprints.org, 24 Feb. 2025, www.preprints.org/manuscript/202502.1873?utm_source=chatgpt.com, https://doi.org/10.20944/preprints202502.1873.v1. Accessed 20 Nov. 2025.

Alam, Ashrafe, and Victor R. Prybutok. “Use of Responsible Artificial Intelligence to Predict Health Insurance Claims in the USA Using Machine Learning Algorithms.” Exploration of Digital Health Technologies, 28 Feb. 2024, pp. 30–45, www.explorationpub.com/Journals/edht/Article/10119, https://doi.org/10.37349/edht.2024.00009. Accessed 20 Nov. 2025.

Bau, Yoon-Teck, and Shuhail Azri Md Hanif. “Comparative Analysis of Machine Learning Algorithms for Health Insurance Pricing.” JOIV : International Journal on Informatics Visualization, vol. 8, no. 1, 31 Mar. 2024, p. 481, joiv.org/index.php/joiv/article/view/2282?utm_source=chatgpt.com, https://doi.org/10.62527/joiv.8.1.2282. Accessed 20 Nov. 2025.

Billa, Mohtaseem. “Medical Insurance Price Prediction Using Machine Learning.” Journal of Electrical Systems, vol. 20, no. 7s, 4 May 2024, pp. 2270–2279, journal.esrgroups.org/jes/article/view/3962?utm_source=chatgpt.com, https://doi.org/10.52783/jes.3962. Accessed 20 Nov. 2025.

California Medical Association. “CMA Joins Lawsuit against MultiPlan and Leading Insurance Providers over Health Care Price-Fixing.” CMADocs, 18 Nov. 2025, www.cmadocs.org/newsroom/news/view/ArticleId/50984/CMA-joins-lawsuit-against-MultiPlan-and-leading-insurance-providers-over-health-care-price-fixing#:~:text=Newsroom%20News%20View-,CMA%20joins%20lawsuit%20against%20MultiPlan%20and%20leading%20insurance%20providers%20over,for%20the%20care%20they%20provide. Accessed 20 Nov. 2025.

Choi, Miri. “Medical Cost Personal Datasets.” Kaggle.com, 2018, www.kaggle.com/datasets/mirichoi0218/insurance. Accessed 20 Nov. 2025.

Denuit, Michel, et al. “Autocalibration and Tweedie-Dominance for Insurance Pricing with Machine Learning.” ArXiv.org, 2021, arxiv.org/abs/2103.03635?utm_source=chatgpt.com. Accessed 20 Nov. 2025.

Gao, Davidson. “Health Insurance Premium Prediction Based on Multiple Machine Learning Algorithms.” Applied and Computational Engineering, vol. 100, no. 1, 24 Jan. 2025, pp. 145–152, direct.ewa.pub/proceedings/ace/article/view/20593?utm_source=chatgpt.com, https://doi.org/10.54254/2755-2721/2025.20593. Accessed 20 Nov. 2025.

Goel, Shivam, and Alka Chaudhary. Prediction of Health Insurance Price Using Machine Learning Algorithms. 28 Feb. 2024, pp. 1345–1350, ieeexplore.ieee.org/document/10498661, https://doi.org/10.23919/indiacom61295.2024.10498661. Accessed 20 Nov. 2025.

Holvoet, Freek, et al. "Neural Networks for Insurance Pricing with Frequency and Severity Data: A Benchmark Study from Data Preprocessing to Technical Tariff." North American Actuarial Journal, vol. 29, no. 3, 4 Apr. 2025, pp. 519–562, arxiv.org/abs/2310.12671?utm_source=chatgpt.com, https://doi.org/10.1080/10920277.2025.2451860. Accessed 20 Nov. 2025.

Kaushik, Keshav, et al. "Machine Learning-Based Regression Framework to Predict Health Insurance Premiums." International Journal of Environmental Research and Public Health, vol. 19, no. 13, 28 June 2022, pp. 7898–7898, pubmed.ncbi.nlm.nih.gov/35805557/, https://doi.org/10.3390/ijerph19137898. Accessed 20 Nov. 2025.

Lakshmi Narasimhan Srinivasagopalan. "Predicting Health Insurance Premiums Using Machine Learning: A Novel Regression-Based Model for Enhanced Accuracy and Personalization." World Journal of Advanced Research and Reviews, vol. 19, no. 1, 30 July 2023, pp. 1580–1592, wjarr.com/sites/default/files/WJARR-2023-1355.pdf, https://doi.org/10.30574/wjarr.2023.19.1.1355.

Laub, Patrick J, et al. "An Interpretable Deep Learning Model for General Insurance Pricing." ArXiv.org, 2025, arxiv.org/abs/2509.08467?utm_source=chatgpt.com. Accessed 20 Nov. 2025.

Lim, Dong-Young. "A Neural Frequency-Severity Model and Its Application to Insurance Claims." ArXiv.org, 2021, arxiv.org/abs/2106.10770?utm_source=chatgpt.com. Accessed 20 Nov. 2025.

Lyu, Ting. "Predictive Modeling for Insurance Pricing: A Comparative Analysis of Actuarial Techniques and Machine Learning Algorithms." Escholarship.org, 2024, escholarship.org/uc/item/0p45d0bv. Accessed 20 Nov. 2025.

Malale Tungu, et al. "Does Health Insurance Contribute to Improved Utilization of Health Care Services for the Elderly in Rural Tanzania? A Cross-Sectional Study." Global Health Action, vol. 13, no. 1, 25 Nov. 2020, pp. 1841962–1841962, ijcjournal.org/index.php/InternationalJournalOfComputer/article/view/1944?utm_source=chatgpt.com, https://doi.org/10.1080/16549716.2020.1841962. Accessed 20 Nov. 2025.

Orji, Ugochukwu, and Elochukwu Ukwandu. "Machine Learning for an Explainable Cost Prediction of Medical Insurance." Machine Learning with Applications, vol. 15, 24 Nov. 2023, pp. 100516–100516, www.sciencedirect.com/science/article/pii/S2666827023000695, https://doi.org/10.1016/j.mlwa.2023.100516. Accessed 20 Nov. 2025.

Wendling, Mike. "Brian Thompson: Who Is UnitedHealthcare CEO Shot Dead in New York?" Bbc.com, BBC News, 5 Dec. 2024, www.bbc.com/news/articles/cvgpl2qn7l5o. Accessed 20 Nov. 2025.

How Does Differential Language Acquisition Affect Cognitive Development in Bilingual and Monolingual Infants? By Elif Yaren Gürcü

ABSTRACT

Early bilingual experience may reveal advantages or disadvantages in infants in the context of linguistic skills, executive functions, and cognitive changes. It is known that the brain structures of bilingual infants develop differently compared to monolinguals, and it is frequently suggested that early bilingualism has positive effects not only on language skills but also on executive and cognitive functions such as inhibition and interference control, cognitive flexibility, working memory, etc. This study synthesizes evidence obtained from research on both views. Furthermore, given that early bilingualism is strongly influenced by external factors, its intersection with contemporary socioeconomic status is examined, and further conclusions are drawn by examining studies addressing this dimension.

KEYWORDS

Bilingualism; Infant; Language Acquisition; Executive Function; Linguistic Advantage; Socioeconomic Status

INTRODUCTION

Language acquisition is one of the fundamental cognitive skills developed during infancy. Language is the product of both genetic and environmental influences on child development. Humans may be born with a biological predisposition to speak, but their experiences shape which language(s) they speak and how they speak[1]. Essentially, there are three types of language users: those who use one language (monolingual), those who use two languages (bilingual), and those who use more than two languages (multilingual). Two-thirds of children worldwide are growing up bilingual[2], and one published report estimates that 21% (11.2 million) of school-age children (ages 5-17) in the United States speak a language other than English at home[3]. This underscores the importance of understanding the benefits of bilingualism and how it impacts child development.

Bilingualism continues to be a subject of research due to its beneficial effects on cognitive functions, since it is generally assumed that being proficient in more than one language has positive effects on cognitive functions [4,5]. The main theory explaining this “bilingual advantage” is that learning more than one language trains the brain, which in turn improves bilinguals’ performance in nonverbal cognitive functions such as planning, attention, working memory, and task switching [6-8]. Another possible explanation for the bilingual advantage is that the executive control circuits required to manage attention in two languages integrate with the linguistic circuits used for language processing, creating a more distributed, bilateral, and efficient network that supports higher levels of performance [9]. In other words, producing a word in one language activates the other language. For this process to proceed smoothly, the brain must possess an efficient selection system. Because bilinguals are constantly active in both

languages, they must direct their attention to the target language and avoid any interference from the other language. This constant attention management is thought to serve as a mental exercise for the executive system and may therefore be linked to the bilingual advantage in EF [10].

Despite the putative advantages of bilingualism mentioned above, there are also some challenges and disadvantages that may be associated with it. The main focus of studies discussing these challenges is mostly on older bilinguals, such as children or young adults; however, it is important to consider their findings, as it is possible to assume that disadvantages may emerge simultaneously with advantages in bilinguals, and that both perspectives should be taken into account. The challenges may arise largely from the fact that bilingual infants must distinguish between two different phonetic systems, syntax, rhythmic features, and other linguistic features[11]. Bilingual speakers may have a smaller vocabulary in each language compared to monolingual speakers; they may also take longer to recall a word while thinking and may score lower on semantic/verbal fluency tests. This can lead to lexical access difficulties in children growing up in bilingual environments, which may manifest as an inability to express their thoughts clearly in either language[12].

This review synthesizes the effects of bilingualism on cognitive development in infants, then evaluates these effects and discusses SES as a moderator. It aims to guide future research by examining linguistic studies.

1. LINGUISTIC ADVANTAGES

One of the differences in the language acquisition process between bilingual infants and monolingual infants is the ability to choose one language among the two they are exposed to, and to utilize this specific language appropriately. At the same time, they have the ability to distinguish between the two spoken languages. Thus, when they engage in verbal communication, they can use a specific language depending on the context and the person they are speaking to. Their ability to choose develops according to the environment in which they grow up. For example, bilingual infants who grow up in an environment where code-switching occurs integrate this into their own language processes. Language proficiency in early infancy (0-12 months) is analyzed with methods such as establishing eye contact, orienting to sounds (Receptive Expressive Emergent Language test (REEL), etc.), expressive language analysis, phonologic and prosodic analysis, and standard scales (Bayley Scales of Infant Development (BSID), Denver 2 developmental screening test, etc.) [11]. In order to better comprehend how bilingual infants develop and utilize such discrimination abilities, several studies have explored their capacity to perceive and discriminate different phonetic sounds.

In a study testing phonetic discrimination in bilingual infants, Bosch and Sebastián-Gallés investigated whether Spanish/Catalan monolingual infants and bilingual infants exposed to both Spanish and Catalan during infancy could discriminate the phonemes /e/ and /ɛ/. They found that this contrast was present in Catalan but not in Spanish. While all infants were able to make this distinction at 4 months, the researchers observed that at 8 months, Catalan monolingual infants continued to discriminate between the two phonemes, while Spanish monolingual infants were

unable to do so. It was emphasized that Spanish-Catalan bilingual infants were unable to make this distinction at 8 months but regained this ability by 12 months. This demonstrated that bilinguals may experience a delay in the development of the ability to perceive phonetic differences between their two native languages, something that can be explained by the more complex nature of linguistic exposure in bilingual environments, but that this ability may emerge differently from both monolingual infants and bilingual infants[13]. In addition to these crucial findings about phonetic perception and discrimination, further research has investigated how bilingual infants process other linguistic features, such as rhythmic structures and word orders, to distinguish two languages.

The basic word orders of languages differ; while some languages construct sentences using a subject-verb-object (SVO) structure, others use a subject-object-verb (SOV) structure. In Werker's study, 7-month-old bilingual infants (exposed to both English, an SVO language, and a SOV language such as Japanese, Korean, Hindi/Punjabi, Farsi, or Turkish) were able to use prosody to segment noun phrases. This demonstrated that, unlike monolinguals, bilingual infants are sensitive to and could utilize prosody, which can be speculated as a remarkable linguistic advantage [11]. In her study on language discrimination in bilingual infants, Werker presented filtered English speech (which is described as stress-timed: a rhythmic pattern with both strong and weak syllables, relative isochrony from one strong syllable to another in fluent speech, vowel reduction in unstressed syllables, and a highly complex syllable structure, including consonant clusters) and filtered Tagalog speech (which is described as syllable-timed: a rhythmic pattern that contains less syllable-level stress, less complex syllable forms, and relative isochrony from one syllable to another in fluent speech) to infants exposed only to English in the womb and to infants exposed equally to both Tagalog and English in the womb. She observed that both types of infants were able to discriminate between the two languages. In a preference test, infants exposed to English in the womb preferred to listen to English, while infants exposed equally to both languages in the womb preferred to listen to both languages equally. This highlighted the fact that bilingual infants can distinguish between two languages (although there may be temporary delays in their ability to do so), generally pay equal attention to both languages (although language preferences may differ depending on context), and are able to perceive rhythmic differences. This skill is important for bilingual infants since they can pay attention to both of their native languages and, at the same time, be able to distinguish between them. Moreover, their sensitivity to rhythmical differences provides them with the tools required for using rhythm to bootstrap the acquisition of both of their languages[11].

While these studies highlight bilingual infants' ability to discriminate phonetic cues and rhythmic differences, further research has examined how differences in acquisition experience shape their linguistic development.

Mercure and colleagues examined three different groups of infants aged 4–8 months: monolinguals, monomodal bilinguals (those exposed to two spoken languages), and bimodal bilinguals (hearing infants of deaf mothers). The study hypothesized that bimodal bilinguals would pay more attention to faces but would have difficulties/delays integrating audiovisual

speech due to their lack of audiovisual speech experience compared to monolingual and monomodal bilingual infants. The study found that monolingual and monomodal bilingual infants became increasingly sensitive to audiovisual inconsistencies across this age range. In contrast, bimodal bilingual infants did not pay more attention to the speaker's mouth (visual cues) or show greater sensitivity to such inconsistencies. This study suggests that language experience influences audiovisual integration in infants. Reduced or more variable audiovisual language experience from the primary caregiver may lead to decreased sensitivity in infants to the integration of visual and auditory cues in speech [14]. As stated in these findings, it can be concluded that bilingualism may provide significant advantages in linguistic functions such as phonetic discrimination, phonological and morphological flexibility, and vocabulary range. It is important to discuss that beyond these linguistic functions, bilingualism can also be found to influence cognitive abilities.

2. ADVANTAGES OF EXECUTIVE AND COGNITIVE FUNCTIONS

Bilingualism is associated with structural changes in the brain and affects brain structure. The main theory explaining this bilingual advantage is that learning more than one language trains the brain, which in turn improves bilinguals' performance on non-verbal cognitive functions such as planning, attention, working memory, task switching, and other tasks thought to tap into executive functions (EF) [4-8]. Executive functions (EF) (also referred to as executive control or cognitive control) refer to a set of mental processes that require concentration and attention in situations where acting automatically or relying on instinct or intuition would be inaccurate, inadequate, or impossible[15,16]. In other words, EFs are higher-order cognitive control processes that influence and guide thoughts and cognitive processes. The three primary EFs are inhibition and interference control, working memory (WM), and cognitive flexibility[17]. From these, higher-order EFs, such as reasoning, problem solving, and planning, are generated[18]. EFs are skills essential for mental and physical health, success in school and life, and cognitive, social, and psychological development. EF development depends on the dynamic interaction between environmental and genetic influences. Among these environmental influences, the importance of education on EF development has been emphasized in some studies[19]. In accordance with this existing knowledge on the role of environmental factors, several research studies have particularly focused on how early bilingual experience may affect EF development.

Some experimental research has shown that children growing up bilingual have superior abilities to manage stimuli competing for attention, a phenomenon often referred to as the “bilingual advantage”[20,21]. The "bilingual advantage" is one of the main topics debated in bilingualism research. Following the publication of positive evidence for a bilingual advantage, the difficulty of replicating previous results and the publication of numerous studies with invalid findings have led to the theory being debated [22-24]. Recently, even the use of the term "bilingual advantage" has been questioned, as its presence or absence may depend on the

observer's interpretation or perspective[25]. This debated subject was clarified by several studies examining cognitive processes linked to early bilingualism.

Bialystok et al. noted that in controlled studies of cognitive performance across the lifespan, bilinguals consistently outperform their monolingual peers. However, according to the same study, the mechanisms responsible for the bilingual advantage in executive control and how cognitive reserve protects against cognitive decline are not understood. They concluded that the impact of bilingualism on cognitive performance is a striking example of how ordinary experience alters cognitive networks and cognitive abilities. The bilinguals included in these studies generally learned a second language not because of preexisting talent or interest, but because life demands it. Their lives included two languages, and therefore their cognitive systems evolved differently from those of their monolingual counterparts. Thus, research with bilinguals provides clear evidence of the flexibility of cognitive systems in response to experience. One possible explanation for the bilingual advantage is that the executive control circuits required to manage attention to two languages integrate with the linguistic circuits used for language processing, creating a more distributed, bilateral, and efficient network that supports high levels of performance[9]. Researchers have further examined the cognitive mechanisms and EF underlying this advantage, focusing specifically on how bilinguals manage the simultaneous processing of two languages.

Producing a word in one language activates the other language. For this activation to proceed fluently, the brain must possess an effective selection system. This selection system is assumed to be based on a domain-general system involved in both language selection and nonverbal processing. Because both languages are constantly active, bilinguals must direct their attention to the target language and avoid any interference from the other language. This sustained attention management is thought to serve as a mental exercise for the executive system and is therefore linked to the bilingual advantage in EF. For cold inhibition that included tasks that required the inhibition of an automatic or prepotent response to neutral stimuli, there were significantly larger effects in published studies, and in unpublished studies, the effect size was even significant in favor of monolinguals[10]. However, not all findings suggest a consistent bilingual advantage. Some studies reported how factors such as age and socioeconomic status can influence cognitive functions in bilinguals.

Buac et al. examined the performance of bilingual Spanish-English speakers and monolingual English-speaking school-aged children on various procedural measures within the framework of a working memory model. The procedural measures included short-term memory measures, working memory measures, and a novel word-learning task. They observed that monolinguals outperformed bilinguals on working memory and word-learning tasks, particularly on short-term tasks. They also found that while nonverbal IQ scores consistently contributed to processing-based performance for monolingual children, for bilingual children, both socioeconomic status and English vocabulary skills significantly predicted performance on processing-based tasks. This finding indicates that there may be an interaction between socioeconomic status and verbal skills in bilingual children, but not in monolingual children[26].

Furthermore, a study by D'Anguilli and colleagues included 81 students (46 girls, 35 boys) aged 9 to 13 (grades 4-8) from a Toronto-area school. All students were Canadian-born, with parents of Italian descent and middle-class families. Their parents spoke both English and Italian, while their grandparents spoke only Italian. They found that the bilingual children outperformed age-matched monolingual children on all tasks in Italian. However, both the less proficient and the more proficient bilingual Italian children scored significantly higher than monolingual English-Canadian children (with similar reading skills) on English tasks involving reading, spelling, syntactic awareness, and working memory. Their findings indicated that bilingualism may be advantageous over monolinguals not only in reading but also in all linguistic tasks requiring word-decoding strategies, providing evidence that exposure to Italian may benefit children learning to read in English [27]. These results, by highlighting how older bilingual children demonstrate clear advantages when they are learning to read, suggest that bilingual infants may also have an advantage over their monolingual peers in reading later in life.

In addition to the advantages of bilingualism across all linguistic tasks requiring both reading and word-decoding strategies, a visual familiarization test was conducted by Singh et al. (2017) to determine whether bilingual infants exhibit basic information-processing advantages compared to monolingual infants. In the study, 114 monolingual or bilingual 6-month-old infants were shown images of a bear and a wolf: one serving as the habituation stimulus and the other as the novel stimulus [28]. Habituation is the gradual reduction of attention of infants towards stimuli that are presented repeatedly [29]. During the habituation phase, infants were presented with these different stimuli. The habituation trials ended when the infants looked away from the monitor for at least one second. A minimum of 20 habituation trials were conducted throughout the study. In conclusion, a study aimed to investigate whether the delayed perceptual narrowing previously reported in bilingual learners could be used to learn words in a new language. They observed that bilingual infants maintained sensitivity to click consonants when learning new words, whereas monolingual infants did not. In light of these findings, they suggested that bilingual and monolingual children exhibited different phonological sensitivities and that experience with two languages may alter the course of the interpretive narrowing commonly documented in monolingual infants. This flexibility, in turn, emphasized the need to selectively provide bilingual children with resources available for learning additional languages[28].

Beyond these findings on perceptual flexibility in bilingual infants, subsequent research has examined whether bilingualism influences broader cognitive functions, such as memory generalization. Brito and Barr (2012) investigated whether early bilingual experience affects memory generalization, "the process by which learned information is transferred to similar situations or stimuli that are not exactly the same.". Using a deferred imitation task with 30 18-month-old infants (15 monolinguals, 15 bilinguals), they tested whether the infants could generalize an action sequence they had observed on one puppet to a different puppet. The experimenter performed three different actions with the puppets in front of the infants: pull off mitten, shake mitten to ring the bell, and replace mitten. Following this 60-second demonstration, there was a 30-minute delay, after which the infants began playing with the puppets. During this

action, an analysis was conducted based on whether the infants could successfully imitate the actions demonstrated by the experimenter. Ultimately, the finding that percentage exposure to the second language, not word production as indexed by the MCDI score, predicts memory generalization suggests that the advantages of bilingualism appear long before the child can communicate proficiently in both languages. Brito and Barr proposed several possible explanations for the advantage of bilingualism in memory generalization found in this study. First, bilingual infants may have selectively attended to the removal of the mitten while ignoring potentially distracting novel perceptual cues during the experiment [30]. This phenomenon, the enhanced selective attention of bilinguals, has also been demonstrated in previous studies[31,32]. Another explanation offered is that bilingual infants form "hierarchical mental representations"—that is, the organization of information from general to specific—earlier than monolingual infants. For example, sentence-subject, predicate-verb. According to this closure, bilingual infants must separate the details of information to retain in order to successfully generalize. Both of these explanations are important because they offer different perspectives for understanding and observing differences in memory generalization between bilingual and monolingual infants [30].

Another study conducted by Brito and Barr (2013) hypothesized that monolingual infants could generalize only to a single feature change, whereas bilingual infants could generalize to multiple feature changes in a stimulus. In the study, 30 monolingual and 28 bilingual 6-month-old infants were exposed to a puppet stimulus. In the first experimental condition, only one feature of the puppet was changed (e.g., color), while the second experimental condition was more challenging, involving a change in two features (e.g., color and shape). The results showed that both monolingual and bilingual 6-month-old infants could remember a single feature change, but only bilingual infants performed delayed imitation of actions when two features changed—for example, an adult stacking the blocks and then the child trying to stack the same blocks in a similar way on another day. In general, both studies by Brito and Barr highlight that bilingual infants demonstrate greater memory advantages than monolingual infants, that is, they are mostly able to generalize cues at 18 months of age [33].

Taken together, these findings emphasize the many possible benefits of bilingualism; however, they may also raise questions about the possible disadvantages that may accompany these advantages.

3. DISADVANTAGES OF BILINGUALISM IN INFANTS

As mentioned above, bilingualism may offer many advantages for infants. Among the information that was synthesized throughout thorough research, there was no credible evidence suggesting that linguistic and cognitive disadvantages may manifest in bilingual infants. However, since every phenomenon has two sides, the possible disadvantages were also addressed in order to evaluate whether bilingualism is truly advantageous.

In the study by Pelham and Abrams (2014), participants were 30 monolingual English speakers, 30 late English-Spanish bilinguals, and 30 early Spanish-English bilinguals who

completed a picture naming task (lexical access) and an attentional network task (executive function). Late and early bilinguals manifested equivalent cognitive effects in both tasks, demonstrating lexical access deficits and executive function benefits. This study indicated that despite its advantages, bilingualism can lead to lexical access difficulties in children growing up in bilingual environments, manifesting as an inability to express thoughts clearly in both languages. Furthermore, the same study showed that bilingual children may not fully develop the skills to form complex concepts and think abstractly. Another disadvantage is that a bilingual child may mix the languages they learn. Consequently, the child may choose words that are easier to pronounce and focus on less complex sounds or shorter words[12].

Another study shows that bilingual speakers may have a smaller vocabulary in each language than monolinguals, take longer to recall a word while thinking, and score lower on semantic/verbal fluency tests. The 2007 study divided 78 college students into two groups based on criteria such as those who considered themselves monolingual/bilingual or native/non-native English speakers. The study's findings indicated that the bilingual group performed in the average range on standardized measures of English vocabulary. However, their performance was significantly lower than that of their monolingual peers. The authors suggest that monolinguals would have had longer and perhaps richer exposure to English than bilinguals who were not born in the United States. This finding may indicate that, despite arriving in the United States before adolescence and possessing a high level of English vocabulary, some non-native English speakers do not have as large an English vocabulary as their monolingual peers [34].

Initially, the review was conducted with the assumption that certain disadvantages, such as those discussed in these studies, might exist. Nevertheless, no credible studies focusing specifically on bilingual infants were identified, and the available evidence was limited to older age groups (children, young adults, etc.). Consequently, it can be stated that the potential disadvantages of bilingualism on infants are not a frequently discussed topic in the literature and that the credibility of existing findings remains low.

DISCUSSION

Based on the findings of the studies reviewed in the literature as a result of our article, observing how infants exposed to two different languages during early cognitive development can acquire both simultaneously can offer new insights into our understanding of language acquisition. Bilingualism is closely related to linguistic performance, EF, and cognitive development, as well as socioeconomic status in infancy. Early bilingualism in infants appears to confer not only linguistic advantages but also benefits non-linguistic cognitive skills such as learning and memory. This suggests that all these advantages of bilingualism may stem from distinctive abilities such as selective attention and perception through hierarchical mental representation, thus helping to explain these benefits.

Although it is discussed that bilingualism may provide numerous cognitive and linguistic advantages, understanding how bilingual infants acquire language compared to monolinguals remains a key area of investigation. Language acquisition is essentially the same for

monolinguals and bilinguals: a growing infant must learn the rules of the language spoken by their caregivers (such as phonetic categories, word order, and perceptual features). Furthermore, early bilingual language acquisition presents both advantages and challenges for infant development. These challenges may be related to the fact that bilingual infants must distinguish between two distinct phonetic systems, syntax, rhythmic features, and other linguistic features [11]. The difference between when bilingual children perform differently from monolinguals and when they do not is determined in part by the demands of the task. Across the three domains of metalinguistic awareness examined, the general pattern is that bilinguals perform better on tasks that require children to ignore misleading information, such as the meaning of a word or sentence. Tasks that assess children's explicit knowledge of structure more directly, such as defining a word or explaining a grammatical error, are performed similarly by both groups. The advantage of these tasks goes to children with more formal language knowledge, such as higher proficiency or a larger vocabulary [35]. As can be seen, a variety of groups and variables have been used to examine differences in language acquisition between monolingual and bilingual infants. Based on these findings, bilingual infants appear to have both specific advantages in specific linguistic cues and temporary delays in the rate of acquisition or deficits in specific skills (e.g., increased sensitivity to visual-visual inconsistencies) compared to monolingual infants. Investigating and identifying the positive or negative effects of bilingualism on linguistic abilities in children is quite challenging. Analyses conducted to identify this issue have used quite different groups and variables. To more clearly investigate the effects on linguistic abilities, future researchers should obtain as much information about the child as possible, such as possible neurodevelopmental or learning disorders, the timing and sources of language acquisition, and educational background, consider the family's socioeconomic status, and conduct research accordingly.

Bilingualism has been shown to have positive effects on cognitive functions and EF, in addition to its effects on linguistic abilities as discussed above. According to Green's[36] Co-Activation Model, bilingualism involves the activation of both languages in the brain, even when only one language is used. This appears to have a positive impact on various cognitive functions, including executive functions[37]. While early exposure to multiple languages may influence domain-general cognitive processes, more research is needed to examine the link between declarative memory development and bilingualism. Examining these cognitive advantages early in development, while infants are still proficient in both languages, may provide a better understanding of the behavioral and underlying neural mechanisms involved [33]. A systematic review summarizing the results of 53 studies published between 1999 and 2020 examining the impact of bilingualism on executive functions revealed that the participant characteristics of the selected studies varied widely, with a wide variability in sample size from a minimum of 12 participants to a maximum of 1,740. In most studies, information about participants' linguistic backgrounds was collected through interviews with caregivers or questionnaires, while in only two studies was information collected directly from participants. A variety of tasks were used to assess executive functions across studies. Studies on bilingualism

have adopted a “monolingual-bilingual” approach, and while some studies define bilingualism based on assessments of proficiency in two languages, others rely on the age of acquisition. This, combined with the lack of a common definition of bilingualism and the varying experiences of individuals and groups that influence brain adaptation in different ways, confounds the findings of all these studies. Across all studies, a wide variety of tasks were used. These included the Woodcock-Johnson Tests of Cognitive Abilities-III and the Attention Network Task for bilingualism- attention, the Corsi Blocks task for assessing visuospatial working memory, the N-back task for assessing nonverbal working memory, various versions of the digit span task, and, in particular, the verbal fluency task. These discrepancies and variability in study results may be due to differences in the tasks used. Furthermore, this systematic review highlights the fact that sociodemographic factors, such as low socioeconomic status or immigrant status, can influence the development of executive functions in diverse ways, and it is crucial to clarify at what specific point in the lifespan the impact of bilingualism should be examined [25].

Moreover, bilingualism can have significant impacts on both an individual's development and the society in which they live. Verbal proficiency underpins children's academic success, which is in turn moderated by individual and environmental factors. Factors influencing both achievements include socioeconomic status (SES), environment, and bilingualism, each of which has been shown to exert different types of influence on these developments, likely for different reasons [38].

Certain sociodemographic factors, such as low SES or immigrant status, influence the development of EF. Immigrant populations often have low socioeconomic status, and the necessity for individuals in immigrant communities to learn a second language is a consequence of their migration to a foreign country. In the United States, there is a high correlation between low socioeconomic status and bilingualism. Studies confirm that low SES has negative effects on the development of various cognitive functions and language skills in children. In this negative context, bilingualism may be a protective factor[39]; in fact, some studies[40,41] have reported an advantage for bilingual participants when socioeconomic status is controlled. The cognitive advantage of bilingualism can be independently enhanced by SES[42,43]. In a study by Filippi et al. (2022), they used a matched subsample from the SCAMP (Synthetics for Camera Measurement of Physiological Signals) dataset. They examined the interaction between socioeconomic status (high or low) and language experience (monolingualism or multilingualism). The sample included 517 monolingual and 329 multilingual secondary school students in London, who underwent executive function assessments at two developmental stages: at ages 11 and 15. The monolingual and multilingual groups were carefully matched on socioeconomic status criteria and then compared across various cognitive skills. The study showed that multilingualism had an overall positive effect on working memory, visuospatial processing, and nonverbal reasoning, with small to moderate effect sizes. They also highlighted that students from lower socioeconomic backgrounds experienced significant improvements in working memory over the period studied[44].

In a study by Bialystok and Shorbaki, the children were 6-year-olds living in a large, linguistically diverse urban area. They were tested individually in a quiet area of their school during a session lasting approximately 30 minutes. The children were given Raven's Progressive Matrices, Verbal Fluency, the Peabody Picture Vocabulary Test, and the Simon Picture Task. At the end of the study, the children were high in overall SES and did not include any children in a group commonly referred to as "low SES." In contrast, the children's experience with other languages spanned a wide spectrum, from monolingualism to fluent bilingualism, and these differences were significant in both categorical and continuous analyses. There were no SES differences in nonverbal intelligence, but all other outcome measures were lower for children in the middle SES group. It is concluded that SES differences, often unrecognized, may be more important in shaping children's development than previously recognized, and these current results confirm that both bilingualism and SES influence verbal and nonverbal development and set limiting conditions for each [45].

Apart from all the points discussed above, it would be beneficial to address certain clinical implications to guide future research and reviews. Clinical implications can lead to discussions regarding potential educational routes for bilingual children, which is why it is crucial to mention these findings.

The idea that bilingual children become confused while learning two languages is discredited. In reality, children are capable of categorizing and learning two distinct syntactic and phonetic systems simultaneously. Moreover, raising an infant under the "one-parent-one-language" principle is not considered a requirement for successful bilingual development.

It is also noted that while assessing proficiency in languages, children's competence in each language is typically measured through their vocabulary range. Two main dual-language indicators have been proposed: total vocabulary and conceptual vocabulary. For total vocabulary, the child's scores in each language are summed; while for conceptual vocabulary, the individual language scores are summed and then the number of items for which the child has words in both languages is subtracted, resulting in a number of concepts for which the child has a word in either language. It has been suggested by Hoff and Core that total vocabulary is a more accurate measure of bilingual children's language development. These implications may help guide future educational pathways and assessment methods for bilingual infants and children. [46]

CONCLUSİON

Bilingualism is a multidimensional phenomenon. While the question of whether bilingualism can become a long-term disadvantage during the transition from infancy to childhood remains relevant, early bilingual experience not only provides linguistic advantages but also has positive effects on problem-solving and cognitive development. Alongside these advantages, individuals who acquire a second language later in life may also face disadvantages such as language confusion, limited vocabulary, and reduced language processing. All of this offers a different perspective on the mask of bilingualism. It suggests that this clustering may

stem from distinctive abilities such as selective attention and variation through formal mental representation, thus contributing to the maintenance of bilingualism. Consequently, these advantages manifest differently depending on an individual's bilingual context and play a crucial role in understanding the differences between bilingual and monolingual infants. Furthermore, comparing effect sizes and statistical analyses across studies, further analyzing participant characteristics, and determining which factors, such as the language used, influence the results will guide future research [25].

CONFLICTS OF INTEREST

The author declares that there are no conflicts of interest related to this work.

Works Cited

1. Crain, S., et al., Nature, nurture and universal grammar. Linguistics and Philosophy, 2001. 24: p. 139–186.
2. Crystal, D., English as a global language. Cambridge: Cambridge University Press, 1997. ISBN: 9780511486999
3.US Census Bureau. American community survey. Washington, DC: US Census Bureau, 2009. Available from: https://www.census.gov/data/developers/data-sets/acs-5year.html (accessed on 2025-9-12)
4. García-Pentón, L., et al., The neuroanatomy of bilingualism: how to turn a hazy view into the full picture. Language Cognition and Neuroscience, 2016. 31(3): p. 303–327.
5. Stein, M., et al., Structural brain changes related to bilingualism: does immersion make a difference? Frontiers in Psychology, 2014. 5: p. 1116.
6. Bialystok, E., et al., The bilingual adaptation: how minds accommodate experience. Psychological Bulletin, 2017. 143: p. 233–262.
7. Namazi, M., et al., A working memory, not bilingual advantage, in controlled attention. International Journal of Bilingual Education and Bilingualism, 2010. 13: p. 597-616.
8. Prior, A., et al., A bilingual advantage in task switching. Bilingualism: Language and Cognition, 2010. 13: p. 253–262.
9. Bialystok., E., Coordination of executive functions in monolingual and bilingual children. Journal of Experimental Child Psychology, 2011. 110: p. 461–468.
10. Gunnerud, H.L., et al., Is bilingualism related to a cognitive advantage in children? A systematic review and meta-analysis. American Psychological Association, 2020. 146(12): p. 1059–1083.
11. Werker, J., Perceptual foundations of bilingual acquisition in infancy. Ann. N.Y. Acad. Sci., 2012. 1251: p. 50–61.
12. Pelham, S.D., et al., Cognitive advantages and disadvantages in early and late bilinguals. J Exp Psychol Learn Mem Cogn., 2014. 40(2): p. 313-325.
13. Bosch, L., et al., Simultaneous bilingualism and the perception of a language-specific vowel contrast in the first year of life. Lang Speech, 2003. 46(2-3): p. 217-243.
14. Mercure, E., et.al., Language experience influences audiovisual speech integration in unimodal and bimodal bilingual infants. Developmental Science, 2019. 22: p. e12701.
15. Burgess, P.W., et al., Theories of frontal lobe executive function: clinical applications. In: Halligan PW, Wade DT, editors. Effectiveness of Rehabilitation for Cognitive Deficits. Oxford Univ. Press. 2005. ISBN: 978-0198526544, p. 211–231.
16. Espy, K.A., Using developmental, cognitive, and neuroscience approaches to understand executive control in young children. Dev. Neuropsychol, 2004. 26: p. 379–384.
17. Lehto, J.E., et al., Dimensions of executive functioning: evidence from children. Br. J. Dev. Psychol, 2003. 21: p. 59–80.
18. Collins A., et al., Reasoning, learning, and creativity: frontal lobe function and human decision-making. PLoS Biol., 2012. 10: p. e1001293.

19. Karbach, J., et al., How useful is executive control training? Age differences in near and far transfer of task-switching training. Developmental Science, 2009. 12(6): p. 978–990.
20. Bialystok, E., et al., Attention and inhibition in bilingual children: evidence from the dimensional change card sort task. Developmental Science, 2004. 7: p. 325–339.
21.Bialystok, E., et al., Cognitive control and lexical access in younger and older bilinguals. Journal of Experimental Psychology: Learning, Memory, and Cognition, 2008. 34, p. 859–873.
22.Stevenson, H. W., et al., Child development and education in Japan. Henry Holt & Co., 1986. ISBN: 978-0716717409
23.Peal, E., The relation of bilingualism to intelligence. Psychological Monographs: General and Applied, 1962. 76(27): p. 1–23.
24.Green, D.W., Language control in bilinguals: the adaptive control hypothesis. J Cogn Psychol, 2013. 25(5): p. 515-530.
25. Giovannoli, J., et.al., The impact of bilingualism on executive functions in children and adolescents: a systematic review based on the PRISMA method. Front. Psychol., 2020. 11: p. 574789.
26. Buac, M., et al., Predictors of processing-based task performance in bilingual and monolingual children. Journal of Communication Disorders, 2016. 62: p. 12–29.
27. D'Angiull, A., et al., The development of reading in English and Italian in bilingual children. Applied Psycholinguistics, 2001. 22: p. 479–507.
28. Singh, L., Bilingual infants demonstrate advantages in learning words in a third language. Child Development, 2018. 89(4): p. e397–e413.
29. Colombo, J., Infant visual habituation. Neurobiol Learn Mem., 2009. 92(2): p. 225-234.
30.Brito, N., et al., Influence of bilingualism on memory generalization during infancy. Developmental Science, 2012. 15: p. 812–816.
31.Mohamed Zied, K., et al., Bilingualism and adult differences in inhibitory mechanisms: evidence from a bilingual Stroop task. Brain and Cognition, 2004. 54(3): p. 254–256.
32.Bialystok, E., et al., The relationship between bilingualism and the development of cognitive processes in problem solving. Applied Psycholinguistics, 2008. 19(1): p. 69–85.
33.Brito, N., et al., Flexible memory retrieval in bilingual 6-month-old infants. Developmental Psychobiology, 2014. 56(5): p. 1156-1163.
34.Portocarrero, J.S., Vocabulary and verbal fluency of bilingual and monolingual college students. Archives of Clinical Neuropsychology, 2007. 22(3): p. 415-422.
35.Bialystok, E., The impact of bilingualism on language and literacy development. The Handbook of Bilingualism and Multilingualism, 2008. p. 577 - 601.
36. Green, D. W., Mental control of the bilingual lexico-semantic system. Bilingualism: Language and Cognition, 1998. 1(2): p. 67 - 81.
37.Bialystok, E., et al., Receptive vocabulary differences in monolingual and bilingual adults. Bilingualism-Language and Cognition, 2012. 15(2): p. 397–401.

38.Pace, A., et al., Measuring success: within and cross-domain predictors of academic and social trajectories in elementary school. Early Childhood Research Quarterly, 2018. 46(12): p. 112–125.
39.Hartanto, A., et al., Bilingualism narrows socioeconomic disparities in executive functions and self-regulatory behaviors during early childhood: evidence from the early childhood longitudinal study. Child Dev., 2019. 90: p. 1215–1235.
40.Engel de Abreu, et al., Bilingualism enriches the poor: enhanced cognitive control in low-income minority children. Psychol. Sci., 2012. 23: p. 1364–1371.
41.Krizman, J., et al., Bilingual enhancements have no socioeconomic boundaries. Dev. Sci., 2016. 19: p. 881–891.
42..Blom, E., et al., The benefits of being bilingual: working memory in bilingual Turkish–Dutch children. J. Exp. Child Psychol., 2014. 128: p. 105–119.
43..Calvo, A., et al., Independent effects of bilingualism and socioeconomic status on language ability and executive functioning. Cognition, 2014. 130: p. 278–288.
44..Filippi, R., et al., Modulatory effects of SES and multilinguistic experience on cognitive development: a longitudinal data analysis of multilingual and monolingual adolescents from the SCAMP cohort. International Journal of Bilingual Education and Bilingualism, 2022. 25 (9): p. 3489–3506.
45..Bialystok E., et al., Subtle increments in socioeconomic status and bilingualism jointly affect children's verbal and nonverbal performance. Journal of Cognition and Development, 2021. 22(3): p. 467-490.
46. .Hoff E., et al., What clinicians need to know about bilingual development. Semin Speech Lang., 2015. 36(2): p. 89-99.

Analysis of Genetic Factors and Diseases that Influence Human Aging By Yuhan Sun

Abstract

This paper explores the multifaceted aspects of human aging, with a primary focus on genetic factors that influence aging and aging-associated diseases. Aging is a complex and dynamic biological process driven by an interplay of intrinsic genetic determinants and extrinsic environmental influences. While previous research, including the Blueprint project led by Brian Johnson, demonstrated the effectiveness of comprehensive medical and lifestyle interventions in achieving biological age reversal, this study emphasizes the genetic underpinnings that contribute to aging at the molecular level. Specifically, the research investigates the roles of 15 key genes and their variants implicated in cellular senescence, DNA damage response, and age-related pathologies. Methodologically, data from genome-wide association studies (GWAS) catalogs were analyzed to identify genetic variants significantly correlated with aging traits, while RNA sequencing was employed to assess gene expression patterns in aging tissues. By categorizing these genes into those exerting direct versus indirect effects on the aging process, the study provides insights into how genetic mechanisms influence cellular senescence, DNA repair capacity, and the progression of age-related diseases such as neurodegenerative disorders and cancer. The findings underscore the intricate genetic architecture of aging and highlight critical genetic pathways that may serve as potential targets for anti-aging therapies. This research advocates for a continued, integrative approach to studying the genetic regulation of aging, with the goal of developing precision-based interventions that mitigate the impact of aging and extend healthspan.

Keywords aging, gene segments, variant, disease, traits

Introduction

1. Basic information about aging

Aging affects physiological functions and can be defined as the accumulation of damage in molecules, cells and tissues over a lifetime; this often decreases an organism's capacity to maintain homeostasis in stress conditions (Rodríguez-Rodero et al., 2011). Aging also increases the susceptibility to many common diseases, with death rates rising approximately exponentially with advancing age. The main scientific effort in human aging, termed 'geroscience', sees ageing as the primary cause of many chronic diseases of later life, including Alzheimer disease, chronic kidney disease, coronary artery disease (CAD), osteoarthritis, stroke, type 2 diabetes mellitus (T2DM) and common cancers, such as breast, prostate and colorectal cancer. Clinical diagnoses of age-associated chronic diseases and cancers can provide accessible proxy measures of ageing. A summary measure of healthspan can be made from the duration of life spent without major age-associated conditions, including dementia, myocardial infarction, stroke and type 2 diabetes

mellitus. Other elements can be included in healthspan, such as physical disabilities, cognitive impairments and mental wellbeing. (Melzer et al., 2019)

Aging is a multifactorial process driven by a combination of environmental factors and genetic factors. Environmental factors play a crucial role in human aging. Exposure to pollutants accelerates the development and progression of cardiovascular, respiratory, metabolic, and neurological diseases by exerting direct effects and influencing epigenetic processes that adversely impact biological aging. Additionally, unhealthy lifestyle choices such as smoking, excessive alcohol consumption, prolonged sun exposure, lack of physical activity, and poor sleep patterns will also accelerate cellular damage. These habits increase oxidative stress and lead to the accumulation of free radicals, which expedite cellular aging. However, genetic factors are also a non-negligible factor that determines human lifespan. According to the genetic theory of aging, your genes (as well as mutations in those genes) are responsible for how long you'll live. Some genes are beneficial and enhance longevity. For example, the gene that helps a person metabolize cholesterol would reduce a person's risk of heart disease. On the contrary, some genes, when mutated are harmful, certain various diseases and conditions related to heritable gene mutations can directly impact lifespan. Specifically, particular genes can increase the risk of cancer and other diseases that can accelerate human aging. Many people are familiar with the BRCA1 and BRCA2 mutations which predispose to breast cancer. These genes are referred to as tumor suppressor genes which code for proteins that control the repair of damaged DNA (or the elimination of the cell with damaged DNA if repair is not possible) (Stibich, 2025).

2. Recent research

In a research conducted in 2010 by Heather E Wheeler and Stuart K Kim, the results demonstrated that FOXO3A and APOE are the only two genes linked to human longevity that have been replicated across several populations. With odds ratios of 1.26 and 1.45 for survival to age 100 in repeat trials for FOXO3A and APOE, respectively, these two genes have modest effect sizes for longevity. Specifically, the ε4 allele of apolipoprotein E (APOE) is well known to increase risk of Alzheimer's disease and cardiovascular disease, and the forkhead box O3A (FOXO3A) transcription factor contains alleles associated with longevity in multiple Asian and European populations. In all cases, the alleles associated with longevity are intronic and unlinked to known coding SNPs, so the functional SNPs may affect gene expression rather than protein activity, but this has not yet been shown. However, the associations found in humans account for small percentages of the variance in lifespan and many other gene associations have not been replicated in additional populations. Therefore, aging is probably a highly polygenic trait. (Wheeler & Kim, 2010)

Moreover, genes related with telomere length exert reverse influences on cancer and cardiovascular diseases and eventually impact human aging pace. (Melzer et al., 2019) Specifically, summary data were available for 35 cancers and 48 non-neoplastic diseases, corresponding to 420 081 cases (median cases, 2526 per disease) and 1 093 105 controls (median, 6789 per disease). Increased telomere length due to germline genetic variation was

generally associated with increased risk for site-specific cancers. The conclusion showcases that longer telomeres probably raise the risk of a number of cancers while lowering the risk of several non-neoplastic conditions, such as heart disease. (Haycock et al., 2017)

Through various research, several genes are linked to T2DM and multiple cancers. For example, ZMIZ1contributes to T2DM (Mahajan et al., 2018), breast cancer (Michailidou et al., 2017), and colorectal cancer (Schmit et al., 2018). And VEGFA is related to T2DM (Mahajan et al., 2018) and prostate cancer (Schumacher et al., 2018), FTO is related to type 2 diabetes mellitus (Mahajan et al., 2018) and colorectal cancer (Schmit et al., 2018). Furthermore, variants in gene TCF7L2 are linked to T2DM (Mahajan et al., 2018), breast cancer (Michailidou et al., 2017), and colorectal cancer (Schmit et al., 2018). TCF7L2 is involved in β-cell proliferation and insulin production (Jin, 2016). Genetic variations at this locus are linked to a higher prevalence of obesity. (Locke et al., 2015) Given the buildup of senescent cells in adipose tissue, these locations emphasize the significance of adiposity as an ageing accelerator. (Tchkonia et al., 2010)

Methodology

1. Search strategy and selection process

A methodical strategy is used to look into the genetic foundations of aging. The first step is to look through pertinent papers in the GWAS Catalog, which has 47 studies linked to features connected with aging. The identification of genetic variations associated with lifespan and age-related disorders is made possible by these research, which cover a variety of human populations with differing ethnicities, age groups, and sample sizes. The next crucial stage is to select variants according to statistical significance, only those SNPs with a GWAS association P-value below a certain threshold (e.g. $P < 1x10^{-5}$) are included in the calculation of the PRS, while all other SNPs are excluded. (Choi et al., 2020) A search strategy includes keywords like "aging," "longevity," and "age-related diseases," in addition to the designated P-value threshold, to guarantee thorough investigation.

2. Analysis through Open Target Genetics

The next step is to look for the particular variations of interest using the Open Target Genetics platform, which offers a comprehensive resource for examining genetic relationships. Each variant's linked genes are found on this platform, and the Variant-to-Gene (V2G) score is a crucial measure to take into account. Since these measures usually indicate a stronger and more trustworthy genetic link, genes with the highest V2G scores and the greatest distance from the variant are given priority. Based on variables like gene expression, regulatory influence, and pathway involvement, the V2G score measures the degree of evidence that connects a specific variant to a gene. High V2G score variants are more likely to affect gene activity and, in turn, phenotypic characteristics, including those associated with aging. Furthermore, because mutations situated in distant non-coding areas or regulatory regions can still have a major impact on gene expression through long-range interactions, the distance between the variant and the

gene is crucial. A strong functional link between the detected gene and the variant is ensured by selecting genes with the highest V2G score and the greatest distance, which raises the possibility that the gene contributes to aging processes.

3. Estimation of genetic expression

RNA sequencing (RNA-seq) is used as a potent tool to evaluate gene expression across different samples in order to further explore the possible function of a gene in aging-related features. A major goal of RNA-seq analysis is to identify differentially expressed and coregulated genes. (Koch et al., 2018) Through the measurement of transcript levels, RNA-seq gives researchers important information about how active a gene is, enabling them to pinpoint genes that are either highly inactive or significantly active. The gene's relative expression is measured by the log2 fold change, where higher activity is indicated by positive values and lower activity by negative values. Significantly active or inactive genes are those with a log2 fold change of more than 1.5 or less than -1.5, respectively, which may indicate that the genes are involved in the related phenotypes. The significant genes identified through RNA-seq are then analyzed in the context of the study title, providing insights into the specific traits or conditions that the gene may influence, thereby advancing the understanding of the genetic mechanisms underlying aging (Trapnell et al., 2012). This method is particularly useful for identifying genes that may play causal roles in aging and age-related disorders by correlating gene expression patterns to phenotypic features.

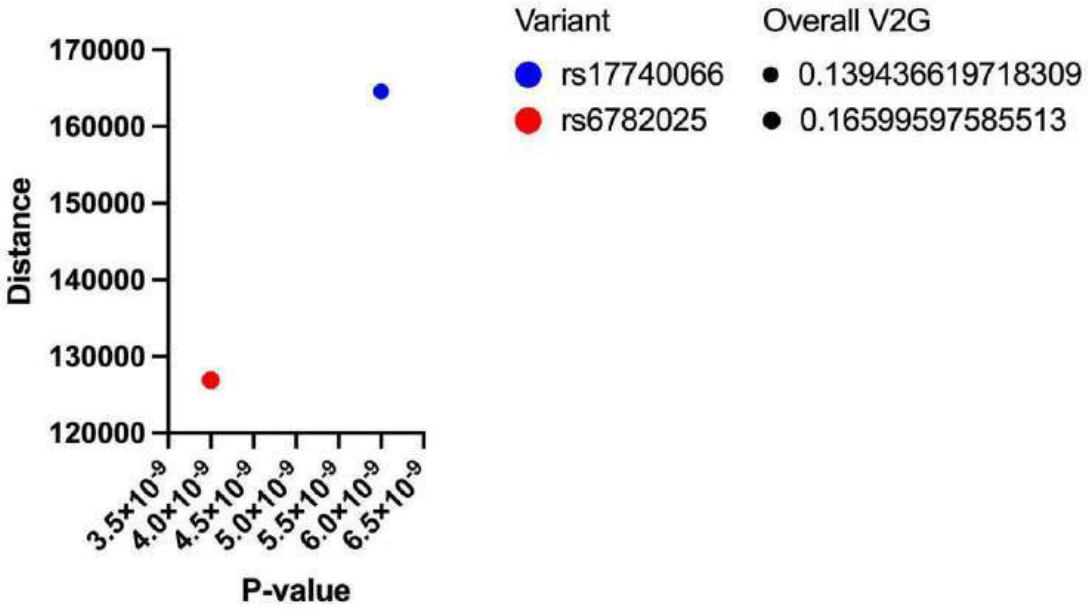
Overview of the gene segments and variants

Variant	P-value	Associate	Traits	Title	Race	Sample n	Distance	V2G	Journal
rs322458	2 x 10-8	STXBP5L	No	A genome	European	502	41604	0.059758551	J Invest D
rs1774006	6 x 10-9	POLQ	Seropositi	A genome	European	502	164552	0.13943662	J Invest D
rs6782025	4 x 10-8	POLQ	Mean plat	A genome	European	502	126859	0.165995976	J Invest D
rs6775899	1 x 10-9	FBXO40	No	A genome	European	502	7,598	0.086519115	J Invest D
rs1041219	3 x 10-6	ATCAY	No	A genome	European	16995	47909	0.079879276	Neurobio
rs4764043	6 x 10-6	GRIN2B	No	A genome	European	16995	19454	0.086519115	Neurobio
rs3112530	7 x 10-6	GRIA1	No	A genome	European	16995	229498	0.033199195	Neurobio
rs1685291	3 x 10-6	MECOM	Mean plat	A genome	European	16995	/	0.013279678	Neurobio
rs8001976	3 x 10-6	NUDT15	Ever take	A genome	European	16995	224381	0.039839034	Neurobio
rs1116296	4 x 10-6	No	No	A genome	European	16995	/	/	Neurobio
rs1020249	8 x 10-6	COL6A3	No	A genome	European	16995	52077	0.193762575	Neurobio
rs2367725	9 x 10-6	ST3GAL3	Haematoc	A genome	European	16995	44333	0.273440644	Neurobio
rs7556898	2 x 10-17	FIGN	None of t	Lifestyle f	East Asia	25460	415991	0.013279678	J Geronto
rs1699807	6 x 10-26	FGF5	Uncatego	Lifestyle f	East Asia	25460	3452	0.146076459	J Geronto
rs1085891	7 x 10-13	POC1B	Uncatego	Lifestyle f	East Asia	25460	168966	0.152716298	J Geronto
rs7412	4 x 10-48	APOE	Uncatego	Lifestyle f	East Asia	25460	3031	0.318712274	J Geronto
rs1260326	3 x 10-16	GCKR	Uncatego	Lifestyle f	East Asia	25460	11234	0.359356137	J Geronto
rs218265	3 x 10-11	KIT	Uncatego	Lifestyle f	East Asia	25460	114435	0.053118712	J Geronto
rs1103748	1 x 10-29	HBG2	No	Lifestyle f	East Asia	25460	54363	0.079879276	J Geronto
rs1203979	3 x 10-28	HBZ	Uncatego	Lifestyle f	East Asia	25460	69139	0.325352113	J Geronto
rs9669651	6 x 10-200	AXIN1	No	Lifestyle f	East Asia	25460	122999	0.112877264	J Geronto
rs5600773	3 x 10-57	HBZ	Uncatego	Lifestyle f	East Asia	25460	95190	0.292152918	J Geronto
rs740000	1 x 10-37	HBZ	measurem	Lifestyle f	East Asia	25460	126998	0.20583501	J Geronto
rs2685125	7 x 10-23	RGS11	Occlusion	Lifestyle f	East Asia	25460	1577	0.293360161	J Geronto
rs7603833	1 x 10-300	AXIN1	Mean cor	Lifestyle f	East Asia	25460	43112	0.079879276	J Geronto
rs1057209	6 x 10-120	AXIN1	Uncatego	Lifestyle f	East Asia	25460	21007	0.326760563	J Geronto
rs7206286	1 x 10-36	PGAP6	Heel bone	Lifestyle f	East Asia	25460	50934	0.373641851	J Geronto
rs887466	5 x 10-10	HLA-C	Uncatego	Genome-v	European	34467	96396	0.367002012	Genome I
rs1709414	3 x 10-8	NKX2-3	Uncatego	Genome-v	European	34467	12420	0.099597586	Genome I
rs1045929	2 x 10-8	MED24	Uncatego	Genome-v	European	34467	42042	0.199396378	Genome I
rs9386796	2 x 10-11	CD164	Uncatego	Genome-v	European	34467	84966	0.172635815	Genome I
rs1179328	6 x 10-18	ZNF248	Eosinoph	Genome-v	European	34449	17730	0.06639839	Genome I
rs93059	3 x 10-9	MANBA	Uncatego	Genome-v	European	34449	213633	0.272434608	Genome I
rs3093956	9 x 10-10	HLA-C	Uncatego	Genome-v	European	34449	187060	0.36056338	Genome I
rs10508861	7 x 10-13	ZNF37A	DNA met	Genome-v	European	34449	319193	0.186720322	Genome I
rs4838595	1 x 10-8	FAM25C	DNA met	Genome-v	European	34449	467413	0.106841046	Genome I
rs941997	9 x 10-22	BLNK	DNA met	Genome-v	European	34449	15492	0.06639839	Genome I
rs1241775	6 x 10-12	SLC29A2	Uncatego	Genome-v	European	34449	63325	0.220724346	Genome I
rs3497091	3 x 10-8	ZFHX3	Uncatego	Genome-v	European	34449	/	0.020120724	Genome I
rs1143899	1 x 10-8	THSD7B	/	Genome-v	African A	6148	/	0.020120724	Genome I
rs1905453	1 x 10-9	ERMN	/	Genome-v	African A	6148	150745	0.106237425	Genome I
rs7813123	2 x 10-21	ITGA9	/	Genome-v	African A	6148	64745	0.059758551	Genome I
rs9853301	6 x 10-9	PYDC2	/	Genome-v	African A	6148	341134	0.019919517	Genome I
rs1162709	7 x 10-9	MAP3K1	/	Genome-v	African A	6148	311398	0.086317907	Genome I
rs2858830	3 x 10-10	CALHM6	/	Genome-v	African A	6148	6034	0.26639839	Genome I
rs3778401	1 x 10-9	RAMACL	/	Genome-v	African A	6148	21120	0.06639839	Genome I
rs7744326	5 x 10-12	RAMACL	/	Genome-v	African A	6148	2989	0.06639839	Genome I
rs1114790	1 x 10-8	SH3GL2	/	Genome-v	African A	6148	169747	0.066599598	Genome I
rs2836455	1 x 10-18	GANC	/	Genome-v	African A	6148	140888	0.086317907	Genome I
rs2227341	6 x 10-25	F2RL3	/	Genome-v	African A	6148	110	0.126358149	Genome I
rs7984054	6 x 10-15	HOOK1	/	Genome-v	European	34,463,	117102	0.300201207	Genome I
rs1214361	4 x 10-15	EDARAD	Intrinsic e	Genome-v	European	34,463,	4278	0.313480885	Genome I
rs1369666	2 x 10-8	SMC4	Intrinsic e	Genome-v	European	34,463,	91964	0.239839034	Genome I

Results

1. POLQ

The graph on the GWAS website shows that the P-values for two variants, rs17740066 (6 × 10^-9) and rs6782025 (4 × 10^-9), both fall below the threshold of 1 × 10^-5, indicating a statistically significant correlation between these variants and the trait of aging. Additionally, the distances between these variants are 164,552 and 126,859 base pairs, respectively. (Clerc et al., 2012b)

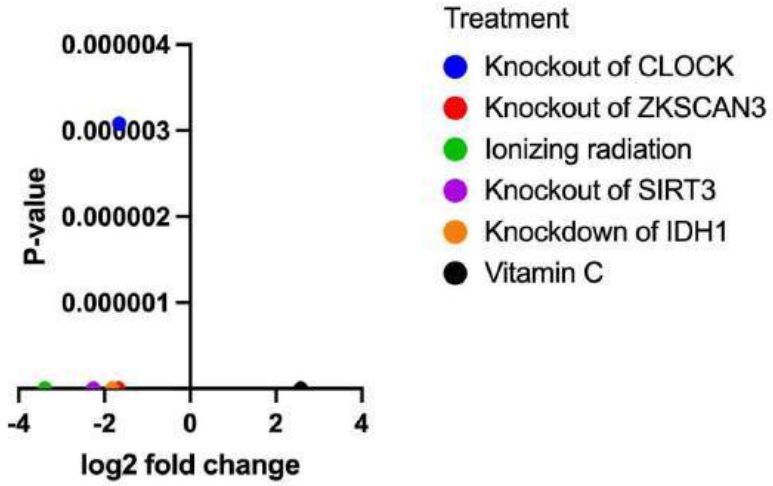


The scatter plot from the Open Targets Genetics website visually depicts the attributes that are closely related with the two variations, emphasizing their possible significance to numerous phenotypic features. The scatter plot shows that rs17740066 is linked to seropositive rheumatoid arthritis, a chronic inflammatory disease marked by joint discomfort, stiffness, inflammation, swelling, and, in rare cases, joint destruction. This disorder is distinguished by the presence of particular antibodies in the blood, which aid in the autoimmune response and subsequent inflammatory processes affecting the joints. Study also reveals that rheumatoid arthritis is associated with premature ageing, accompanied by dysfunction in multiple organ systems. (Chen et al., 2023) It also shows that rs6782025 is closely related with mean platelet volume--when the average volume is abnormal, it is easy to cause symptoms such as anemia. Another prominent trait of rs6782025 is Calcium levels. The average elderly person is in negative calcium balance and accordingly is losing bone mass. (Heaney et al., 1982) Here is the influence of the lost of Calcium level, with people become older, a large amount of calcium nutrients in the body are consumed, and calcium needs to be transferred from the bones into the blood, resulting in a decrease in bone density, leading to osteoporosis. The loss of bone calcium in elderly people can reach 30% ~ 50%. Long-term transfer of bone calcium into the blood may

lead to an increase in the amount of calcium in blood vessels, tissues, and cells. Subsequently, the blood vessel wall, myocardium, kidney calcium deposition, resulting in numbness, neurasthenia, apathy, constipation, lethargy, sexual dysfunction, arteriosclerosis, coronary heart disease, diabetes, lithiasis, tumors and other senile diseases. At this time, the thyroid C cells will secrete calcitonin to promote the reduction of bone calcium, and in the reduction process formed the ectopic deposition of free calcium on the edge of the great bones - osteosis, that is, bone hyperplasia is caused by calcium deficiency. These pathological and physiological changes disrupt the lives of many middle-aged and elderly people. As a result, these two variations have a significant impact on human aging and the aging-related illnesses.

Furthermore, the data in the form indicate that rs17740066 has a distance of 164552 and a V2G of 0.139436619718309 with the gene POLQ, whereas rs6782025 has a distance of 126859 and a V2G of 0.16599597585513. This suggests that the POLQ gene is primarily responsible for controlling or influencing those two variations. POLQ is a Protein Coding gene. Pol θ is encoded by the POLQ gene in mammalian cells. DNA polymerase theta (pol θ) is encoded in the genomes of many eukaryotes, though not in fungi. The C-terminal third of the protein is a family A DNA polymerase with additional insertion elements relative to prokaryotic homologs. (Wood & Doublié, 2016) Diseases associated with POLQ include Xeroderma Pigmentosum and Fanconi Anemia. Among its related pathways are Homology Directed Repair and Activation of the pre-replicative complex. Gene Ontology (GO) annotations related to this gene include nucleic acid binding and damaged DNA binding.

Through investigating the studies presented in the RNA-sequencing, POLQ's close relationship with aging can be reinforced.

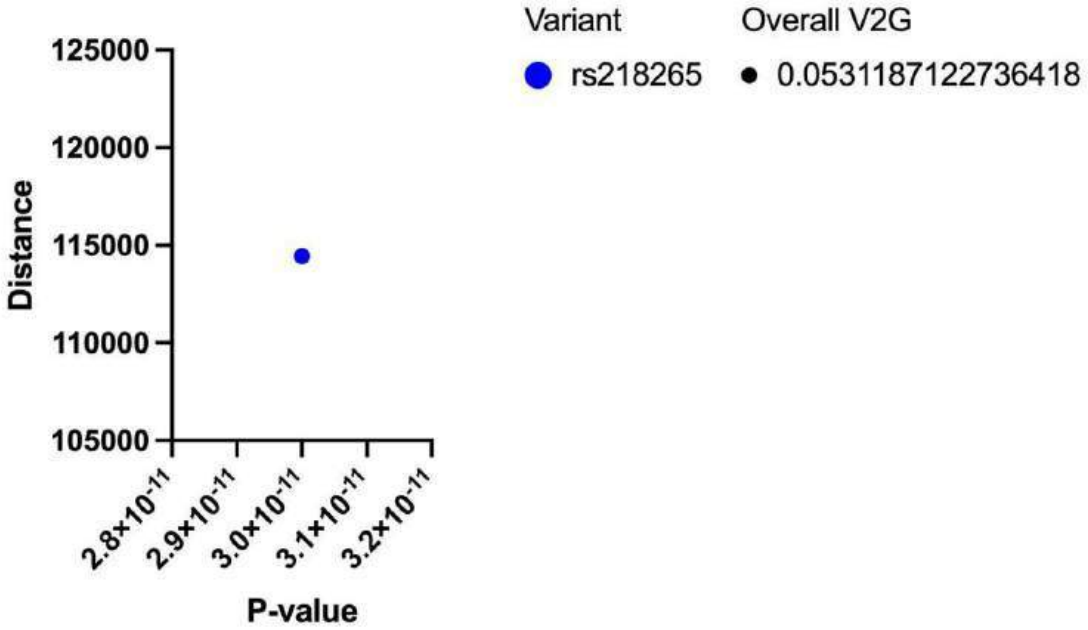


In a study investigating the gene CLOCK, which is associated with aging, the researchers observed a log2 fold change of -1.65821 for POLQ following CLOCK knockout, which is below the threshold of -1.5. The P-value for POLQ was 3.08x10^-6 (Liang et al., 2020), indicating a significant reduction in POLQ expression when CLOCK is absent. Similarly, in a study on ZKSCAN3, a gene closely related to aging, the investigators found a log2 fold change of

-1.67861 for POLQ following ZKSCAN3 knockout, with a P-value of 2.45x10^-10 (Hu et al., 2020). These results suggest a substantial decrease in POLQ expression upon the knockout of ZKSCAN3. Several studies have demonstrated a significant relationship between the gene POLQ and aging-related processes. In a study examining the transcriptome signature of cellular senescence induced by ionizing radiation, the log2 fold change of POLQ was -3.39263, with a highly significant P-value of 4.50x10^-17 (Casella et al., 2019), underscoring its strong association with cellular senescence. Similarly, in research involving SIRT3, another gene implicated in aging, POLQ exhibited a log2 fold change of -2.25797, which is below the threshold of -1.5, and a P-value of 6.54x10^-18 (Diao et al., 2021), further reinforcing its connection to aging. In a study on the gene IDH1, known to influence aging, POLQ's log2 fold change was -1.82117, lower than -1.5, and the P-value was 1.13x10^-10 (Wang et al., 2020), suggesting that POLQ plays a role in the aging processes regulated by IDH1. Finally, a study on Vitamin C's effects on Werner syndrome, a model of aging, reported a log2 fold change of POLQ of 2.5728, which is above 1.5, with a P-value of 8.27x10^-15 (Li et al., 2016). This positive fold change provides additional evidence supporting the involvement of POLQ in aging. Collectively, these studies highlight the significant role of POLQ in aging-related pathways.

2. KIT

The graph on the GWAS website shows that the P-value for the variant rs218265 is 3x10^-11, which is below the threshold of 1x10^-5, indicating a statistically significant correlation between this variant and the trait of aging.



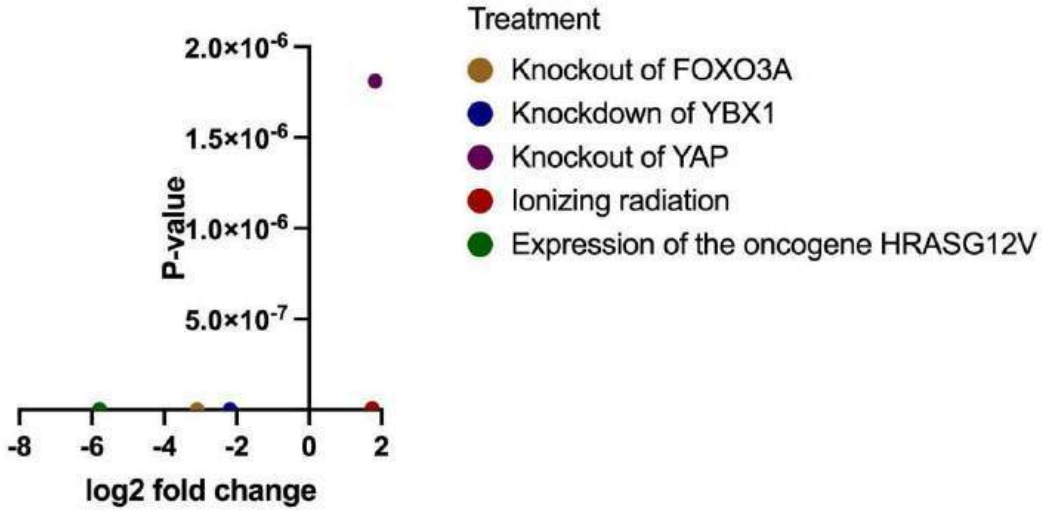
On the website of open target genetics, the scatter graph presented the closely related traits of the variant. It demonstrates that rs218265 is significantly related to cardiovascular diseases (CVDs) , which are the leading cause of death globally, taking an estimated 17.9 million lives each year. CVDs are a group of disorders of the heart and blood vessels and include

coronary heart disease, cerebrovascular disease, rheumatic heart disease and other conditions. More than four out of five CVD deaths are due to heart attacks and strokes, and one third of these deaths occur prematurely in people under 70 years of age. The CVDs will eventually trigger mortality at an early age and can accelerate human aging. (Zhou et al., 2022) The specific variant is also closely connected with the cell proliferation disorder which results in abnormal cell division and regeneration, demonstrating an abnormal increase or decrease in the number of cells. The morphological structure, biochemical characteristics and physiological functions of the daughter cells produced by division and proliferation can not form a specific or specific cell pathological phenomenon. Abnormal cell division will also encourage the development of cancer. Cancer and its treatment can also be “disease drivers” of aging. In both older and younger adults, evidence demonstrates that cancer and its treatment increases the risk of developing decreased resilience, functional impairments, chronic diseases, and frailty. (Sedrak & Cohen, 2022) The variant corresponds to the disease of the visual system that are the leading causes of blindness and low vision, such as age-related macular degeneration, cataract, diabetic retinopathy, and glaucoma. (National Eye Institute, n.d.) Other common eye disorders include amblyopia and strabismus. Moreover, this variant can also impact the expression that leads to endocrine system disease. This kind of disorder dominates the secretion of hormones, and this is exacerbated by changes in the hormonal network during aging, accompanied by insufficient or excessive hormones, which are less sensitive to their effects in tissues. The changes in endocrine systems will affect age-related intrinsic mechanisms. (Van Den Beld et al., 2018) These changes translate clinically into sarcopenia, fat gain, bone loss, insulin signaling dysfunction, impaired immune function, and, more importantly, reduced quality of life. Accordingly, endocrine diseases are one of the key factors that have an impact on people’s aging. Lastly, this variant is related with several illnesses, such as gastrointestinal disease, infectious disease, musculoskeletal or connective tissue disease, nervous system disease and so on. Those disorders can have a negative influence on a human's immune system, certain organs, and body structures, driving human aging.

Furthermore, the data in the form shows that rs218265 has a distance of 114435 and a V2G of 0.0531187122736418 from the gene KIT, indicating that rs218265 is controlled by the gene KIT. The KIT gene provides instructions for making a member of a protein family called receptor tyrosine kinases. (KIT KIT Proto-oncogene, Receptor Tyrosine Kinase [Homo Sapiens (Human)] - Gene - NCBI, n.d.) Receptor tyrosine kinases transmit signals from the cell surface into the cell through a process called signal transduction. The KIT protein is found in the cell membrane of certain cell types where a specific protein, called stem cell factor, attaches (binds) to it. This binding turns on (activates) the KIT protein, which then activates other proteins inside the cell by adding a cluster of oxygen and phosphorus atoms (a phosphate group) at specific positions. This process, called phosphorylation, leads to the activation of a series of proteins in multiple signaling pathways. The signaling pathways stimulated by the KIT protein control many important cellular processes such as cell growth and division (proliferation), survival, and movement (migration). KIT protein signaling is important for the development and function of

certain cell types, including reproductive cells (germ cells), early blood cells (hematopoietic stem cells), white blood cells called mast cells, cells in the gastrointestinal tract called interstitial cells of Cajal (ICCs), and cells called melanocytes. Melanocytes produce the pigment melanin, which contributes to hair, eye, and skin color.

In the following study of RNA-sequencing, there is more evidence that can reinforce the strong connection between KIT and aging.

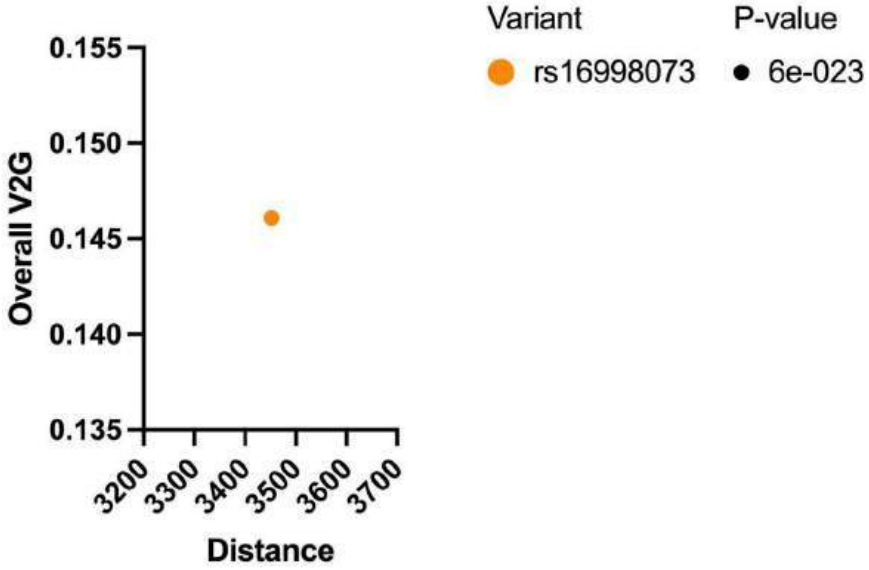


Several studies have highlighted the significant relationship between the gene KIT and aging-related processes. In a study examining the effects of FOXO3A knockout, the log2 fold change of KIT was -3.10085, well below the threshold of -1.5, with a highly significant P-value of 1.43x10^-23. (Zhang et al., 2020) This suggests a substantial decrease in KIT expression in the absence of FOXO3A, thereby reinforcing the connection between KIT and aging. Similarly, in a study investigating the knockout of YBX1, another gene linked to aging, the log2 fold change of KIT was -2.18922, below -1.5, with a P-value of 1.13x10^-13(Ma et al., 2020), further supporting the notion that KIT expression is downregulated when YBX1 is absent.

In contrast, in a study focused on alleviating senescence and osteoarthritis through YAP knockout, the log2 fold change of KIT was 1.81828, above the threshold of 1.5, with a P-value of 1.81x10^-6.(Fu et al., 2019) This finding suggests that a decrease in YAP leads to an increase in KIT expression, further implicating KIT in aging-related pathways. Moreover, in a study exploring the transcriptome signature of cellular senescence induced by ionizing radiation, the log2 fold change of KIT was 1.73589, also greater than 1.5, with a P-value of 5.98x10^-9. (Casella et al., 2019) These results reinforce the notion that KIT is closely related to aging. Finally, in research examining the expression of the oncogene HRASG12V, the log2 fold change of KIT was -5.79938, much lower than -1.5, with an exceptionally low P-value of 3.22x10^-44 (Diao et al., 2021), further supporting the significant regulatory role of KIT in aging-related processes. Collectively, these findings underscore the critical involvement of KIT in aging and age-related diseases.

3. FGF5

In the graph on the GWAS website, the P-value of the variant rs16998073 is 6x10^-26, which is significantly less than 1x10^-5, demonstrating the significance of the correlation between this variant and the trait of aging.

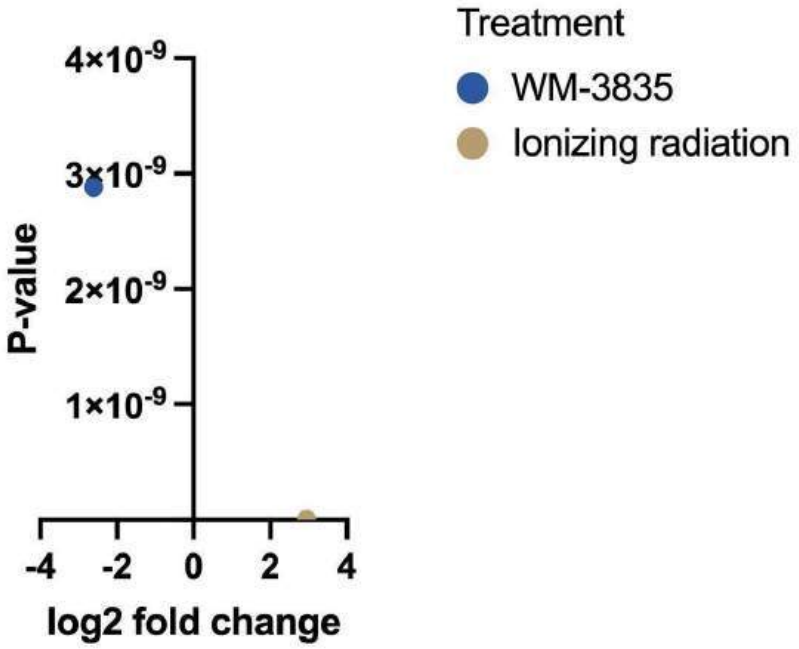


On the website of open target genetics, the scatter graph presented the closely related traits of this variant. It shows that rs16998073 is closely related with cardiovascular diseases (CVDs). The scatter graph also suggests that rs16998073 is related to nervous system disease. Disorders of the nervous system may involve the following: (1) Vascular disorders, such as stroke, transient ischemic attack (TIA), subarachnoid hemorrhage, subdural hemorrhage and hematoma, and extradural hemorrhage. (2) Infections, such as meningitis, encephalitis, polio, and epidural abscess. (3) Structural disorders, such as brain or spinal cord injury, Bell's palsy, cervical spondylosis, carpal tunnel syndrome, brain or spinal cord tumors, peripheral neuropathy, and Guillain-Barré syndrome. (4) Functional disorders, such as headache, epilepsy, dizziness, and neuralgia. (5) Degeneration, such as Parkinson disease, multiple sclerosis, amyotrophic lateral sclerosis (ALS), Huntington chorea, and Alzheimer disease, which are all considered as diseases of old age. (Reeve et al., 2014)

In addition, the data in the form shows that rs16998073 has a distance of 3452 and V2G of 0.146076458752515 with the gene FGF5. It symbolizes that this variant has a non-negligible relationship with the gene FGF5. The protein encoded by this gene is a member of the fibroblast growth factor (FGF) family. FGF family members possess broad mitogenic and cell survival activities, and are involved in a variety of biological processes, including embryonic development, cell growth, morphogenesis, tissue repair, tumor growth and invasion.This gene was identified as an oncogene, which confers transforming potential when transfected into mammalian cells. (FGF5 Fibroblast Growth Factor 5 [Homo Sapiens (Human)] - Gene - NCBI, n.d.) FGF proteins interact with a family of specific tyrosine kinase receptors, a process often

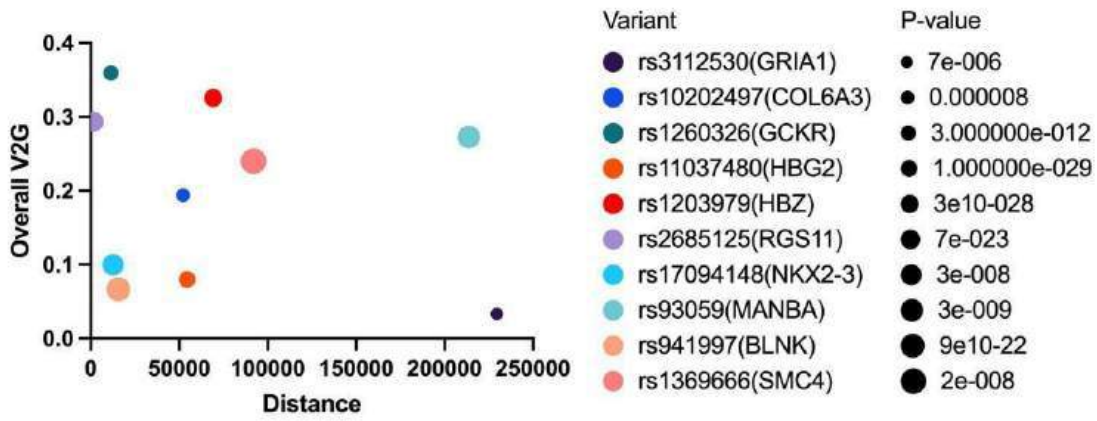
regulated by proteoglycans or extracellular binding protein cofactors. A number of intracellular signalling cascades are known to be activated after FGF-FGFR interaction including PI3K-AKT, PLCγ, RAS-MAPK and STAT pathways.

By looking at the result of the RNA-sequencing study of FGF5, more evidence shows that FGF5 is one of the main dominant genes that controls aging.



Several studies have provided strong evidence linking FGF5 to aging-related processes. In a study on cellular senescence, the researchers treated cells with WM-3835 and observed a log2 fold change of -2.6136 for FGF5, which is below the threshold of -1.5, with a P-value of 2.92x10^-10. (W. Wang et al., 2021) This suggests a significant downregulation of FGF5 expression, underscoring its close association with aging. Similarly, in a study investigating the transcriptome signature of cellular senescence induced by ionizing radiation, FGF5 exhibited a log2 fold change of 2.94404, well above 1.5, with an exceptionally low P-value of 5.99x10^-38 (Casella et al., 2019), further supporting the notion that FGF5 plays a critical role in aging-related pathways. Additionally, in a study focused on lifespan extension, researchers compared gene expression between senescent and young cells and found that FGF5 had a log2 fold change of 4.55812, well above the 1.5 threshold, with a P-value of 5.00x10^-5. (Suda et al., 2021) This result further reinforces the significant involvement of FGF5 in aging processes and its potential role in regulating lifespan. Collectively, these studies highlight the strong relationship between FGF5 and aging, suggesting its pivotal role in cellular senescence and age-related traits.

Other Genes



1. GRIA1

According to the study conducted by Walter S. on 16995 European (U.S., Italy, Netherlands, Germany), the variant rs3112530, which has the P-value of 7x10^-6, GRIA1 has the distance of 229498 and the V2G of 0.0331991951710261, indicating that this variant is associated with gene GRIA1. (Walter et al., 2011)

GRIA1 is also known as glutamate ionotropic receptor AMPA type subunit 1. Glutamate receptors are the predominant excitatory neurotransmitter receptors in the mammalian brain and are activated in a variety of normal neurophysiologic processes. These receptors are heteromeric protein complexes with multiple subunits, each possessing transmembrane regions, and all arranged to form a ligand-gated ion channel. The classification of glutamate receptors is based on their activation by different pharmacologic agonists. This gene belongs to a family of alpha-amino-3-hydroxy-5-methyl-4-isoxazole propionate (AMPA) receptors. Alternatively spliced transcript variants encoding different isoforms have been found for this gene. (GRIA1 Glutamate Ionotropic Receptor AMPA Type Subunit 1 [Homo Sapiens (Human)] - Gene - NCBI, n.d.)

Several studies have investigated the relationship between gene GRIA1 and mesenchymal stem cells (MSCs) and various genes associated with aging and cellular senescence. GRIA1 is closely related to gene ZKSCAN3 with a log2 fold change of 2.20569 and the P-value of 6.89x10^-7. According to the study conducted by Hu, ZKSCAN3 demonstrates its ability to counteract cellular senescence by stabilizing heterochromatin. (Hu et al., 2020) Likely, GRIA1 is closely related to gene FOXO with a log2 fold change of -1.80364 and the P-value of 2.60x10^-18. According to the study conducted by Yan, FOXO3-Engineered Human ESC-Derived Vascular Cells can promote vascular protection and regeneration. (Yan et al., 2019) Additionally, GRIA1 is highly related to gene APOE with a log2 fold change of 2.52727 and the P-value of 1.98x10^-24. The research of Zhao reveals that destabilizing heterochromatin by APOE can mediate senescence. (Zhao et al., 2022)

2. COL6A3

According to the study conducted by Walter S. on 16995 European (U.S., Italy, Netherlands, Germany), the variant rs10202497, which has the P-value of 8x10^-6, COL6A3 has

the distance of 52077 and the V2G of 0.193762575452716, showing that this variant is associated with gene COL6A3. (Walter et al., 2011).

COL6A3 is also known as collagen type VI alpha 3 chain. This gene encodes the alpha-3 chain, one of the three alpha chains of type VI collagen, a beaded filament collagen found in most connective tissues. The alpha-3 chain of type VI collagen is much larger than the alpha-1 and -2 chains. This difference in size is largely due to an increase in the number of subdomains, similar to von Willebrand Factor type A domains, that are found in the amino terminal globular domain of all the alpha chains. These domains have been shown to bind extracellular matrix proteins, an interaction that explains the importance of this collagen in organizing matrix components. Mutations in the type VI collagen genes are associated with Bethlem myopathy, a rare autosomal dominant proximal myopathy with early childhood onset. Mutations in this gene are also a cause of Ullrich congenital muscular dystrophy, also referred to as Ullrich scleroatonic muscular dystrophy, an autosomal recessive congenital myopathy that is more severe than Bethlem myopathy. (COL6A3 Collagen Type VI Alpha 3 Chain [Homo Sapiens (Human)] - Gene - NCBI, n.d.)

COL6A3 is related to Werner syndrome, a human mesenchymal precursor cell, linking to another gene called KAT7. It has the log2 fold change of 1.5272 and the P-value is 6.07x10^-207. In Wang's study, by utilizing CRISPR, researchers identified KAT7 as a driver of cellular senescence. (W. Wang et al., 2021b) This gene is also related to Early passage mesenchymal stem cells and for this kind of cell there's another gene that has close relationship with COL6A3 called SIRT3. It has the log2 fold change of -2.45656 and the P-value is 9.56x10^-249. Those genes also demonstrate that SIRT3 consolidates heterochromatin and counteracts senescence in Diao's research. (Diao et al., 2021) Furthermore, COL6A3 is related to the Mesenchymal stem cell and the linked gene called CBX4. It has the log2 fold change of -1.72061 and the P-value is 9.75x10^-21. According to Ren's investigation result, CBX4 can maintain nucleolar homeostasis and alleviates senescence and osteoarthritis. (Ren et al., 2019) Lastly, COL6A3 is related to Human induced pluripotent stem (iPS) cell-derived neural progenitor cells. It has the log2 fold change of -1.5 and the P-value is 2.60x10^-29. Their study proved the function of dysregulation in iPSC models of Alzheimer's Disease which is also related to human aging. (Meyer et al., 2019)

3. GCKR

According to the study conducted by Lin 25460 East Asian (Taiwan), the variant rs1260326, which has the P-value of 3x10^-16, GCKR has the distance of 11234 and the V2G of 0.359356136820925. (Lin, 2021)

Through Open Target Genetics, the related traits of this variant are demonstrated. It is related to cardiovascular disease, cell proliferation disorder, disease of visual system, endocrine system disease, gastrointestinal disease, genetic, familial or congenital disease, hematologic disease, infectious disease, injury, poisoning or other complication, integumentary system disease, musculoskeletal or connective tissue disease, nervous system disease, pancreas disease,

phenotype, pregnancy or perinatal disease, psychiatric disorder, reproductive system or breast disease, respiratory or thoracic disease, urinary system disease.

GCKR is known as a glucokinase regulator. This gene encodes a protein belonging to the GCKR subfamily of the SIS (Sugar ISomerase) family of proteins. The gene product is a regulatory protein that inhibits glucokinase in liver and pancreatic islet cells by binding non-covalently to form an inactive complex with the enzyme. This gene is considered a susceptibility gene candidate for a form of maturity-onset diabetes of the young (MODY). (GCKR Glucokinase Regulator [Homo Sapiens (Human)] - Gene - NCBI, n.d.)

GCKR is related to the human arterial endothelial cell. It has the log2 fold change of -1.65892 and the P-value is 6.26x10^-35. In Casella's study, the results show transcriptome signatures of cellular senescence related to certain genes, including GCKR. Specifically, cellular senescence, an integral component of aging and cancer, arises in response to diverse triggers, including telomere attrition, macromolecular damage and signaling from activated oncogenes. At present, senescent cells are identified by the combined presence of multiple traits, such as senescence-associated protein expression and secretion, DNA damage and β-galactosidase activity. The intersection of the altered transcriptomes revealed 50 RNAs consistently elevated and 18 RNAs consistently reduced across all senescence models, including many protein-coding mRNAs and some non-coding RNAs. We propose that these shared transcriptome profiles will enable the identification of senescent cells in vivo, the investigation of their roles in aging and malignancy and the development of strategies to target senescent cells therapeutically. (Casella et al., 2019b)

4. HBG2

According to the study conducted by Lin 25460 East Asian (Taiwan), the variant rs11037480, which has the P-value of 1x10^-29, HBG2 has the distance of 54363 and the V2G of 0.0798792756539235. (Lin, 2021)

HBG2 is identified as hemoglobin subunit gamma 2. The gamma globin genes (HBG1 and HBG2) are normally expressed in the fetal liver, spleen and bone marrow. Two gamma chains together with two alpha chains constitute fetal hemoglobin (HbF) which is normally replaced by adult hemoglobin (HbA) at birth. In some beta-thalassemias and related conditions, gamma chain production continues into adulthood. The two types of gamma chains differ at residue 136 where glycine is found in the G-gamma product (HBG2) and alanine is found in the A-gamma product (HBG1). The former is predominant at birth. (HBG2 Hemoglobin Subunit Gamma 2 [Homo Sapiens (Human)] - Gene - NCBI, n.d.) HBG2 is related to human diploid fibroblasts IMR90. It has the log2 fold change of -2.73989 and the P-value is 3.77x10^-13. In Casella's study, the results show transcriptome signatures of cellular senescence related to certain genes, including HBG2.

5. HBZ

According to the study conducted by Lin 25460 East Asian (Taiwan), the variant rs56007737, which has the P-value of 3x10^-57, HBZ has the distance of 95190 and the V2G of 0.29215291750503. It is also associated with the variant rs740000, which has the P-value of 1 x 10-37, HBZ has the distance of 126998 and the V2G of 0.205835010060362. (Lin, 2021) Those variants are related to several disorders that can accelerate human aging, including cardiovascular disease, cell proliferation disorder, infectious disease, poisoning or other complication, integumentary system disease, measurement, reproductive system or breast disease, respiratory or thoracic disease, urinary system disease.

HBZ is known as hemoglobin subunit zeta. Zeta-globin is an alpha-like hemoglobin. The zeta-globin polypeptide is synthesized in the yolk sac of the early embryo, while alpha-globin is produced throughout fetal and adult life. The zeta-globin gene is a member of the human alpha-globin gene cluster that includes five functional genes and two pseudogenes. (HBZ Hemoglobin Subunit Zeta [Homo Sapiens (Human)] - Gene - NCBI, n.d.) The gene HBZ is related to HeLa cells and linked to the gene called SPT6. It has the log2 fold change of 3.82769 and the P-value is 1.09x10^-6. The study shows that deregulated expression of mammalian lncRNA through loss of SPT6 can induce R-Loop formation, replication stress, and cellular senescence. (Nojima et al., 2018)

6. RGS11

According to the study conducted by Lin 25460 East Asian (Taiwan), the variant rs2685125, which has the P-value of 7x10^-23, RGS11 has the distance of 1577 and the V2G of 0.293360160965794. (Lin, 2021)

RGS11 is a regulator of G protein signaling 11. The protein encoded by this gene belongs to the RGS (regulator of G protein signaling) family. Members of the RGS family act as GTPase-activating proteins on the alpha subunits of heterotrimeric, signal-transducing G proteins. This protein inhibits signal transduction by increasing the GTPase activity of G protein alpha subunits, thereby driving them into their inactive GDP-bound form. Alternative splicing occurs at this locus and four transcript variants encoding distinct isoforms have been identified. (RGS11 Regulator of G Protein Signaling 11 [Homo Sapiens (Human)] - Gene - NCBI, n.d.) RGS11 is related to human diploid fibroblasts WI38. It has the log2 fold change of 1.69134 and the P-value is 8.52x10-8. In Casella's study, the results show transcriptome signatures of cellular senescence related to certain genes, including RGS11. (Casella, 2019)

7. **NKX2-3**

This gene is presented in the study termed Genome-wide association studies identify 137 genetic loci for DNA methylation biomarkers of aging by McCartney DL. The study is conducted on 34467 Europeans. (McCartney et al., 2021)

Through the data Open Target Genetics, variant rs17094148, which has the P-value of 3x10^-8, is related to gene NKX2-3. For this variant, NKX2-3 has the distance of 12420 and the V2G of 0.0995975855130784. The variant-related traits include cell proliferation disorder,

endocrine system disease, and gastrointestinal disease. Another variant rs11190127 with P-value of 5x10^-8 is also related to gene NKX2-3. NKX2-3 has the distance of 20717 and the V2G of 0.0663983903420523. This variant is related to DNA methylation GrimAge acceleration, DNA methylation PhenoAge acceleration, DNA methylation Hannum age acceleration, Anal and rectal polyp, gastrointestinal disease. Specifically, DNA methylation (DNAm) is a fundamental biochemical modification which occurs over the lifespan of an individual and it is a significant component in the aging process. Methylation level of CpG sites plays an important role in finding the age of a person. DNA methylation is a major control program that modulates gene expression in a plethora of organisms. Aging and age-related diseases include defined changes in 5-methylcytosine content and are generally characterized by genome-wide hypomethylation and promoter-specific hypermethylation. These changes in the epigenetic landscape represent potential disease biomarkers and are thought to contribute to age-related pathologies, such as cancer, osteoarthritis, and neurodegeneration. Some diseases, such as a hereditary form of sensory neuropathy accompanied by dementia, are directly caused by methylomic changes. (Johnson et al., 2012)

Gene NKX2-3 is NK2 homeobox 3. This gene encodes a homeodomain-containing transcription factor. The encoded protein is a member of the NKX family of homeodomain transcription factors. Studies of similar proteins in mouse and rat have indicated a potential role in cellular differentiation. (NKX2-3 NK2 Homeobox 3 [Homo Sapiens (Human)] - Gene - NCBI, n.d.) Gene NKX2-3 is related to HeLa cell and linked to another gene called FOXO3. Zhang's study reveals the log2 fold change of -3.3199 and the P-value of 1.54x10^-52. Those genes both express a single-cell transcriptomic landscape of primate arterial aging. (Zhang et al., 2020)

8. MANBA

This gene is presented in the study termed Genome-wide association studies identify 137 genetic loci for DNA methylation biomarkers of aging by McCartney DL. The study is conducted on 34467 Europeans. (McCartney et al., 2021)

Through Open Target Genetics, variant rs93059, which has the P-value of 3x10^-9, is closely related to gene MANBA, which has the distance of 213633 and the V2G of 0.272434607645875. Certain related traits of the variant are cell proliferation disorder, immune system disease, integumentary system disease, nervous system disease, and respiratory or thoracic disease.

MANBA is mannosidase beta. This gene encodes a member of the glycosyl hydrolase 2 family. The encoded protein localizes to the lysosome where it is the final exoglycosidase in the pathway for N-linked glycoprotein oligosaccharide catabolism. Mutations in this gene are associated with beta-mannosidosis, a lysosomal storage disease that has a wide spectrum of neurological involvement. (MANBA Mannosidase Beta [Homo Sapiens (Human)] - Gene - NCBI, n.d.) Gene MANBA is related to human diploid fibroblasts WI38. It has the log2 fold change of 1.87274 and the P-value is 5.22x10^-16. In Casella's study, the results show

transcriptome signatures of cellular senescence related to certain genes, including MANBA. (Casella et al., 2019)

9. BLNK

This gene is presented in the study termed Genome-wide association studies identify 137 genetic loci for DNA methylation biomarkers of aging by McCartney DL. The study is conducted on 34467 Europeans. (McCartney et al., 2021)

Open Target Genetics reveals that variant rs941997 has the P-value of 9x10^-22, and BLNK has the distance of 15492 and the V2G of 0.0663983903420523. The variant-related traits are DNA methylation Hannum age acceleration.

BLNK is the B cell linker. This gene encodes a cytoplasmic linker or adaptor protein that plays a critical role in B cell development. This protein bridges B cell receptor-associated kinase activation with downstream signaling pathways, thereby affecting various biological functions. The phosphorylation of five tyrosine residues is necessary for this protein to nucleate distinct signaling effectors following B cell receptor activation. Mutations in this gene cause hypoglobulinemia and absent B cells, a disease in which the pro- to pre-B-cell transition is developmentally blocked. Deficiency in this protein has also been shown in some cases of pre-B acute lymphoblastic leukemia. Alternatively spliced transcript variants have been found for this gene. (MANBA Mannosidase Beta [Homo Sapiens (Human)] - Gene - NCBI, n.d.) The gene is related to human diploid fibroblasts WI38. It has the log2 fold change of 5.96356 and the P-value is 1.07x10^-21. The study also shows that BLNK is corresponding to transcriptome signature of cellular senescence. (Casella et al., 2019)

10. SMC4

This gene is presented in the study termed Genome-wide association studies identify 137 genetic loci for DNA methylation biomarkers of aging by McCartney DL. The study is conducted on 34467 Europeans. (McCartney et al., 2021)

Open Target Genetics reveals that variant rs1369666 has the P-value of 2 x 10-8, SMC4 has the distance of 91964 and the V2G of 0.239839034205231. The variant-related traits are intrinsic epigenetic age acceleration, cardiovascular disease, haemorrhoidal disease, mouth ulcers, mouth/teeth dental problems, eosinophil counts, liver enzyme levels (alanine transaminase), Red blood cell count, Neutrophil percentage of granulocytes, Eosinophil count, Low density lipoprotein cholesterol levels, Mean corpuscular volume, Monocyte count, Eosinophil percentage of white cells, Eosinophil counts, High cholesterol.

SMC4 is structural maintenance of chromosomes 4. This gene belongs to the 'structural maintenance of chromosomes' (SMC) gene family. Members of this gene family play a role in two changes in chromosome structure during mitotic segregation of chromosomes- chromosome condensation and sister chromatid cohesion. The protein encoded by this gene is likely a subunit of the 13S condensin complex, which is involved in chromosome condensation. A pseudogene related to this gene is located on chromosome 2. (SMC4 Structural Maintenance of

Chromosomes 4 [Homo Sapiens (Human)] - Gene - NCBI, n.d.-b) It is related to WRN-/- mesenchymal stem cells. It has the log2 fold change of 2.1861 and the P-value is 4.24x10^-55. The study reveals the ability that Vitamin C alleviates aging defects in a stem cell model for Werner syndrome. (Li et al., 2016) And it is related to KGN cells and related to the gene called IDH1. It has the log2 fold change of -1.54821 and the P-value is 4.117x10^-36, suggesting that SMC4 plays a role in the aging processes regulated by IDH1. (Wang et al., 2020) Additionally, it is related to HeLa cells and another gene called SPT6. It has the log2 fold change of -2.86845 and the P-value is 4.94x10^-44. Studies suggest that loss of SPT6 induces R-Loop formation, replication stress, and cellular senescence. (Nojima, 2018) Finally, SMC4 is related to mesenchymal stem cells and another gene called YAP. It has the log2 fold change of -1.58241and the P-value is 2.29x10^-165. YAP can alleviate senescence and osteoarthritis, and up-regulate FOXD1, and eventually maintain nucleolar homeostasis. (Fu et al., 2019)

Discussion

There are several limits to my analysis that should be noted. First, the statistical data I used were drawn from a small subset of populations rather than being representative of different racial and ethnic groupings. This suggests that the findings may not be universally relevant to all humans, as genetic variability between populations can influence aging-related variables. Future research should include more varied populations to improve the generalizability of the findings. This could aid in the identification of genetic variables that have a greater universal influence across demographic groupings. Second, the variants included in my study reflect only a small subset of the numerous genetic variations that may influence aging. In the realm of aging research, there are various genetic variants, but only a few have been clearly related to aging processes. Furthermore, the importance of each variety varies, with some having a greater impact on the aging process than others. This presents a possible bias, as the variants I focused on may not be the most important when it comes to aging. In the future, a more extensive investigation of genetic variants, including lesser-known ones, could help explain which ones play the most important roles in aging.

Conclusion

There are several genes and variations that contribute to human aging, but our understanding of their exact roles is still limited. As the field of aging study expands, future studies must delve further into these genetic aspects. By undertaking more comprehensive and diversified research, we can address the limitations of previous studies, such as biased population samples and incomplete variation analysis. This will provide more accurate insights and potential treatments in the aging process.

Works Cited

Rodríguez-Rodero, S., Fernández-Morera, J. L., Menéndez-Torre, E., Calvanese, V., Fernández, A. F., & Fraga, M. F. (2011, April 28). Aging Genetics and aging. https://pmc.ncbi.nlm.nih.gov/articles/PMC3295054/

Melzer, D., Pilling, L. C., & Ferrucci, L. (2019). The genetics of human aging. Nature Reviews Genetics, 21(2), 88–101. https://doi.org/10.1038/s41576-019-0183-6

Stibich, M., PhD. (2025, January 7). What is the genetic theory of aging? Verywell healthy. https://www.verywellhealth.com/the-genetic-theory-of-aging-2224222

Wheeler, H. E., & Kim, S. K. (2010). Genetics and genomics of human ageing. Philosophical Transactions of the Royal Society B Biological Sciences, 366(1561), 43–50. https://doi.org/10.1098/rstb.2010.0259

Haycock, P. C., Burgess, S., Nounu, A., Zheng, J., Okoli, G. N., Bowden, J., Wade, K. H., Timpson, N. J., Evans, D. M., Willeit, P., Aviv, A., Gaunt, T. R., Hemani, G., Mangino, M., Ellis, H. P., Kurian, K. M., Pooley, K. A., Eeles, R. A., Lee, J. E., . . . Smith, G. D. (2017). Association between telomere length and risk of cancer and Non-Neoplastic diseases. JAMA Oncology, 3(5), 636. https://doi.org/10.1001/jamaoncol.2016.5945

Mahajan, A., Taliun, D., Thurner, M., Robertson, N. R., Torres, J. M., Rayner, N. W., Payne, A. J., Steinthorsdottir, V., Scott, R. A., Grarup, N., Cook, J. P., Schmidt, E. M., Wuttke, M., Sarnowski, C., Mägi, R., Nano, J., Gieger, C., Trompet, S., Lecoeur, C., . . . McCarthy, M. I. (2018). Fine-mapping type 2 diabetes loci to single-variant resolution using high-density imputation and islet-specific epigenome maps. Nature Genetics, 50(11), 1505–1513. https://doi.org/10.1038/s41588-018-0241-6

Michailidou, K., Lindström, S., Dennis, J., Beesley, J., Hui, S., Kar, S., Lemaçon, A., Soucy, P., Glubb, D., Rostamianfar, A., Bolla, M. K., Wang, Q., Tyrer, J., Dicks, E., Lee, A., Wang, Z., Allen, J., Keeman, R., Eilber, U., . . . Engel, C. (2017). Association analysis identifies 65 new breast cancer risk loci. Nature, 551(7678), 92–94. https://doi.org/10.1038/nature24284

Schmit, S. L., Edlund, C. K., Schumacher, F. R., Gong, J., Harrison, T. A., Huyghe, J. R., Qu, C., Melas, M., Van Den Berg, D. J., Wang, H., Tring, S., Plummer, S. J., Albanes, D., Alonso, M. H., Amos, C. I., Anton, K., Aragaki, A. K., Arndt, V., Barry, E. L., . . . Levine, D. (2018). Novel Common Genetic Susceptibility LOCI for colorectal cancer. JNCI Journal of the National Cancer Institute, 111(2), 146–157. https://doi.org/10.1093/jnci/djy099

Schumacher, F. R., Olama, A. a. A., Berndt, S. I., Benlloch, S., Ahmed, M., Saunders, E. J., Dadaev, T., Leongamornlert, D., Anokian, E., Cieza-Borrella, C., Goh, C., Brook, M. N., Sheng, X., Fachal, L., Dennis, J., Tyrer, J., Muir, K., Lophatananon, A., Stevens, V. L., . . . Cybulski, C. (2018). Association analyses of more than 140,000 men identify 63 new prostate cancer susceptibility loci. Nature Genetics, 50(7), 928–936. https://doi.org/10.1038/s41588-018-0142-8

Jin, T. (2016). Current understanding on role of the WNT signaling pathway effector TCF7L2 in glucose homeostasis. Endocrine Reviews, 37(3), 254–277. https://doi.org/10.1210/er.2015-1146

Tchkonia, T., Morbeck, D. E., Von Zglinicki, T., Van Deursen, J., Lustgarten, J., Scrable, H., Khosla, S., Jensen, M. D., & Kirkland, J. L. (2010). Fat tissue, aging, and cellular senescence. Aging Cell, 9(5), 667–684. https://doi.org/10.1111/j.1474-9726.2010.00608.x

Choi, S. W., Mak, T. S., & O'Reilly, P. F. (2020). Tutorial: a guide to performing polygenic risk score analyses. Nature Protocols, 15(9), 2759–2772. https://doi.org/10.1038/s41596-020-0353-1

Koch, C. M., Chiu, S. F., Akbarpour, M., Bharat, A., Ridge, K. M., Bartom, E. T., & Winter, D. R. (2018). A Beginner's Guide to analysis of RNA sequencing data. American Journal of Respiratory Cell and Molecular Biology, 59(2), 145–157. https://doi.org/10.1165/rcmb.2017-0430tr

Trapnell, C., Roberts, A., Goff, L., Pertea, G., Kim, D., Kelley, D. R., Pimentel, H., Salzberg, S. L., Rinn, J. L., & Pachter, L. (2012). Differential gene and transcript expression analysis of RNA-seq experiments with TopHat and Cufflinks. Nature Protocols, 7(3), 562–578. https://doi.org/10.1038/nprot.2012.016

Clerc, S. L., Taing, L., Ezzedine, K., Latreille, J., Delaneau, O., Labib, T., Coulonges, C., Bernard, A., Melak, S., Carpentier, W., Malvy, D., Jdid, R., Galan, P., Hercberg, S., Morizot, F., Guinot, C., Tschachler, E., & Zagury, J. F. (2012b). A Genome-Wide Association study in Caucasian women points out a putative role of the STXBP5L gene in facial photoaging. Journal of Investigative Dermatology, 133(4), 929–935. https://doi.org/10.1038/jid.2012.458

Liang, C., Liu, Z., Song, M., Li, W., Wu, Z., Wang, Z., Wang, Q., Wang, S., Yan, K., Sun, L., Hishida, T., Cai, Y., Belmonte, J. C. I., Guillen, P., Chan, P., Zhou, Q., Zhang, W., Qu, J., & Liu, G. (2020). Stabilization of heterochromatin by CLOCK promotes stem cell rejuvenation and cartilage regeneration. Cell Research, 31(2), 187–205. https://doi.org/10.1038/s41422-020-0385-7

Hu, H., Ji, Q., Song, M., Ren, J., Liu, Z., Wang, Z., Liu, X., Yan, K., Hu, J., Jing, Y., Wang, S., Zhang, W., Liu, G., & Qu, J. (2020). ZKSCAN3 counteracts cellular senescence by stabilizing heterochromatin. Nucleic Acids Research, 48(11), 6001–6018. https://doi.org/10.1093/nar/gkaa425

Chen, L., Wu, B., Mo, L., Chen, H., Zhao, Y., Tan, T., Chen, L., Li, Y., Yao, P., & Tang, Y. (2023). Associations between biological ageing and the risk of, genetic susceptibility to, and life expectancy associated with rheumatoid arthritis: a secondary analysis of two observational studies. The Lancet Healthy Longevity, 5(1), e45–e55. https://doi.org/10.1016/s2666-7568(23)00220-9

Heaney, R. P., Gallagher, J. C., Johnston, C. C., Neer, R., Parfitt, A. M., & Whedon, G. D. (1982). Calcium nutrition and bone health in the elderly. American Journal of Clinical Nutrition, 36(5), 986–1013. https://doi.org/10.1093/ajcn/36.5.986

Wood, R. D., & Doublié, S. (2016). DNA polymerase θ (POLQ), double-strand break repair, and cancer. DNA Repair, 44, 22–32. https://doi.org/10.1016/j.dnarep.2016.05.003

Casella, G., Munk, R., Kim, K. M., Piao, Y., De, S., Abdelmohsen, K., & Gorospe, M. (2019). Transcriptome signature of cellular senescence. Nucleic Acids Research, 47(21), 11476. https://doi.org/10.1093/nar/gkz879

Diao, Z., Ji, Q., Wu, Z., Zhang, W., Cai, Y., Wang, Z., Hu, J., Liu, Z., Wang, Q., Bi, S., Huang, D., Ji, Z., Liu, G., Wang, S., Song, M., & Qu, J. (2021). SIRT3 consolidates heterochromatin and counteracts senescence. Nucleic Acids Research, 49(8), 4203–4219. https://doi.org/10.1093/nar/gkab161

Wang, S., Zheng, Y., Li, J., Yu, Y., Zhang, W., Song, M., Liu, Z., Min, Z., Hu, H., Jing, Y., He, X., Sun, L., Ma, L., Esteban, C. R., Chan, P., Qiao, J., Zhou, Q., Belmonte, J. C. I., Qu, J., . . . Liu, G. (2020). Single-Cell Transcriptomic Atlas of Primate Ovarian aging. Cell, 180(3), 585-600.e19. https://doi.org/10.1016/j.cell.2020.01.009

Li, Y., Zhang, W., Chang, L., Han, Y., Sun, L., Gong, X., Tang, H., Liu, Z., Deng, H., Ye, Y., Wang, Y., Li, J., Qiao, J., Qu, J., Zhang, W., & Liu, G. (2016). Vitamin C alleviates aging defects in a stem cell model for Werner syndrome. Protein & Cell, 7(7), 478–488. https://doi.org/10.1007/s13238-016-0278-1

Zhou, M., Zhao, G., Zeng, Y., Zhu, J., Cheng, F., & Liang, W. (2022). Aging and cardiovascular disease: current status and challenges. Reviews in Cardiovascular Medicine, 23(4). https://doi.org/10.31083/j.rcm2304135

Sedrak, M. S., & Cohen, H. J. (2022). The Aging–Cancer Cycle: Mechanisms and Opportunities for intervention. The Journals of Gerontology Series A, 78(7), 1234–1238. https://doi.org/10.1093/gerona/glac247

National Eye Institute. (n.d.). Vision and Aging Resources | National Eye Institute. https://www.nei.nih.gov/learn-about-eye-health/outreach-resources/vision-and-aging-resources

Van Den Beld, A. W., Kaufman, J., Zillikens, M. C., Lamberts, S. W. J., Egan, J. M., & Van Der Lely, A. J. (2018). The physiology of endocrine systems with ageing. The Lancet Diabetes & Endocrinology, 6(8), 647–658. https://doi.org/10.1016/s2213-8587(18)30026-3

KIT KIT proto-oncogene, receptor tyrosine kinase [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/3815

Zhang, W., Zhang, S., Yan, P., Ren, J., Song, M., Li, J., Lei, J., Pan, H., Wang, S., Ma, X., Ma, S., Li, H., Sun, F., Wan, H., Li, W., Chan, P., Zhou, Q., Liu, G., Tang, F., & Qu, J. (2020). A single-cell transcriptomic landscape of primate arterial aging. Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-15997-0

Ma, S., Sun, S., Geng, L., Song, M., Wang, W., Ye, Y., Ji, Q., Zou, Z., Wang, S., He, X., Li, W., Esteban, C. R., Long, X., Guo, G., Chan, P., Zhou, Q., Belmonte, J. C. I., Zhang, W., Qu, J., & Liu, G. (2020). Caloric restriction reprograms the Single-Cell transcriptional landscape of Rattus Norvegicus aging. Cell, 180(5), 984-1001.e22. https://doi.org/10.1016/j.cell.2020.02.008

Fu, L., Hu, Y., Song, M., Liu, Z., Zhang, W., Yu, F., Wu, J., Wang, S., Belmonte, J. C. I., Chan, P., Qu, J., Tang, F., & Liu, G. (2019). Up-regulation of FOXD1 by YAP alleviates senescence and osteoarthritis. PLoS Biology, 17(4), e3000201. https://doi.org/10.1371/journal.pbio.3000201

Reeve, A., Simcox, E., & Turnbull, D. (2014). Ageing and Parkinson's disease: Why is advancing age the biggest risk factor? Ageing Research Reviews, 14, 19–30. https://doi.org/10.1016/j.arr.2014.01.004

FGF5 fibroblast growth factor 5 [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/2250

Wang, W., Zheng, Y., Sun, S., Li, W., Song, M., Ji, Q., Wu, Z., Liu, Z., Fan, Y., Liu, F., Li, J., Esteban, C. R., Wang, S., Zhou, Q., Belmonte, J. C. I., Zhang, W., Qu, J., Tang, F., & Liu, G. (2021). A genome-wide CRISPR-based screen identifies KAT7 as a driver of cellular senescence. Science Translational Medicine, 13(575). https://doi.org/10.1126/scitranslmed.abd2655

Suda, M., Shimizu, I., Katsuumi, G., Yoshida, Y., Hayashi, Y., Ikegami, R., Matsumoto, N., Yoshida, Y., Mikawa, R., Katayama, A., Wada, J., Seki, M., Suzuki, Y., Iwama, A., Nakagami, H., Nagasawa, A., Morishita, R., Sugimoto, M., Okuda, S., . . . Minamino, T. (2021). Senolytic vaccination improves normal and pathological age-related phenotypes and increases lifespan in progeroid mice. Nature Aging, 1(12), 1117–1126. https://doi.org/10.1038/s43587-021-00151-2

Walter, S., Atzmon, G., Demerath, E. W., Garcia, M. E., Kaplan, R. C., Kumari, M., Lunetta, K. L., Milaneschi, Y., Tanaka, T., Tranah, G. J., Völker, U., Yu, L., Arnold, A., Benjamin, E. J., Biffar, R., Buchman, A. S., Boerwinkle, E., Couper, D., De Jager, P. L., . . . Franceschini, N. (2011). A genome-wide association study of aging. Neurobiology of Aging, 32(11), 2109.e15-2109.e28. https://doi.org/10.1016/j.neurobiolaging.2011.05.026

GRIA1 glutamate ionotropic receptor AMPA type subunit 1 [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/2890

Yan, P., Li, Q., Wang, L., Lu, P., Suzuki, K., Liu, Z., Lei, J., Li, W., He, X., Wang, S., Ding, J., Chan, P., Zhang, W., Song, M., Belmonte, J. C. I., Qu, J., Tang, F., & Liu, G. (2019). FOXO3-Engineered human ESC-Derived vascular cells promote vascular protection and regeneration. Cell Stem Cell, 24(3), 447-461.e8. https://doi.org/10.1016/j.stem.2018.12.002

Zhao, H., Ji, Q., Wu, Z., Wang, S., Ren, J., Yan, K., Wang, Z., Hu, J., Chu, Q., Hu, H., Cai, Y., Wang, Q., Huang, D., Ji, Z., Li, J., Belmonte, J. C. I., Song, M., Zhang, W., Qu, J., & Liu, G. (2022). Destabilizing heterochromatin by APOE mediates senescence. Nature Aging, 2(4), 303–316. https://doi.org/10.1038/s43587-022-00186-z

COL6A3 collagen type VI alpha 3 chain [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/1293

Ren, X., Hu, B., Song, M., Ding, Z., Dang, Y., Liu, Z., Zhang, W., Ji, Q., Ren, R., Ding, J., Chan, P., Jiang, C., Ye, K., Qu, J., Tang, F., & Liu, G. (2019). Maintenance of nucleolar

homeostasis by CBX4 alleviates senescence and osteoarthritis. Cell Reports, 26(13), 3643-3656.e7. https://doi.org/10.1016/j.celrep.2019.02.088

Meyer, K., Feldman, H. M., Lu, T., Drake, D., Lim, E. T., Ling, K., Bishop, N. A., Pan, Y., Seo, J., Lin, Y., Su, S. C., Church, G. M., Tsai, L., & Yankner, B. A. (2019). REST and neural gene network dysregulation in IPSC models of Alzheimer's disease. Cell Reports, 26(5), 1112-1127.e9. https://doi.org/10.1016/j.celrep.2019.01.023

Lin, W. (2021). Lifestyle factors and genetic variants on 2 biological age measures: evidence from 94 443 Taiwan Biobank participants. The Journals of Gerontology Series A, 77(6), 1189–1198. https://doi.org/10.1093/gerona/glab251

GCKR glucokinase regulator [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/2646

HBG2 hemoglobin subunit gamma 2 [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/3048

HBZ hemoglobin subunit zeta [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/3050

Nojima, T., Tellier, M., Foxwell, J., De Almeida, C. R., Tan-Wong, S. M., Dhir, S., Dujardin, G., Dhir, A., Murphy, S., & Proudfoot, N. J. (2018). Deregulated Expression of Mammalian lncRNA through Loss of SPT6 Induces R-Loop Formation, Replication Stress, and Cellular Senescence. Molecular Cell, 72(6), 970-984.e7. https://doi.org/10.1016/j.molcel.2018.10.011

RGS11 regulator of G protein signaling 11 [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/8786

McCartney, D. L., Min, J. L., Richmond, R. C., Lu, A. T., Sobczyk, M. K., Davies, G., Broer, L., Guo, X., Jeong, A., Jung, J., Kasela, S., Katrinli, S., Kuo, P., Matias-Garcia, P. R., Mishra, P. P., Nygaard, M., Palviainen, T., Patki, A., Raffield, L. M., . . . Marioni, R. E. (2021). Genome-wide association studies identify 137 genetic loci for DNA methylation biomarkers of aging. Genome Biology, 22(1). https://doi.org/10.1186/s13059-021-02398-9

Johnson, A. A., Akman, K., Calimport, S. R., Wuttke, D., Stolzing, A., & De Magalhães, J. P. (2012). The role of DNA methylation in aging, Rejuvenation, and Age-Related Disease. Rejuvenation Research, 15(5), 483–494. https://doi.org/10.1089/rej.2012.1324

NKX2-3 NK2 homeobox 3 [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/159296

MANBA mannosidase beta [Homo sapiens (human)] - Gene - NCBI. (n.d.). https://www.ncbi.nlm.nih.gov/gene/4126

SMC4 structural maintenance of chromosomes 4 [Homo sapiens (human)] - Gene - NCBI. (n.d.-b). https://www.ncbi.nlm.nih.gov/gene/10051

The Fragility of Progress: A Feminist and Constructivist Analysis of Women's Education in Afghanistan By Zoe Smallman

Abstract

This paper employs a qualitative case study approach to examine the persistent fragility of women's educational rights in Afghanistan. Using Feminist IR theory and Constructivism as analytical frameworks, it traces the shifting status of Afghan women from 1990 to the present. The first section explores the Taliban's rise and use of restrictive educational policies, framed through selective interpretations of Islamic principles, to reinforce patriarchal authority and legitimize control. The second section analysed the US-led interventions beginning in 2001, which brought short-lived improvements in women's rights but was driven by a paternalistic "saviour" narrative that imposed Western democratic ideals on existing social structures. The final section analyses the Taliban's return to power in 2021 and the rapid erasure of previous progress, revealing the deep structural vulnerabilities underlying these regressions. Overall, the paper argues that women's right to education in Afghanistan have remained precarious, dependent on external intervention rather than internal reform, leaving them vulnerable to cyclical suppression.

Introduction

The global perception of Afghan women has long been constructed through political narratives and external representations rather than through their own lived experiences. Few images have influenced this perception more powerfully than Steve McCurry's 1984 photograph of Sharbat Gula (seen in figure 1), popularly known as Afghan Girl, which appeared on the cover of National Geographic in 1985. The image, with Gula's piercing green eyes and expression that conveyed both fear and defiance, became the emblem of Afghan women, shaping Western understanding of the country and its women for decades to come. Yet, the title, Afghan Girl, strips Sharbat Gula of her name and individuality, transforming her into a symbol for humanitarian discourse, rather than a subject of her own story. This dehumanization reflects a broader pattern in which Western media and policy framed Afghan women as passive victims in need of rescue, building a narrative that fuelled interventionist agendas under the guise of liberation and stability.



Figure 1: Steve McCurry, "Afghan Girl: Found," The New York Times, November 26 2021, https://www.nytimes.com/2021/11/26/world/europe/afghan-girl-national-geographic.html.

By juxtaposing McCurry's 1984 photograph of Gula with later photographs taken after years of hardship and conflict, one can trace the physical and emotional toll of the decades of political upheaval. Her transformation mirrors that of the nation- caught between external forces, internal struggles, and recurring erasure of women's agency. This paper critiques such romanticized portrayal of Afghan women's suffering as a visual and political tool, arguing such representations obscured human rights violations rather than addressing them.

Conceptual Framework

The treatment of women in Afghanistan can be better understood through the lens of Feminist IR and Constructivism, causing a more reflective interpretation of the wars and violence, rooted in identity and power. Greater than the policy battles, both domestically and internationally, lay ideological struggles establishing the groundwork for continued subordination of women. Feminist IR highlights how many international debates and interventions have continuously overlooked women, positioning them as secondary players to men. Specifically in the case of Afghanistan, the United States intervened with the status of women's rights to legitimize their power and gain control, gains that were quickly dismantled after the Taliban's return to power. This emphasizes how gender can be used to
gain status and is often just a piece of a broader hidden agenda. Constructivism was simultaneously present and is the belief that identity is shaped socially with norms and values, causing it to be ingrained at a very deep level. These constructions influence the government definition of policy and more principle, causing a shifted meaning of women's rights based on who had the authority at that time. Despite this paper encapsulating the time period from the 1990s to the present, these theories do not disintegrate and instead persist over time. They are useful in explaining certain rhetoric or actions taken throughout the whole interaction between the Taliban and the United States. They are used to better explain the challenge as not just solely liberating these people, but rather how their ideologies conflicted and they both struggled to gain complete authority. It also includes a look at the many international bodies and organizations that played a role in shaping the outcome of Afghanistan. This clarifies that the U.S. intervention and its accompanying savior complex were just performative roles instead of lasting change. This paper refines that narrative and demonstrates how these gains were ultimately proved unstable.

Section 1 - The Taliban and the Weaponization of Gender Norms

The emergence of the Taliban in Afghanistan in 1991 can not be understood in isolation; it was a product of decades of political instability, foreign intervention, and social upheaval. Following the Soviet withdrawal in 1989, Afghanistan was left fractured. The Soviet Union continued to support the government of Dr Najibullah till he was ousted in 1992, and the Mujahideen took over. [1] The Peshawar Accord of 1992 aimed at providing a transitional government and was instrumental in

bringing the rise of the Mujahideen. Additional issues arose when the Mujahideen Pashtun leader opposed the government, and factional divisions within the Mujahideen started to turn on one another.

As for the Taliban, many of its early members were religious students (taliban) from madrassas in Pakistan, institutions that had been heavily influenced by Gulf funding and sustained in part by U.S. aid channelled during the Cold War to support the anti-Soviet government. They brought with them the Islamic religion and the language of Pashto, as well as practices of violence and strong restrictions against the rights of women in politics, education, society, and more. Against the backdrop of factional violence and widespread disillusionment with corrupt warlords, the Taliban presented themselves as a movement of piety, justice, and order rooted in a strict interpretation of Islamic law. With material backing from Pakistan and sympathetic networks across the Gulf, they rapidly expanded, and by 1996 had seized Kabul, consolidating power over most of the country.

Reform was brought quickly following the Taliban's rise to power. In 1996 and earlier, many women had readily available access to education or the ability to educate others. [2] Once the Taliban took control, these rights were diminished. [3] Excluding a few schools in rural parts of the country, women were not allowed to go to any school or university. Since they were not allowed to work outside of their homes, their roles became largely domestic. If they chose to leave the house, the trip had to include a burqa (head-to-toe covering), and it was crucial for a man who was related to them to be by their side. [4] Failure to meet these requirements was met with harsh consequences. The edicts that were instated were shared by Radio Sharia; however, the opportunity for interpretation caused abuse of Islamic law in order to diminish the status of women in the country. [5]

Slight divergences from guidelines were not able to evade punishment, with the maximum consequence being enforced. Testimonies focused on small actions, such as a Kabul woman in 2001 moving her chadari while looking at cloth in a store. This was met with a beating by wire by the hands of Taliban guards, and the possibility of taking action was out of the question due to the rigidity and profound trepidation in the air. This extended to group punishment as in 1996 when Voice of Shari'a, a Taliban-run radio, spoke on 225 women who all were lashed due to their lack of adherence to rules that required wearing burquas, further regulations that restricted women's freedom. Extreme instances included a woman in Langham Province in 1997 being stoned to death for allegedly committing a sin of adultery. [6] The punishments went beyond the pursuit of justice and instead infringed upon basic human rights.

Through a feminist IR lens, these restrictions can be understood as a deliberate project of gendered power: women's exclusion from education and public life ensured their political and economic dependence, while reinforcing a patriarchal social order that sustained Taliban control. [7] Meanwhile, a constructivist perspective highlights how the Taliban framed these policies as rooted in religion and Afghan cultural authenticity, constructing a collective identity that normalised women's subordination. In this sense, education became not just a social right, but a battleground over the very

meaning of Afghan identity and state legitimacy. [8] These ideologies help to frame the treatment of women in a larger political picture, where their exclusion by law and policy was justified by various cultural claims.

Looking at worldwide connections, the lack of acceptance of women and the treatment they were enduring at the hands of the Taliban regime, caused an equal absence of support from international bodies. [9] The UN and other international organizations struggled to apply universal standards, especially relating to human rights, across all of Afghanistan. The country was largely diverse, with the different environments and stark differences in social and economic conditions making consistent enforcement a difficult task. Additionally, when it came to providing aid, humanitarian agencies grappled with whether delivering relief in dire situations might inadvertently legitimize the Taliban's rule. This conflict was a reflection of a broader discussion between the long-term fight to protect universal human rights and the necessity of reducing human suffering. [10]

By 1999, women's status had been stagnant if not deteriorating. The causes were traced to multiple factors, including the impact of war, restrictive policies targeting women, and entrenched social customs that reinforced their subordinate roles. [11] An overall summary of the situation at this time showed that female education was effectively banned across most of the country. Home-based schooling was permitted in some arrears, but was extremely limited and generally required special permission, leaving very few girls able to get schooling. UNICEF data indicated that primary school attendance more than doubled from 11 per cent of girls to 36 per cent of boys. This lent itself to adult literacy rates, which had women at 15 per cent in comparison to males at 47 per cent. [12] Women were also banned from teaching as workers, lowering the overall rates of education as fewer children had teachers to provide them with schooling. From a feminist IR standpoint, the Taliban kept control while continuously removing women from the picture, while a constructivist lens shows how this treatment was legitimized by cultural and religious means. This background set the stage for the discussions and global initiatives on human rights and education that would surface in the years after the Taliban's initial rise to power.

The Taliban's rule demonstrated how gendered subordination was not merely a social by-product but a central mechanism of governance and legitimacy. Through feminist IR analysis, this period reveals how the exclusion of women from education and public life sustained political control by reproducing dependence and silencing alternative forms of authority. Yet, from a constructivist standpoint, these same practices were legitimised through claims to cultural authenticity and religious morality-constructing an Afghan identity that equated order with patriarchal discipline. When the United States and its allies intervened in Afghanistan in 2001, these narratives did not disappear but were reconfigured. The discourse shifted from the Taliban's "protection" of women's virtue to the West's "liberation" of Afghan women, illustrating a
parallel logic where gender continued to serve as a site of ideological construction. In this sense, both the Taliban and the U.S.-led coalition employed women's bodies and rights as symbolic terrain upon which competing visions of civilisation, sovereignty, and legitimacy were inscribed. This

continuity underscores how gender operates in international politics not only as a measure of social progress but as an instrument through which power is constructed, justified, and exercised.

Section 2 - US Intervention and the Fragile Empowerment of Afghan women

Looking forward to the late 1990s, tension heightened between the Taliban regime and foreign entities. Collectively, the UN Security Council decided on Resolution 1267, which merged the Taliban and Al-Qaeda into the category of terrorists, setting them up as a threat to the security of the US, both internally and externally. [13] This threat materialised in the attacks of 9/11 orchestrated by Al-Qaeda, where the World Trade Center in New York City was destroyed by two hijacked planes, killing all passengers and many in the buildings as well as the surrounding areas. This did not pass by US officials peacefully, and the response was a joint resolution signed by President Bush in order to allow force to attack anyone with relations to the attacks. Following this, there was combat between the US and Taliban/Al-Qaeda forces in the air, but also conflict between the Taliban and other Afghan rivals on the ground. The Taliban took some significant losses, such as at Mazar-e-Sharif, and this led to the eventual discussion of a transitional government by the UN with the help of many outside agencies to open a new chapter for Afghanistan.

In December 2001, Afghan factions signed the Bonn Agreement, which laid the groundwork for an era of reconstruction in Afghanistan. Hamid Karzai was chosen as interim leader, but had extensive support from groups such as NATO and the US. [14] An overview of the aims of these new initiatives backed by the US included rebuilding the state, counterterrorism, which was an especially crucial goal following the attacks, and humanitarian relief to alleviate the suffering of the Afghan population under the previous regime. While women in the United States were still fighting for equal rights as men at this time, many individuals and many women's rights organizations extended their efforts to Afghanistan, where the need was more urgent to restore women's education and overall provide women with basic human rights that they were deprived of under the Taliban.

The intervention of U.S. forces was framed as necessary on many moral principles to provide relief for the oppressed women. It was a concept often referred to as the "saving Afghan women" rhetoric and was visualized in many statements by the US government and leaders to justify their enforcement of national ideals in Afghanistan. In 2001, Laura Bush gave a radio address [15] that emphasized the urgency of the US military gains to not just fight terrorism, but fight for the dignity of women. She noted that the practices and treatment of women by the Taliban could not be categorized as religiously motivated because, universally, Muslims have not aligned themselves with the same principles. Women had no access to health care, few social rights, and almost no access to education. This was a call for the people of America to join in the efforts to expand women's rights in many different facets. The perspective on Afghanistan that the populations in the US received was one where they were helpless people who needed saving by Western forces. When looking at this in various articles and news reports on the situation in Afghanistan, it reinforced the inferiority of the United States and the protection scenario rhetoric. [16] This legitimized violence or harsh methods that

the US partook in, as many came to the conclusion that it was benefiting these foreign people who needed their assistance.

Nevertheless, despite the mindset of outside influences, the changes could be considered, to a large extent, effective and oriented at increasing rights. Honing in on education, the US Congress wanted to support various higher education programs and offer opportunities for in-person and online schooling. They also promoted Afghan women having scholarship access as well as the ability to attend various universities. [17] These offers were largely supported by the billions of dollars from international bodies to fund these educational routes. Tangible results were obtained that demonstrated the impact this had. Statistically, an enrollment of about 3.9 million in 2004 nearly doubled to 6.2 million by 2008 . Looking at these numbers specifically for girls saw an increase from a mere 839,000 to 2.2 million. [18] This was not just an effort to increase the education of young girls, but also to give women teaching opportunities and to provide them with a stable income. UNICEF noted that between the years 2006-2008, 25,435 female teachers were trained throughout urban and rural areas. [19] The trends were all upward, and many women could finally have the chance to grow their minds and not be fearful of brutal punishment for trying to learn.

However, it is also important to note that these new changes had boundaries. Education was limited mainly to wealthier or more easily accessible areas of Afghanistan. While many schools were added, there were not enough in remote areas, making it consistently difficult for women living in those communities to access. Many parents did not feel comfortable sending their young girls long distances in order to get to the new school locations, for fear of what they could encounter along the way. [20] As with all efforts of social change, there were advances as well as challenges, but the US intervention created meaningful possibilities for many women living in Afghanistan, largely sustained by international resources.

Women and young girls who had become accustomed to their subordinate place in society jumped at the chance to find work or simply to learn. Groups would meet in neighborhoods to increase literacy, as well as attend classes for reading and writing skills. Mothers would learn to teach their children, and the overall atmosphere was a growth mindset intellectually. Illiteracy was an extreme struggle not just in communication, but also because women were now more frequently out of their houses and needed to be able to understand where they were and where they were going. Even simple things became accomplishments for some, such as being able to write their name. [21] Shaharzad Akbar from Jawzjan, Afghanistan, was the first Afghan woman to study at a graduate level at Oxford University. At the age of 15, she came back from Pakistan to her home in Afghanistan to find parents paying for their girls to be educated in her father's village. She recognized how lucky she was to have had amazing educational access, and understood that this would not be possible without continued attention and sustained support, something that was not guaranteed for much time after 2011 when Shaharzad spoke these statements. [22]

Returning to the "saving Afghan women" and shifting to a feminist IR perspective, we can see how easily these stories and narratives can have an influence on foreign opinion and policy. Women were portrayed as weak and in need of salvation, which caused the entrance of the US to be

in support of this instead of the message focusing on the violence that was inflicted in order to reach those goals. This raises the question of whether that logic was genuine or just used to legitimize international means. This tactic has been used throughout history, such as in the past with slavery in Africa, and the white savior complex, justifying the poor treatment of individuals. The US had a paternalistic view of Afghanistan, which resulted in the people being largely dependent on it. When looking at this period through a constructivist view, we see how easily social constructs can be intertwined with values in a country. When the US came in they reframed the norms of the country and believed them to be accepted by all. This is where the fault in their methods mainly lies. Constructivism is often not universal, and many had spent so many years under the Taliban that they truly believed restricting women of their rights was not an expectation but was simply right, despite the fact that it infringed upon human rights. As stated before, the spread of US influence did not reach all corners of the country, leaving many stuck in the past. This made it difficult for these new shifts to be ingrained and made the progress vulnerable for the future.

Section 3-Collapse and Continuity: Reconstructing Patriarchal Control

The Taliban had been attempting to regain control of Afghanistan before finally doing so in 2021. However, international groups such as the UN insisted that any return to power be contingent on a peace agreement to ensure Afghanistan would not revert to terrorism or the rigid social constructs of the previous Taliban regime. Negotiations were intermittent, but both the Taliban and Afghan government expressed interest in peace, with the Taliban emphasizing their desire to reestablish an Islamic-based rule. Over time, the US began to reduce its military presence, cutting troop levels in half. Eventually, in 2021, under President Joe Biden, the US completely withdrew from Afghanistan, as the Taliban would not continue progressive discussion unless they were gone. The removal of U.S. troops got rid of the main barrier stopping the return of the Taliban regime. The civil negotiation between the Afghan officials and the Taliban was one-sided, and the Taliban began to quickly gain control in many capitals and important parts of the country. [23] By mid-2021 the Kabul had fallen to the Taliban, which was representative of a new stage where all of the gains made during U.S. intervention were quickly reversed, and a collapse of women's rights accompanied it.

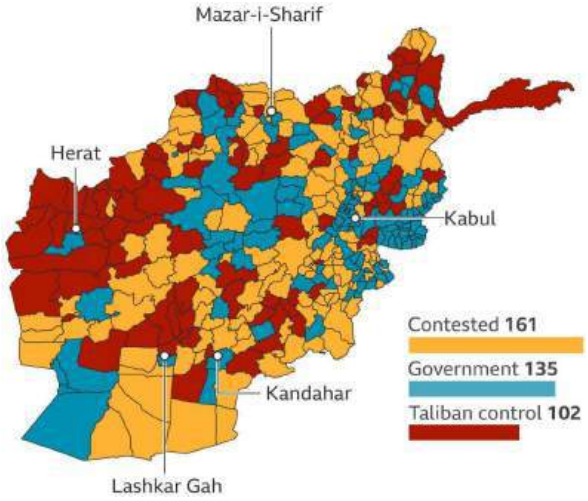


Figure 2: "BBC News, "Afghanistan at a Glance: Map of Conflict and Control," BBC News, August 28, 2021, https://www.bbc.com/news/world-asia-57933979

An overwhelming 1.5 million girls have not been able to attend secondary school in Afghanistan since 2021. [24] Since then, changes have been made so that women are no longer allowed to work in NGO's, or seek entertainment in parks, and can't even maintain their health at a gym. They have been excluded from politics completely, and the new rules regarding their role in society have caused many women to return to their households and stay there. Due to many women losing their jobs, they can no longer support their families and are at a disadvantage financially. The Taliban tries to please calls for change by speaking on the eventual reinstatement of certain rights; however, these promises are empty, and women have continued to be discriminated against. [25] This does not encapsulate the full extent of it, as the violence is seemingly the most immoral part of the Taliban's new reign. Between 2022 and 2024, there were a reported 840 incidences of gender-based violence. This included, but was not limited to, killings, torture, degrading treatment, and rape. [26] To explain this rapid regression, constructivism reveals how a major power, especially a violent one in the case of the Taliban, can alter societal expectations and enforce them into a construct. The Taliban justified ignoring basic human rights with religious means, despite the fact that the majority of the Islamic world condemned their treatment of women and their abuse of religious values. Their conquering of land was not the sole factor in their regaining control, but their reinstatement of beliefs, ones which had been deeply ingrained previously and were still able to return even after being hidden for so long. That is a reason why the policy and ideas the U.S. instated were so delicate; they clashed with domestic norms and the framework that the Taliban had enforced.

Despite the removal of troops from Afghanistan, the U.S. and many international organizations continued to monitor the state of Afghanistan. They were deeply concerned with the Taliban's return and their blatant violation of so many rights, especially for women. They completely ignored many international laws and proceeded forward with their values and methods. Specifically, organizations such as Human Rights Watch, Amnesty International, and ICC have labeled this as crimes against humanity. However, a widespread rhetoric has made this task challenging as many worldwide debates between saving lives with humanitarian aid or helping the rights of women. [27] Often, women's rights get sacrificed in this struggle, and this has led to the ongoing cycle of oppression of their freedoms. The UN Women organization has worked not only to promote awareness of the erosion of rights, but also actively helps in many ways. They have worked to aid financially in many ways and partnered with over 200 women's organizations as of 2024 to further assist. [28] UN Women and others recognize the common feminist IR perspective where international politics marginalize women to serve what they believe to be greater needs; military, financial needs, etc.

Looking at it from an internal perspective, there was a lot of turmoil and factioning within the Taliban itself. "While the extremist faction supports "original Taliban ideology" and rejects the education and employment of women, the reformist faction consists of many members who are

themselves educated and have daughters who are attending school," as cited in Women in National Security: Afghan Women's Education under the Taliban. [29] Prior to the Taliban's return through their takeover, many empty promises were made. Girls were told that they could return to school at the start of the next school year, instilling excitement and hope in many young girls eager to get an education. However, when they went to school, they were all sent away, and this was an impact of the Taliban's internal divisions, which could not come to a consensus on what to do with women's education. It showcases how belief systems can shape political behavior, a constructivist view, and even though the two groups had differing views, their views still became norms. Opposing the Taliban are the powerful women who refuse to give up. Many have created undercover classrooms that are all run by volunteers, and work to educate the youth at the risk of being caught and facing consequences. Others have led media initiatives such as informative broadcasts, spread knowledge of their situations on social media, defied the Taliban through art and literature, etc. [30]

From a quick glance, the gains for women appeared to be major milestones; however, this was merely a facade as they were vulnerable due to the shifting objectives by external powers and failure to enforce new ideals in the minds of the Afghan people. The institutions built by the United States, as noted by government sources, were not fleshed out and did not account for the previously established Afghan identity within politics and social life. 9 billion dollars were used to help counteract terrorism and help security in the country, but the misuse of this money and the inability to enforce the practice made the mission within Afghanistan fleeting. Some acknowledged that due to these goals being short-term and money being thrown around, the United States added to the corruption and chaos within the country. [31] This can be better understood through a constructivist perspective, as the U.S. aimed to impose its own standards on a country already at risk. They did not account for the deeply enforced protocols of the Taliban, which had shaped the lives of people and therefore underestimated how difficult it would be to have complete reform within the country. They created an American-backed government, but it experienced corruption and could not do its job. They treated the country as a fresh start rather than a place with already established communities and expectations. There was a belief that Western political ideas could help through liberal intervention, and that practices such as capitalism, democracy, and rights would magically help the country. In the end, the local realities did not align with these goals, and therefore, internal turmoil was imminent. [32]

Conclusions

The fight for women's rights to become a universal principle remains both challenging and ongoing. As Afghanistan illustrates, progress can be swiftly undone when foundations for change are placed by external bodies and not rooted in local beliefs and culture. The U.S. attempted to establish its own model of government and leadership in Afghanistan, but when the foreign roots were withdrawn, Afghan society reverted to old patterns. There is a delicate balance struggle between international aid and maintaining the existing framework, which was not respected during the period of U.S. occupation. A veil of humanitarianism concealed a deeper intention of gaining moral acclaim in aiding a nation that international actors had defined as helpless.

The Taliban's violent practices and terrorism were one of many reasons the U.S. justified its intervention in 2021, but also led to their subsequent downfall in 2021 and reemergence of the Taliban. The failure to achieve lasting change underscores the persistence of deeply embedded social constructs which connects back to the theories of Feminist IR and Constructivism. Feminist IR, as we saw throughout the different stories created by external sources, were instruments for legitimizing intervention and political efforts without equality being of true value. The rhetoric of liberation was a tool to invoke support of the often violent methods to stop the Taliban or political turmoil within the country. Constructivism deepens this understanding by showing that even though the U.S. was able to make new policies and regulations to promote women's education, they were not able to alter the definitions of gender equality and who deserved to get an education. True lasting change, therefore, must come internally through Afghan-led governance and cultural integration without disregard for the years of standards that created an Afghan identity. Even though many women have been fighting for more rights, this push-back must extend and gain support. Culture can not be shifted unless the people living in Afghanistan have a part in it. Afghanistan continues to be a country facing extreme unrest, and women's rights are still taken away, but it is not the role of other countries to impose their own values and instead, they should be supporting these marginalized groups and collaborating to provide resources without detailing how situations should be handled. Practically, this can begin with the Afghan government investing in local schools in both urban and rural locations. At some point, it would hopefully expand to ensuring girls could safely access these centers of learning, receive scholarship funding, and for women to have a say in these policies. The end goal is that education be defined as a human right.

As Malala Yousafzai reminds us, "One child, one teacher, one book, one pen can change the world," cited from Malala Yousafzai's book I Am Malala: The Story of the Girl Who Stood Up for Education and Was Shot by the Taliban. [33] The potential for change lies in the hands of the strong Afghan women, who can continue to grow their minds. Everyone has a voice and should not be forced to keep quiet when they are not allowed to have this privilege of knowledge. There remains hope in the eyes of many Afghan women as they continue to teach and learn, quietly rebuilding a fractured nation from within.

Works Cited

Amnesty International. Afghanistan 2024. Amnesty International, 2024. https://www.amnesty.org/en/location/asia-and-the-pacific/south-asia/afghanistan/report-afghanista n/.

Amnesty International. Women in Afghanistan: The Violations Continue. 1997. https://www.amnesty.org/fr/wp-content/uploads/2021/06/asa110051997en.pdf.

Barr, Heather. "The Taliban and the Global Backlash against Women's Rights." Human Rights Watch, Georgetown Journal of International Affairs, February 6, 2024. https://www.hrw.org/news/2024/02/06/taliban-and-global-backlash-against-womens-rights.

Bhatia, Michael. "The Future of the Mujahideen: Legitimacy, Legacy and Demobilization in Post-Bonn Afghanistan." International Peacekeeping 14, no. 1 (2007): 90-107.

Council on Foreign Relations. "A Timeline of the U.S. War in Afghanistan." Council on Foreign Relations, 2021. https://www.cfr.org/timeline/us-war-afghanistan.

Fair Observer. Kabiri, Roya. "Afghan Women's Quiet Revolution against the Taliban." Fair Observer, May 2025. https://www.fairobserver.com/world-news/afghan-womens-quiet-revolution-against-the-taliban/.

Garaga, Nikhitha. "A Social Constructivist Analysis of the Afghanistan War." Political Science, March 28, 2024. https://www.colorado.edu/polisci/2024/03/28/social-constructivist-analysis-afghanistan-war.

Gall, Carlotta. "Threats and Responses: Education - Long in Dark, Afghan Women Say to Read Is Finally to See." The New York Times, September 22, 2002. https://www.nytimes.com/2002/09/22/world/threats-responses-education-long-dark-afghan-wome n-say-read-finally-see.htm.

Guardian Staff Reporter. "Life in Afghanistan on International Women's Day." The Guardian, March 8, 2011. https://www.theguardian.com/global-development/2011/mar/08/afghanistan-international-wo men s-day.

Human Rights Watch. Afghanistan: Humanity Denied - Systematic Violations of Women's Rights in Afghanistan. New York: Human Rights Watch, October 2001. https://www.hrw.org/reports/2001/afghan3/afgwrd1001.pdf.

Human Rights Watch. "Four Ways to Support Girls' Access to Education in Afghanistan." March 20, 2022. https://www.hrw.org/news/2022/03/20/four-ways-support-girls-access-education-afghanistan.

Senior Coordinator for International Women's Issues. "Women and Girls in Afghanistan." U.S. Department of State, March 10, 1998.

Special Inspector General for Afghanistan Reconstruction (SIGAR). What We Need to Learn: Lessons from Twenty Years of Afghanistan Reconstruction (SIGAR-21-46-LL). 2021. https://www.sigar.mil/pdf/lessonslearned/SIGAR-21-46-LL.pdf.

UNESCO. "Banned from Education: A Review of the Right to Education in Afghanistan." UNESCO.org, 2021. https://www.unesco.org/en/articles/banned-education-review-right-education-afghanistan.

United Nations Children's Fund (UNICEF). Consolidated Results Report - Afghanistan: Programme Cycle 2006-2008. Afghanistan: UNICEF, 2009. https://www.unicef.org/executiveboard/media/30051/file/2009-AS-Afghanistan-CRR.pdf.

United Nations Inter-Agency Gender Mission. Report of the Inter-Agency Gender Mission to Afghanistan. New York: United Nations, September 1997. https://www.un.org/womenwatch/afghanistan/documents/1997_IGMreport.pdf.

United Nations Office of the High Commissioner for Human Rights (OHCHR). "Afghanistan: UN Experts Say 20 Years of Progress for Women and Girls' Rights Erased Since Taliban Takeover." March 8, 2023. https://www.ohchr.org/en/press-releases/2023/03/afghanistan-un-experts-say-20-years-progress-w omen-and-girls-rights-erased.

UN Women. "Afghanistan's Women Are Still Fighting: Inside the Fight for Rights under Taliban." June 27, 2025. https://www.unwomen.org/en/news-stories/feature-story/2025/06/afghanistans-women-are-still-fi ghting-inside-the-fight-for-rights-under-taliban.

UN Women Asia and the Pacific. Fighting Erasure. July 2024. https://asiapacific.unwomen.org/sites/default/files/2024-09/af-c1116-fighting_erasure-2024.pdf.

U.S. Government. "U.S. Lessons Learned in Afghanistan." GovInfo.gov, January 15, 2020. https://www.govinfo.gov/content/pkg/CHRG-116hhrg38915/html/CHRG-116hhrg38915.htm.

World Bank. "Afghanistan Girls' Schools: Achieving Results in a Difficult Environment." February 25, 2010. https://www.worldbank.org/en/news/feature/2010/02/25/afghanistan-girls-schools-achieving-resu lts-in-a-difficult-environment.

Women in International Security (WIIS). "Afghan Women's Education under the Taliban." https://wiisglobal.org/afghan-womens-education-under-the-taliban/.

Yousafzai, Malala, and Christina Lamb. I Am Malala: The Story of the Girl Who Stood Up for Education and Was Shot by the Taliban. New York: Little, Brown and Company, 2013.

[1]Michael Bhatia, 'The Future of the Mujahideen: Legitimacy, Legacy and Demobilization in Post-Bonn Afghanistan', International Peacekeeping 14, no. 1 (2007): 90, 90.

[2] Senior Coordinator for International Women's Issues, "Women and Girls in Afghanistan", March 10, 1998.

[3] Ibid

[4] Ibid

[5] Human Rights Watch. 2001. "AFGHANISTAN HUMANITY DENIED Systematic Violations Women's Rights in Afghanistan."

https://www.hrw.org/reports/2001/afghan3/afgwrd1001.pdf.

6 "Amnesty International Women in Afghanistan: The Violations Continue." 1997. https://www.amnesty.org/fr/wp-content/uploads/2021/06/asa110051997en.pdf.

[7] Human Rights Watch. 2001. "AFGHANISTAN HUMANITY DENIED Systematic Violations of Women's Rights in Afghanistan." https://www.hrw.org/reports/2001/afghan3/afgwrd1001.pdf.

[8] United Nations Inter-Agency Gender Mission, Report of the Inter-Agency Gender Mission to Afghanistan (New York: United Nations, September 1997), https://www.un.org/womenwatch/afghanistan/documents/1997_IGMreport.pdf

[9] Council on Foreign Relations. 2021. "A Timeline of the U.S. War in Afghanistan." Council on Foreign Relations. Council on Foreign Relations. 2021. https://www.cfr.org/timeline/us-war-afghanistan.

[10] Ibid

[11] United Nations Inter-Agency Gender Mission, Report of the Inter-Agency Gender Mission to Afghanistan (New York: United Nations, September 1997), https://www.un.org/womenwatch/afghanistan/documents/1997_IGMreport.pdf

[12] Human Rights Watch. Afghanistan: Humanity Denied - Systematic Violations of Women's Rights in Afghanistan. New York: Human Rights Watch, October 2001. https://www.hrw.org/reports/2001/afghan3/afgwrd1001.pdf

[13] "Technical Difficulties." 2025. State.gov. 2025. https://www.state.gov/wp-content/uploads/2024/09/Report-6-Plans-to-Support-the-People-of-Afghanistan.

[14] World Bank, "Afghanistan Girls' Schools: Achieving Results in a Difficult Environment," February 25, 2010, https://www.worldbank.org/en/news/feature/2010/02/25/afghanistan-girls-schools-achieving-results-in-a-difficult-en vironment

[15] United Nations Children's Fund (UNICEF), Consolidated Results Report - Afghanistan: Programme Cycle 20026-2008 (Afghanistan: UNICEF, 2009), https://www.unicef.org/executiveboard/media/30051/file/2009-AS-Afghanistan-CRR.pdf

[16] Eva Sajoo, Education and Emergency: Women in post-2001 Afghanistan (Research Pu blication, Inter-Agency Network for Education in Emergencies (INEE), December 31, 2008), https://inee.org/sites/default/files/resources/Sajoo_Education_Emergency_Women_in_Post_2001_Afghanistan.pdf

[17] Carlotta Gall, "Threats and Responses: Education - Long in Dark, Afghan Women Say to Read Is Finally to See," The New York Times, September 22, 2002, https://www.nytimes.com/2002/09/22/world/threats-responses-education-long-dark-afghan-women-say-read-finally-s ee.htm

[18] Guardian staff reporter. 2011. "Life in Afghanistan on International Women's Day." The Guardian. The Guardian. March 8, 2011. https://www.theguardian.com/global-development/2011/mar/08/afghanistan-international-womens-day.

[19] Council on Foreign Relations. 2021. "A Timeline of the U.S. War in Afghanistan." Council on Foreign Relations. Council on Foreign Relations. 2021. https://www.cfr.org/timeline/us-war-afghanistan.

[20] UNESCO. 2021. "Banned from Education: A Review of the Right to Education in Afghanistan." Unesco.org. 2021. https://www.unesco.org/en/articles/banned-education-review-right-education-afghanist

[21] United Nations Office of the High Commissioner for Human Rights, "Afghanistan: UN Experts Say 20 Years of Progress for Women and GIrls' Rights Erased Since Taliban Takeover," March 8, 2023, https://www.ohchr.org/en/press-releases/2023/03/afghanistan-un-experts-say-20-years-progress-women-and-girls-rig hts-erased

[22] Amnesty International. 2024. "Afghanistan 2024." Amnesty International. Amnesty International. 2024. https://www.amnesty.org/en/location/asia-and-the-pacific/south-asia/afghanistan/report-afghanistan/.

[23] Barr, Heather. 2024. "The Taliban and the Global Backlash against Women's Rights." Human Rights Watch. Georgetown Journal of International Affairs. February 6, 2024. https://www.hrw.org/news/2024/02/06/taliban-and-global-backlash-against-womens-rights.

[24] UN Women, "Afghanistan's Women Are Still Fighting: Inside the Fight for Rights under Taliban," June 27 2025, https://www.unwomen.org/en/news-stories/feature-story/2025/06/afghanistans-women-are-still-fighting-inside-the-fi ght-for-rights-under-taliban

[25] Kabiri, Roya. 2025. "Afghan Women's Quiet Revolution against the Taliban." Fair Observer. May 2025. https://www.fairobserver.com/world-news/afghan-womens-quiet-revolution-against-the-taliban/.

26 "- U.S. LESSONS LEARNED in AFGHANISTAN." 2020. Www.govinfo.gov. January 15, 2020. https://www.govinfo.gov/content/pkg/CHRG-116hhrg38915/html/CHRG-116hhrg38915.htm.

[27] Garaga, Nikhitha. 2024. "A Social Constructivist Analysis of the Afghanistan War." Political Science. March 28, 2024. https://www.colorado.edu/polisci/2024/03/28/social-constructivist-analysis-afghanistan-war.

[28] UN Women Asia and the Pacific, Fighting Erasure (July 2024),

https://asiapacific.unwomen.org/sites/default/files/2024-09/af-c1116-fighting_erasure-2024.pdf

29 "Afghan Women's Education under the Taliban - WIIS | Women in International Security." n.d. https://wiisglobal.org/afghan-womens-education-under-the-taliban/.

[30] Human Rights Watch, "Four Ways to Support Girls' Access to Education in Afghanistan," March 20, 2022, https://www.hrw.org/news/2022/03/20/four-ways-support-girls-access-education-afghanistan

[31] Special Inspector General for Afghanistan Reconstruction (SIGAR), What We Need to Learn: Lessons from Twenty Years of Afghanistan Reconstruction (SIGAR-21-46-LL), 2021, https://www.sigar.mil/pdf/lessonslearned/SIGAR-21-46-LL.pdf

[32] Ibid

[33] Malala Yousafzai with Christina Lamb, I Am Malala: The Story of the Girl Who Stood Up for Education and Was Shot by the Taliban (New York: Little, Brown and Company, 2013)

Performing Ourselves: A Sociological Analysis of Power, Capital, and Control in Social Media Sociology By Ivan Hua

Abstract

Over the past decade, social media has evolved primarily from a communication tool into a sociological infrastructure, organizing identity, power, and hierarchy in contemporary society. We attempt to examine this transformation through multiple levels of analysis. At the micro level, social media platforms reshape identity by merging audiences into a single, curated "singularity," where authenticity is traded for performance catered to algorithms and audiences. At the meso level, social media redefines social hierarchies, where visibility is transformed into a new form of digital capital. Seemingly ordinary individuals such as TikTok creators or online investors can convert attention into status, wealth, and influence—illustrating Bourdieu's concept of capital conversion and Goffman's theory of performance. Finally, at the macro level, platforms can act as systems of governance, which we have seen through the incorporation of digital surveillance and algorithmic control, in ways that resemble Marx's critique of capitalism and Foucault's panopticism. Interestingly enough, these same infrastructures can also act to enable resistance, as seen in movements like #MeToo and #BlackLivesMatter, which highlights the roles played by social media. We conclude by acknowledging the challenges and future of social media, ranging from its effects on youth identity, mental health, and misinformation to emerging efforts toward regulation, design reform, and digital literacy. Drawing on the works of multiple theorists such as Goffman, Bourdieu, Foucault, and Baudrillard, we aim to analyze the shift in paradigm from social media as a reflection of society to one of its most powerful architects.

Introduction

Every day, millions of people scroll through their phones and watch strangers on TikTok shape their taste in music, sense of humor, and even political opinions, all without even realizing it. This is not a "side effect" of social media; in fact, it is its central function. Over the past two decades, social media platforms have transformed from a niche space that was primarily a mode of communication into an infrastructure that now shapes identity, power, and economics in life. What began as tools for sharing photos and updates now dictates how people present themselves, and to a greater extent, how societies exercise control. This paper explores four major characteristics of this transformation. First, it examines the growth and rise of social media, showing how platforms can become an integral part of daily life and rework society's basic rhythms. Second, it analyzes the shift in paradigm of identity and self-presentation, examining how platforms can gather audiences into a single space and pressure creators to maintain curated, marketable selves. Third, it considers the opportunities created in social mobility and hierarchies, highlighting how digital capital can create new pathways to visibility and control, from Insta influencers to meme-driven financial movements. Finally, it investigates the new forms of power, governance, and control created on the platforms, where misinformation, algorithmic manipulation, and digital labor exploitation can act as enablers of resistance and instruments of

surveillance. Together, these themes serve to elucidate why social media matters sociologically. Platforms are no longer neutral communication tools; they are environments where performance, capital, and control intersect. By incorporating theories from Goffman, Bourdieu, Foucault, Baudrillard, and others, we can observe how internet media is woven into modern society, shaping who we are, how we relate, and what truly holds power in the 21st century**.**

Topic 1: Growth and Rise of Social Media

The growth of social media is arguably one of the most significant transformations in modern-day history. Although early versions such as Friendster and MySpace clearly demonstrated the potential for digital networking, the explosive growth of the new-age platforms such as Facebook, Twitter, Instagram, and TikTok turned online webspaces into global infrastructures. By the late 2010s, billions of users were active across platforms, with some estimates suggesting over two-thirds of all internet users were participating in some form of social media (Our World in Data). Among younger generations, this was even more noticeable, with one source suggesting that over 90 percent of people aged 16 to 24 in many high-income countries used it daily. These trends support the growing shift from social media as a novelty into full acknowledgement of a deeply embedded part of everyday life.[30]

What makes this shift significant is not just the scale, but the continuously growing function. Social media is increasingly absorbing interactions that were once confined to distinct social spaces. Political activities, friendships, news, commerce, and even dating, to name a few, have all migrated online, restructured by the expanding reach of online platforms. Social hashtags like #MeToo and #BlackLivesMatter mobilized millions, showing how collective action could be organized through purely digital signals, rewriting the conventional wisdom of in-person unions or party meetings. At the same time, families, schools, and even intimate relationships began to rely on platforms as mediating infrastructures. Some digital sociology scholars have begun to endorse that social media has "reconstructed the basic appearance of social life" itself as the lines between private and public, personal and professional, began to blur and reshape expectations for visibility and participation.[31]

From a theoretical standpoint, we can see this transformation echoing earlier changes in mass media but on a new scale. While television and newspapers tend to centralize flows of information, platforms distribute it laterally, enabling billions to produce, curate, and circulate content. For example, Baudrillard's idea of "hyperreality" shows how signs and images online frequently don't correlate to material reality. Frequently, we see memes, viral content, and curated feeds from the platform algorithm shaping perception more than direct experience itself. Goffman's observations on "self-presentation" grow increasingly literal, as social media turns life itself into an everyday performance for unseen audiences. Bourdieu's theory of capital can

---

[30] Esteban Ortiz-Ospina, "The Rise of Social Media," *Our World in Data*, September 18, 2019, https://ourworldindata.org/rise-of-social-mediabegbegunun.

[31] Pete Fussey and Silke Roth, "Digitizing Sociology: Continuity and Change in the Internet Era," *Sociology* 54, no. 4 (2020): 659–74, https://doi.orredefinesg/10.1177/0038038520918562.

explain the concept of visibility as a currency; like any other accumulating resource, it can be converted into status or money. These theoretical frameworks work together to show how social media has evolved from a simple tool of communication to an entire infrastructure that continues to re-arrange the meaning of identity, community, and power.

Most importantly, the global adoption of social media signals a structural transformation in the way societies operate. Platforms have now become sites of "labor", as users generate data and content that companies can monetize, echoing Marx's concerns about exploitation. They can act as tools of authority, as states and corporations use digital tracing for surveillance, sorting, and control, containing aspects of Foucault's panopticism in new, datafied forms. And they can dually be used for resistance, where movements unite against inequality, yet at the cost of leaving behind exploitable records as digital footprints. Today, it is easy to see that social media does not simply reflect society, but acts to shape it, as it continues to work itself into the organization of everyday life and redefines the balance between freedom, power, and control in the digital age.

Topic 2: Identity and Self Presentation (Micro)

Erving Goffman argues in *The Presentation of Self in Everyday Life* (1959) that the concept of social life is built on performance. Individuals act like performers on a stage, presenting themselves differently to friends, parents, teachers, or strangers, depending on the setting and audience. This flexibility in presentation is no mistake; it is the normal way of managing social life. The ability for individuals to shift their tone, style, or even identity depending on context plays an important role in the way people manage impressions and relationships.[32] Social media, however, changes the conditions of this performance. Instead of allowing people to adapt to their distinct target audiences, platforms merge them into a singular domain that promotes the idea of continuous, curated content.

José van Dijck (2013) calls this merger the production of a curated singularity. Profiles on Facebook, LinkedIn, and Instagram encourage users to merge personal, professional, and branded selves into one single, cohesive identity often with the end goal of marketing. Facebook's Timeline shows life as one continuous biography, where milestones, photos, and posts are arranged to form a single narrative. LinkedIn similarly structures workers' resumes in an entrepreneurial format, where showcasing skills and endorsements unite to form a professional narrative. Logically, this would serve to benefit both advertisers and employers since these unified identities are easier to track and monetize.[33] Mark Zuckerberg articulated this exact ideology in 2010 when he claimed that "having two identities for yourself is an example of a lack of integrity." By rebranding ordinary role changes, such as joking with friends one way or

[32] Erving Goffman, "The Presentation of Self in Eworkers'veryday Life," in *Social Theory Re-Wired*, 3rd ed. (Routledge, 2023).
[33] José van Dijck, "'You Have One Identity': Performing the Self on Facebook and LinkedIn," *Media, Culture & Society* 35, no. 2 (2013): 199–215, https://doi.org/10.1177/0163443712468605.

respectfully addressing a boss in another, as dishonesty, he redefined authenticity as singularity.[34] Yet in reality, this has always been how people navigate social life.

Curated identities don't just stop at how users look online; they also reshape how they feel about themselves. Once one's self is organized into their continuous, presentable profile, it must be perpetually maintained and affirmed. This is where Bauman's concept of liquid modernity (via Murthy, 2012) comes into play. In a society packed with instability through jobs, relationships, and rapid readjustment, social media becomes a venue for personal validation. Even seemingly mundane posts, such as tweeting "I had one too many espresso shots today," serve as an assertion of identity. Such actions are not just an activity but a declaration: "I am here, I matter." The curated singularity needs constant attention, and regular posting can affirm for one and their following network that they are alive and present.[35]

The pressure to perform based on pre-set expectations is reinforced by curated algorithms that social media platforms employ. Arbitrary numbers such as likes, follower amount, and view count become metrics that shape how young people perceive themselves. It is far from uncommon to see teenagers scrolling their stories, checking their view count as an evaluation metric for how "popular" they are. Dopamine-driven feedback loops of posting and sharing can condition users to become hooked on self-promotion. Most algorithms reward oversharing by pushing individuals to judge and create their content based on measurable reactions. Authenticity is determined by numbers: a "casual" photo can only be considered authentic if a certain amount of engagement is reached. What starts as performance for a projected audience is quickly restructured into performance for an algorithmic one.

Research shows that this impact on youth identity is substantial.Vogel et al. (2014/2015) states that constant comparison on platforms like Facebook leads to lower self-esteem, particularly when users view profiles displaying high amounts of content.[36] Xie's (2024) work on beauty standards highlights how exposure to edited and filtered images reinforces unrealistic ideals, fueling body dissatisfaction, social anxiety, and a distorted sense of self. On platforms like Instagram and TikTok, feeds are populated with images that have been subtly, or sometimes heavily, altered through filters, editing apps, or recently AI alteration. For young users, repeated exposure to these perfect images redefines what feels "normal," making ordinary appearances seem inadequate by comparison. What begins as performance for attention soon morphs into a cycle of comparison. The "friends" we measure ourselves against are not our real peers but polished and idealized versions. This dangerous pressure is particularly sharp for adolescents,

---

[34] "Is Having Two Identities a Lack of Integrity? | TechLi," accessed September 28, 2025, https://www.techli.com/zuckerberg-doesnt-understand-identity-or-integrity/3354/amp/.
[35] Dhiraj Murthy, "Towards a Sociological Understanding of Social Media: Theorizing Twitter," *Sociology* 46, no. 6 (2012): 1059–73, https://doi.org/10.1177/0038038511422553.
[36] Erin A. Vogel et al., "Social Comparison, Social Media, and Self-Esteem," *Psychology of Popular Media Culture* (US) 3, no. 4 (2014): 206–22, https://doi.org/10.1037/ppm0000047.

who have an acute sensitivity to peer approval and are still forming stable conceptions of themselves.[37]

The consequences of the backstage vs frontstage dynamic are best seen in Essena O'Neill's 2015 Instagram exit. O' Neill was an Australian influencer with hundreds of thousands of followers who quit social media. Shortly afterwards, she revealed how her supposedly casual posts were all staged for likes and brand partnerships. Spontaneous beach photos and authentic "candid" moments came with confessions: she hadn't eaten all day to look thin, or it had taken hundreds of attempts to get the one posted photo that appeared effortless. O'Neill's revelations show how the pressure to perform perfectly for the constant gaze of audiences and algorithms. Potential moments of errors or candidness were locked away, hidden behind the curated singularity, as she strove to present her polished and profiled "real" self. Her story serves as a reminder that platform mechanics reward performances of authenticity over actual authenticity, where even moments of vulnerability are created into content.[38]

Xie's analysis and O'Neill's confessions demonstrate how self-presentation online is molded by powerful cultural and technological pressures. The number of likes, comments, and shares that posts receive magnifies beauty ideals by selecting which images deserve to be seen. At the same time, the popularity of social media makes it difficult to remove oneself from this vicious cycle without social cost. These dynamics exemplify how identities are not just curated and affirmed, but also how easily performance can be molded. As users feel compelled to create and post for others rather than themselves, their sense of authenticity and self-worth continue to diminish.

Topic 3: Social Structure and Hierarchies (Meso)

One of the most remarkable changes at the meso level is the effectiveness with which social media can reorganize social hierarchy. Before platforms existed, widespread recognition and respect were mainly reserved for those who achieved extraordinary things: world-class athletes, bestselling authors, renowned doctors, and famous political leaders. These were the figures drawing most of the attention, endorsements, and cultural sway from the widespread public for most of history. Social media, however, greatly reduces the barrier to visibility and provides new pathways to influence. In today's world, a teenager with no otherworldly talent beyond knowing the up-to-date trends can gather the symbolic capital that was once only able to be held by few.

In this respect, we can turn to Bourdieu's theories of capital to understand the lowered threshold of hierarchy that has been created. Social capital, once gauged by who you knew in

---

[37] Zijing Xie, "The Influence of Social Media on Perception of Body Image and Beauty Standards on Young People," *Transactions on Social Science, Education and Humanities Research* 5 (April 2024): 143–48, https://doi.org/10.62051/67rvhh97.

[38] Elle Hunt, "Essena O'Neill Quits Instagram Claiming Social Media 'Is Not Real Life,'" Media, *The Guardian*, November 3, 2015, https://www.theguardian.com/media/2015/nov/0the most attention, endorsements, and cultural authority from the 3/instagram-star-essena-oneill-quits-2d-life-to-reveal-true-story-behind-images.

your own community, now extends through follower networks and online visibility. Cultural capital, which used to be restricted to the domain of those with formal education in fine arts or classical works, is now redefined to include those with "meme" fluency and digital editing mastery. Symbolic capital, the recognition and legitimacy provided by institutions, is now represented as blue checkmarks, content-creator endorsement, and follower count. Academia in this field has now even begun to propose a new term: "digital capital," referring to a separate category that involves the reach and resources that decide who can thrive on platforms. The ability to perform capital conversion, where the visibility one accumulates can translate into prestige or new opportunities, is a metric that is growing increasingly central in meso-level groups.[39]

One person who illustrates this concept perfectly is Charli D'Amelio. For many months, she held the title of being the most-followed person on TikTok, with well over 100 million followers as a teenager. To the fascination, or disdain, of many, she produced mostly mundane content that many outsiders may have found curious how someone like her could become so popular. She did not set records or write books or even move politics forward; in fact, most of her videos involved performing viral dances to the latest pop music. However, the results spoke for themselves, and the sheer number of followers that she amassed quickly converted into symbolic and economic capital in the form of brand sponsorships, mainstream media appearances, and even her own reality show. So, to answer the million-dollar question proposed by critics, "Why is she famous?" The simple solution is how social media platforms reward consistency, timing, and visibility as forms of cultural capital, sometimes even in the absence of the standard signs of talent that were previously necessary.

D'Amelio's meteoric ascent also reveals how fame is becoming increasingly connected to platform architecture. As explained in *The New Yorker*, TikTok itself will regularly introduce new users to D'Amelio as a "safe" entry point into the app. Her accessible dance routines act as a good fit for the platform's algorithm, which tends to favor relatable content and repeated watch time. D'Amelio's understanding and mastery of TikTok's architecture allow her to flawlessly execute her performances. Each factor, including expressions, timing, and flow, makes her dances seem accessible, prompting millions of users to attempt to replicate her dances. One can argue that her symbolic capital was not organically accumulated but, in fact, engineered inherently by how TikTok's discovery feed operates. The ability to be relatable and ordinary was precisely what allowed her, by the logic of the platform, to be extraordinary.[40]

Another popular figure, Addison Rae, has also taken a similar journey but with her own distinct twist. Her ascent on TikTok, like D'Amelio, was based on performing trends rather than showcasing rare talents. However, she accumulated symbolic capital at an entirely different level

[39] Pierre Bourdieu, "The Forms of Capital," in *The Sociology of Economic Life*, 3rd ed. (Routledge, 2011).

[40] Cassidy George, "How Charli D'Amelio Became the Face of TikTok," Cultural Comment, *The New Yorker*, September 5, 2020, https://www.newyorker.com/culture/cultural-comment/how-charli-damelio-became-the-face-of-tiktok.

as she parlayed those opportunities into acting roles on Netflix, a Streamy Award, music collaborations, and lucrative brand deals. It is important to understand that these opportunities didn't stem from her acting or singing talent, but because of her celebrity status obtained by the platform itself. Here we can witness Bourdieu's theory of capital conversion in practice. The digital social capital of followers and engagement that Rae gained was converted into cultural and symbolic capital (celebrity legitimacy), which in turn led to economic capital of contracts and salaries. This conversion underscores the millions of creators who hope to follow a similar path, with social media offering another way to rise in social hierarchy.

Rae's success is also a reminder of the value of branding and charisma within social media. Although she was one of the earliest TikTokers to reach a million followers back in 2019, primarily through using trending sounds and viral dances like the "Renegade," she continued to sustain her popularity by connecting with viewers through authenticity and adaptability. Unlike other creators who focus on fancy equipment and flashy aesthetics, many of her videos are still filmed on her iPhone. Her content continues to remain accessible to her millions of viewers despite partnerships with stars like Charli. Rae has created a brand that prioritizes relatability without sacrificing glamour. In one video, she can be a singer; the next a dancer, influencer, or actor, all at once. This adaptable persona makes her a perfect example of the ways that symbolic capital can become augmented when tailored towards platform expectations and current pop culture references.[41]

The infrastructure of social media contributes to the undermining of older hierarchies that dictate who "deserves" influence in favor of systems where visibility itself serves as both a resource and a reward. D'Amelio and Rae did not require the approval of the ruling institutions, wealthy elites in society, or the traditional credentials of individuals in the past that were seen as legitimate. Rather, their influence is derived from their ability to fit into the platform's focus on relatibilty and branding, and then converting that currency into opportunities far beyond TikTok.

This reasoning also goes beyond platform celebrities, extending into the architecture of online influence on large groups of people. One textbook example involves the infamous WallStreetBets and the GameStop short squeeze as a meso-level power play. In January 2021, multiple members of the Reddit forum r/WallStreetBets collaborated on a widespread effort to drive up the stock price of GameStop (GME) shares, resulting in a short squeeze that led to hedge funds holding large amounts of short positions suffering major losses. At the height of the frenzy (around January 27), GME shares grew to over $300–$400 per share, a massive increase after hovering slightly under $20 for most of the month earlier. This incident, while mostly isolated, was a major shock to large institutions that were often in positions of control and marked by the sheer number of users that participated leading to resulting volatility.

This phenomenon was epitomized by Keith Gill. As a popular member of online communities, he had slowly accumulated a large amount of GME stocks starting around 2019, while openly posting his analysis and position updates on online forums. His social media posts

[41] "Who Is Addison Rae? And Why Is She So Popular?," Podcastle Blog, July 30, 2024, https://podcastle.ai/blog/who-is-addison-rae/.

and digital presence worked to bring together a large band of retail investors to act in concert, something that would be much harder to have coordinated in traditional in-person events. The resulting movement surprised both markets and regulators equally. Brokerages such as Robinhood and others temporarily limited the purchase of highly shorted stocks during the incident, sparking outrage and leading to inquiries in Congress.

The stock world has continued to change in many ways recently and with it, comes many lessons. First, this change shows us that digital communities with shared goals and interests can come together to disrupt conventional capital flows. The Gamestop incident was not the first example of this type of incident but it is widely believed to be the most public and widespread which revealed weakness in market architecture and the lack of transparency around clearinghouse requirements. The resulting panic and aftermath forced brokerages to re-examine their own risk controls and access policies. It also fostered conversation about who "owns" influence, revealing that those lower on the network hierarchy can at least temporarily warp the system while working together.[42]

Another significant example of evolving group dynamics is seen in the rise of Facebook. Originally meant as a way to digitize the "face books" handed out to students through documenting the university's social capital (who you knew, who you were friends with, who you were dating), it began quickly restructuring how students interacted. Campus hierarchies, which had once revolved around face-to-face networks such as clubs or Greek life or shared dormitories, began to take hold online. Students could now publicly broadcast identity, status, and connections, uniting different campus audiences together. When Facebook was first launched, the prestige provided by the Harvard name provided the symbolic capital needed to thrive. As the app itself grew more popular and other users from different universities began to make accounts on the platform, that capital was poured back into the broader university ecosystem where undergraduates could brand themselves anywhere, not just at Harvard.[43]

The mixing of institutional prestige and personal branding filters down to college sports as well. The creation of Name, Image, and Likeness (NIL) rights was a game changer in its own right for athletes. In the past, many of the best athletes forewent their senior year to turn pro, where most of the money and visibility were. It is not uncommon today, however, for some athletes to remain in college longer, with some even taking super senior years to grow their public profile and social media followings. Online fame through symbolic capital can now be converted to cash directly through sponsorships and endorsements, giving athletes an economic incentive to stay, whereas before they'd risk getting injured by staying and losing everything.

---

[42] "The GameStop Episode: What Happened and What Does It Mean?," Cato Institute, October 14, 2021,
hgame-changerttps://www.cato.org/cato-journal/fall-2021/gamestop-episode-what-happened-what-does-it-mean.

[43] Alexis C. Madrigal, "Before It Conquered the World, Facebook Conquered Harvard," Technology, *The Atlantic*, February 4, 2019,
https://www.theatlantic.com/technology/archive/2019/02/and-then-there-was-thefacebookcom/582004/.

This recasts the meso-level dynamics of college athletics. No longer is performance stats the only method for succeeding; charisma and likability through digital presence can be equally as important, if not more, for athletes who don't have a realistic chance of making it pro. In Bourdieu's terms, NIL rights are a fast track to capital conversion. How well you perform and are noticed (cultural capital), along with the name brand of your university's athletics (institutional capital), are directly converted into follower counts (social capital), which is then finally converted into economic capital through brand deals. The blueprint of success for college athletes is being redefined not just around those who play the best on the field but also for those who perform the best for the audiences on and off it.[44]

One final example of the meso-level domain is online dating, where social media is reconfiguring what intimacy truly involves. Apps such as Tinder, Bumble, and Hinge redefine how people make (and break) relationships by moving the dating scene from local networks to an algorithm-based market. Yet again, we can use the example of Bourdieu's capital to make sense of this pattern. Cultural capital is created through witty bios and artificial aesthetics that are cherry-picked. Social capital is accumulated through the number of matches and connections. Symbolic capital is shown through external markers such as educational prestige or job title. A hugely controversial feature, however, is the ability to subscribe or pay extra for premium features that apps suggest will lead to greater success.[45] Some data suggests that these apps have beneficial effects, such as increasing diversity by breaking down geographic and class boundaries that once limited dating circles.[46] However, it is clear that they also uphold hierarchies, as algorithms push forward the most "attractive" profiles based on engagement. Just like the broader economy, the dating market reflects the idea that visibility is currency. Those who have more of it will get seen first, be able to choose from more, and will be overall more valued and prioritized.

Topic 4: Power, Governance, and Control (Macro)

At the highest level, social media platforms function as systems of governance. Not only do they offer forums for mass communication, they also define the conditions of what becomes truth through visibility. Not unlike states or bureaucracies themselves, one could argue they are just as important centrally in deciding the rules that shape society. The power of these systems is most visible through the manipulation of data for political acts, as algorithms silently condition what becomes visible and what does not by allowing the spread of misinformation. Sociology

---

[44] "Beyond the Field: New Research Highlights How NIL Is Reshaping College Athlete Identity," July 29, 2025, https://news.ufl.edu/2025/07/college-athletes-roles-and-identities/.

[45] Jo Barraket and Millsom S. Henry-Waring, "Getting It on(Line): Sociological Perspectives on e-Dating," *Journal of Sociology* 44, no. 2 (2008): 149–65, https://doi.org/10.1177/1440783308089167.

[46] "Research Shows Dating Apps, Sites Are Leading to More Diverse Couples," UNM UCAM Newsroom, accessed September 28, 2025, https://news.unm.edu/news/research-shows-dating-apps-sites-are-leading-to-more-diverse-couples.

provides us with the theoretical framework to trace this development to deeper systematic traditions, which help us see how platforms assemble entertainment, work, and surveillance into a new form of order.

The concept of hyperreality, articulated by Jean Baudrillard, captures one of the most important aspects of this order. In the state of hyperreality, representations switch from the representing the state of reality to becoming reality itself. Signs and images that would normally be separate from the material world take on an existence of their own. We can see this trend particularly on social media platforms suchTikTok. The algorithm rewards engagement over accuracy, and content that is sensationalized, often misinformation, quickly becomes more popular than factual but "boring" reporting. Clickbait works because of the inherent nature of social media platforms: Success is measured not based on factual verification but view count and replay rates. Internal studies of TikTok illustrate how quickly user feeds will narrow to a few curated interests and lock them into almost homogenous videos with self-confirming principles. We can see in this instance how platforms are not just reflecting a person's interests, they activately work to create new realities where false information is more widely shared than truth. The popular parody media account NBACentel rose to prominence over displaying false breaking news or stories that would even fool real players and prominent sports media personalities, something that would become a central and even expected theme of the account. Hyperreality is not just a foreign concept; it is seen everyday when people scroll through their normal feeds, where a viral post or meme regardless of the truth is seen as more convincing than direct experience.[47]

While hyperreality can explain the distortion of truth from bad actors, the Cambridge Analytica scandal shows how powerful data can be and the influence that can be obtained through its use. In this instance, private information on Facebook was collected and sold to political campaigns that were then able to custom tailor ads to targeted voters. Sociologically speaking, the impact is less about the morally gray use of data, but rather a prime example of how social media infrastructures can transform our routine digital footprints into tools of governance. The commodification of social life, through the transformation of friendships or personal preference, into data products becomes yet another way that parties can exert political influence during elections. Contrary to pre-social media times, control does not need to be through in-person persuasion at large political rallies. Now, any politician can use online data sets to monitor and influence populations using their own behavioral patterns.[48]

---

[47] Andy McLaverty-Robinson, "Jean Baudrillard: The Masses," *Ceasefire Magazine*, October 25, 2012, https://ceasefiremagazine.co.uk/in-theory-baudrillard-12/.

[48] Carole Cadwalladr and Emma Graham-Harrison, "Revealed: 50 Million Facebook Profiles Harvested for Cambridge Analytica in Major Data Breach," News, *The Guardian*, March 17, 2018, https://www.theguardian.com/news/2018/mar/17/cambridge-analytica-facebook-influence-us-election.

Max Weber defined bureaucracy as domination by rules and regulations that is characterized by depersonalized and calculated decision making.[49] Many platform algorithms function in a similar manner. From TikTok's For You Page to Instagram's Explore tab, social media determines visiblity by using watch time and replay engagement as primary criteria. While the process itself isn't entirely clear to those outside of the social engineers within the companies, it is clear that each algorithm produces clear winners and losers through algorithmic feeds.[50] A study of the 2024 U.S. presidential race found that TikTok disproportionately recommended Republican content.[51] If visibility is power, then logically we can deduce that these algorithms can skew political discourse with no public accountability, a dangerous precedent to be set. In Weber's terms, this is now bureaucracy, but only this time without a trail. The result is an algorithm that can make consequential decisions through hidden methods that no one can argue with. The feeling of randomness between viral content or unnoticed ones is what creators describe as the experience of algorithmic domination.[52]

Despite this unequal range of outcomes, many nonetheless continue to participate eagerly in this system in hopes of becoming the next viral creator. Karl Marx's theory of alienation and exploitation, the idea that capitalism separates workers from the products of their labor while the owners of capital unfairly profit, helps explain this phenomenon.[53] On social media, the forces at play are slightly different but the principle is nonetheless similar. Creators generate enormous amounts of content and data, often through their own cost, while platforms capture all the profits through advertisements and data mining. P.J. Rey dubs this "playboy," a combination of play and labor where exploitation is concealed by the apparent enjoyment involved. Influencers illustrate this idea clearly. They work countless hours, unpaid, to generate content that allow them to reach monetization requirements all while their income is at the mercy of algorithmic changes they have no control over.[54] The birth of nonplayer character (NPC) streaming shows this dynamic: streamers perform canned responses to digital "gifts" in return for donations. What appears to be casual fun to viewers is actually an intensely regulated system of production, driven by the platform's tipping mechanics and ranking system.[55]

---

[49] Christian Fuchs, "Power in the Age of Social Media," *Heathwood Journal of Critical Theory* 1, no. 1 (2015): 1–29.
[50] Fabian Baumann et al., "Dynamics of Algorithmic Content Amplification on TikTok," arXiv:2503.20231, preprint, arXiv, March 26, 2025, https://doi.org/10.48550/arXiv.2503.20231.
[51] Hazem Ibrahim et al., "TikTok's Recommendations Skewed towards Republican Content during the 2024 U.S. Presidential Race," arXiv:2501.17831, preprint, arXiv, May 7, 2025, https://doi.org/10.48550/arXiv.2501.17831.
[52] Fuchs, "Power in the Age of Social Media."
[53] "Alienation: A Theoretical Overview," accessed September 18, 2025, https://pjpr.scione.com/cms/abstract.php?id=547.
[54] Murthy, "Towards a Sociological Understanding of Social Media."
[55] Gene Park, "Analysis | Why TikTokers Are Pretending to Be Robots and Saying 'Ice Cream so Good,'" *The Washington Post*, July 17, 2023, https://www.washingtonpost.com/arts-entertainment/2023/07/17/npc-pinkydoll-tiktok-live-streaming-robot/.

The theory of surveillance and discipline developed by Michel Foucault elucidates how such governance can penetrate into everyday conduct. In his model of the panopticon, individuals will police themselves, convinced that they're under watch. It's worth noting that social media takes this to the extreme by making this dynamic constant at all times. All of your posts become public and permanent, searchable, and often monitored by universities, employers, or governments. The classic saying "The Internet never forgets," highlights this as any digital footprint can conceivably be archiveable forever. Accordingly, people begin to censor themselves, often trading authenticity for safer versions of their lives.[56] The stakes are even higher for activists, who need to worry about searchable records that authorities can track. Movements like BLM, Me Too, and MilkTeaAlliance united millions across the nation, but the same visibility that social media augmented for them also made it easier for retaliation by government authorities. In this way, social media simultaneously amplifies and restricts by enabling resistance, while simultaneously exposing it to surveillance and prohibiting effective concealment.

Johan Galtung's framework of violence illuminates these damages further. Direct violence occurs when protestors are arrested due to the content in their own posts. Structural violence shows up when algorithms suppress marginalized individuals and content, creating inequalities in visibility. Cultural violence occurs when hate speech and stereotypes become so prevalent in feeds that they begin to feel normal, artificially creating prejudice into everyday digital life. These forms of violence reveal that platforms don't just host communication; instead, they actively shape the conditions that can lead to harm occurring.[57]

Finally, Christian Fuchs argues that power on social media is dialectical: it always has both domination and resistance. Social justice movements now have new tools for mobilization, but those same tools also expand the capability for surveillance through the corporations and the state. The very systems that amplify each social movement also log them, transforming the collective voice into a series of data points that can be later exploited. At the macro level of social media, we see this existing dichotomy between empowerment and constraint.

Altogether, these cases and theories demonstrate that platforms cannot be considered neutral tools, but rather infrastructures of governance. They produce hyperreal environments in which fiction outpaces fact, convert personal information into political power, and determine visibility through algorithmic rule. Simultaneously, they police behavior through surveillance and replicate violence in structural and cultural manifestations. As we have seen multiple times, social media is not simply communication technology anymore. It is a system of power that works to liberate and imprison by expanding the realm of what freedom truly means, even as it creates new oversight and constraints.

---

[56] Fuchs, "Power in the Age of Social Media."
[57] Desmond Upton Patton et al., "Social Media as a Vector for Youth Violence: A Review of the Literature," *Computers in Human Behavior* 35 (June 2014): 548–53, https://doi.org/10.1016/j.chb.2014.02.043.

Topic 5: Challenges, Solutions, and Future Trajectories

As social media approaches its third decade of dominance since arriving into the mainstream, it faces a multitude of challenges. Researchers and public officials have begin to issue warnings over the mental health effects, especially among the younger generation as usage is almost ubiquitous amongst 13–17 year-olds and nearly one-third say they are online "almost constantly". Heavy users, defined as three or more hours of use in a day, are twice as likely to have depression and anxiety symptoms, according to some studies. Almost half of teens have also reported that social media makes them feel worse about their body image.[58] At the societal level, whistleblowers warn that these platforms feed misinformation and intensify political polarization. In 2021, Facebook's very own ex-employee Frances Haugen testified that the company "puts astronomical profits before people" claiming that it would harm children and undermine democracies. Internal documents also endorsed that algorithms had made platform content more divisive and that Facebook knew Instagram was "like cigarettes" for teen girls' self-esteem.[59] Meanwhile, social media companies continue to profit from users' unpaid labor ("playbor"), and new forms of digital exploitation continue to arise, from influencers competing over algorithmic visibility to viral live streamers performing repetitive NPC actions for tips. These challenges highlight that the social media ecosystem, as it stands, often rewards negative behaviour by fueling extreme content, encouraging constant performance, and monetizing personal data, all while being relatively free from consequences.[60]

As these challenges continue to arise, many have called on policymakers to take action. Governments have begun to respond, as advocates recommend regulation of Big Tech in a similar manner to other industries of public concern. Some have argued that Facebook should be "treated like the tobacco industry" and subject to government oversight after publication of its negative effects were revealed. In testimony by Haugen , she and other lawmakers advocated for transparency mandates that would force companies to disclose their algorithms and data publicly. As a result of mounting pressure, policymakers in the U.S. and around the world are considering tighter rules on data privacy, especially involving protections from minors. Europe's Digital Services Act, as one recent example, will require large platforms to identify risks such as disinformation and algorithm manipulation, and take actions to mitigate them. Social media companies themselves, facing public pressure, have implemented initial changes meant to

---

[58] Office of the Surgeon General, "Social Media and Youth Mental Health," Page, May 28, 2024, https://www.hhs.gov/surgeongeneral/reports-and-publications/youth-mental-health/social-media/index.html.

[59] Dan Milmo and Kari Paul, "Facebook Harms Children and Is Damaging Democracy, Claims Whistleblower," Technology, *The Guardian*, October 6, 2021, https://www.theguardian.com/technology/2021/oct/05/facebook-harms-children-damaging-democracy-claims-whistleblower.

[60] Gene Park, "Analysis | Why TikTokers Are Pretending to Be Robots and Saying 'Ice Cream so Good,'" *The Washington Post*, July 17, 2023, https://www.washingtonpost.com/arts-entertainment/2023/07/17/npc-pinkydoll-tiktok-live-streaming-robot/.

combat these problems. Instagram and TikTok have currently added warnings after detecting length of usage to curb endless scrolling. TikTok has even considered adding default time limits upon account creation for teen users in 2023.[61] Privacy pushback is also becoming increasingly more common. Many Gen Z users tend to have more privacy settings enabled than millennials, by setting their accounts to private mode or not posting at all to avoid any dangers associated with visibility. Ironically, the most fluent generation with social media is leading a backlash to the idea of "sharing everything." So it is no surprise that when Meta released camera-equipped smart glasses, many of the younger generation flooded the news pages with outrage over the perceived lack of consent while recording, forcing executives to reconsider the debate on social boundaries. As one expert noted, due to countless stories told of the dangers of visibility and permanence on social media, Gen Z has "been forced to give extra thought to their digital footprints," so it isn't shocking that they inherently would reject constant surveillance. This pushback is essentially an informal social regulation: new norms and rules are developing from users themselves in the name of privacy and balance.[62]

To address the multi-dimensional problems of social media, solutions will need to be just as multi-dimensional. Firstly, governments can begin to regulate social media transparency standards more closely and enforce strict policy guidelines to improve safety. As an example, some lawmakers have suggested regular audits of algorithms similar to health codes or classifying platforms as publishers to hold them liable for misinformation. Next, platforms can begin to redesign their interface and structure to focus on ethical practices regarding engagement. Currently while algorithms reward "shock factor" and "clickbait" content, a proposed solution would be to put more weight on verified information within. Even small changes such as Twitter's new fact check is one step towards promoting design that can reduce the negative effects social media brings. Lastly, as schools and communities began to incorporate social media habits and online media literacy into their curriculum, moving towards standardization so that children and parents can begin to understand the dangers is crucial. Many digital advisory practices encourage "device-free" times for developing children and encourage protective measures for healthy social media use.

The future of social media will likely contain both exciting innovations and new dilemmas. While people commonly refer to space as the last unexplored frontier, one could argue that the rise of new technologies is just as unexplored. The development of the metaverse concept where social media can converge with virtual reality has been advertised by many companies as the next evolution of the digital age. Supporters contend that this continues to

---

[61] Dan Milmo and Kari Paul, "Facebook Harms Children and Is Damaging Democracy, Claims Whistleblower," Technology, *The Guardian*, October 6, 2021, https://www.theguardian.com/technology/2021/oct/05/facebook-harms-children-damaging-democracy-claims-whistleblower.

[62] Tatum Hunter, "Smart Glasses Record People in Public. The Most Online Generation Is Pushing Back.," *The Washington Post*, August 27, 2025, https://www.washingtonpost.com/technology/2025/08/27/gen-z-smart-glasses-digital-privacy-consent/.

improve connections across the globe, for example, as new virtual concerts with friends across the country or even the world enjoying the same experience all at once. In fact, platforms like VRChat and Meta's Horizon Worlds already let users interact together in virtual 3D spaces, further reducing the barriers that once limited socialization. Early evidence suggests these virtual spaces can fulfill social needs in novel ways. During the COVID-19 lockdowns, for instance, some isolated people found community in social VR events.[63] Participants in one study said putting on a headset and mingling in AltspaceVR felt so real that *"when I take the headset off it kind of feels like I left my house and went out and did something"*, a powerful antidote to loneliness.[64] Such experiences hint at a future where digital interactions become ever more lifelike, allowing people to *"meet"* and explore together in rich simulated worlds. Crucially, these virtual gatherings can be far more accessible and affordable than physical travel or events – attending a VR conference or class costs vastly less than flying to another city, potentially democratizing access to knowledge and social capital. The promise of cheaper, borderless social experiences is thus real. A college student in a rural town can put on VR goggles and instantly join a study group or a party on a virtual tropical island, transcending what their offline environment offers.

However, the path to this futuristic vision is not smooth, and it raises sociological questions of its own. So far, the grandest metaverse ambitions have outpaced reality. After Facebook's high-profile rebranding to "Meta" in 2021 and billions were invested, its flagship Horizon Worlds struggled to attract even 200,000 monthly users out of Facebook's 3+ billion base. Niche gaming worlds like Roblox, Fortnite, and Decentraland have passionate followings, but remain unconnected. Analysts note that hype has cooled and one CEO even remarked that the metaverse went from an *"inevitable digital frontier"* to a "niche, experimental space with uncertain viability", after consumers largely failed to show up despite companies "throwing billions" at it. Currently, there are numerous barriers for virtual reality to truly replace the current social networks including high costs, technical limitations, and the simple fact that users tend to shy away from change.[65] Additionally, there remains the large concern that linking social media to any sort of virtual or augmented reality will only increase privacy and surveillance concerns in unprecedented ways. AR glasses that can secretly record on everyday surroundings reduce the boundary between public and private space. We have already seen examples of this possible backlash in Google Glass, which indicates growing public resistance to the idea of constant monitoring, no matter how beneficial the idea may be. Navigating these boundaries very

---

[63] "The Intersection of Social Media and Virtual Reality: Future Trends," Multipost Digital, accessed October 10, 2025, https://www.multipostdigital.com/blog/nllm9vsl1tlm8yn8e0r83rwp5rndt3.

[64] Keith Kenyon et al., "Social Virtual Reality Helps to Reduce Feelings of Loneliness and Social Anxiety during the Covid-19 Pandemic," *Scientific Reports* 13, no. 1 (2023): 19282, https://doi.org/10.1038/s41598-023-46494-1.

[65] "What Happened to the Metaverse?," CRM Magazine, February 28, 2025, https://www.destinationcrm.com/Articles/ReadArticle.aspx?ArticleID=168177.

carefully in order to maintain public trust will be crucial to advancing the future of immersive social media.

Despite the potential it holds, artificial intelligence continues to be a double-edged technology. On one hand, newer models allow for entirely automated content creation and editing, but on the other, lead to the widespread creation of fake or manipulative content. The rise of *deepfakes* exemplifies the problems that AI creators face. In 2022, during Russia's invasion of Ukraine, an AI created video briefly circulated showing President Zelensky urging surrender to his people. While it was quickly debunked as fake and removed, experts warn that next-generation AI creations will be even more convincing and harder to spot, thereby increasing the potential of social media feeds full of misinformation. Unless detection tools and public awareness continues to grow, we could be facing a large threat of the lines between reality and artificial content completely collapsing. For a positive change however, AI-driven platforms could give rise to new, creative abilities that users can take advantage of, such as personal AI avatars that interact with us based on our preferences or custom algorithms that auto-generate music and art that we enjoy. Such possibilities continue to blur the distinction between human and machine creations on social platforms, raising important questions about authenticity and trust we give to these.[66]

Finally, we may witness a shift in the current landscape of social media allocation. The era of a few giant, centralized platforms could give way to a more decentralized network of communities. Already, dissatisfaction with mainstream platforms' algorithms and policies has fueled the growth of alternatives like Mastodon (part of the federated "fediverse") and various niche networks. These decentralized or community-owned platforms seek to return power to users, letting them control content moderation and data. They align with a utopian vision of digital public spaces free from corporate control. Whether these can grow beyond niche audiences remains to be seen, but they represent an important *experimentation* in how social life online could be organized differently. Even within big platforms, private group chats and ephemeral messaging (Snapchat, WhatsApp, Discord servers) have surged, suggesting many users prefer smaller-scale intimacy over the open broadcast model of the past. In sum, the next chapter of social media could be more fragmented – a patchwork of immersive worlds, AI-driven interactions, and community micro-networks – or, alternatively, see new dominant players emerge from the pack.

Conclusion

Two decades ago, it would have been hard to fathom that a handful of casual sites used for photo sharing and college socializing would have grown into massive multimedia corporations that shape society itself. Yet as this paper has shown, social media platforms have evolved into full-blown infrastructures that play an enormous role in how we live, think, and

[66] Tom Simonite, "A Zelensky Deepfake Was Quickly Defeated. The Next One Might Not Be," Tags, *Wired*, n.d., accessed October 10, 2025, https://www.wired.com/story/zelensky-deepfake-facebook-twitter-playbook/.

connect with one another. They have reshaped the micro level of identity, turning the performance of self into a constant act that is fine tuned for both audience and algorithm. They have redrafted meso-level social structures by producing new hierarchies of influence where digital capital can launch an average individual to celebrity status or bring together online communities to majorly shift financial markets. And at the macro scale, they have collected new forms of power by obscuring reality through the lens of hyperrealness, allowing for surveillance and manipulation on a mass scale, but also producing new tools for resistance and social change. This interaction of performance, capital, and control across these platforms makes it clear that social media is no longer a neutral reflection of society; it is an active force for change where power is continuously being redistributed.

Sociologically, what makes this subject so important is the paradoxical character of these transformations. We have seen the multiple benefits that social media can give rise to, from allowing a voice to the marginalized to connecting loved ones across long distances. Similarly, we have also witnessed the downsides of dominance from it that can obscure the intended purpose, such as capitalizing on profit from unpaid digital labor and extending the surveillance ability from the state. As theorist Christian Fuchs writes, digital platforms exemplify "a dialectic of empowerment and control, liberation and domination," often simultaneously.[67] The challenge for this upcoming generation is to be able to make use of the positive potential of these technologies while minimizing the collateral damage that can occur. This will likely require a collective effort on multiple fronts, as the platforms themselves can strive to adhere to digital ethics while the government provides counsel and oversight that keep pace with the growing innovations in Silicon Valley. The future of social media is still very much determined by the actions we can take in the present. Whether it harnesses the vast benefits that can be provided or deepens the shortcomings that we've identified in the paper will depend on how well society can grasp these forces at work and how boldly we decide to act on that knowledge. Ultimately, the story of social media is the story of us in the 21st century. We alone can decide how we perform, connect, and decide which sort of communities we want to build for ourselves as the world around us moves forward.

[67] Milmo and Paul, "Facebook Harms Children and Is Damaging Democracy, Claims Whistleblower," October 6, 2021.

Works Cited

"Alienation: A Theoretical Overview." Accessed September 18, 2025. https://pjpr.scione.com/cms/abstract.php?id=547.

Barraket, Jo, and Millsom S. Henry-Waring. "Getting It on(Line): Sociological Perspectives on e-Dating." Journal of Sociology 44, no. 2 (2008): 149–65. https://doi.org/10.1177/1440783308089167.

Baumann, Fabian, Nipun Arora, Iyad Rahwan, and Agnieszka Czaplicka. "Dynamics of Algorithmic Content Amplification on TikTok." arXiv:2503.20231. Preprint, arXiv, March 26, 2025. https://doi.org/10.48550/arXiv.2503.20231.

"Beyond the Field: New Research Highlights How NIL Is Reshaping College Athlete Identity." July 29, 2025. https://news.ufl.edu/2025/07/college-athletes-roles-and-identities/.

Bourdieu, Pierre. "The Forms of Capital." In The Sociology of Economic Life, 3rd ed. Routledge, 2011.

Cadwalladr, Carole, and Emma Graham-Harrison. "Revealed: 50 Million Facebook Profiles Harvested for Cambridge Analytica in Major Data Breach." News. The Guardian, March 17, 2018. https://www.theguardian.com/news/2018/mar/17/cambridge-analytica-facebook-influence-us-election.

Cato Institute. "The GameStop Episode: What Happened and What Does It Mean?" October 14, 2021. https://www.cato.org/cato-journal/fall-2021/gamestop-episode-what-happened-what-does-it-mean.

CRM Magazine. "What Happened to the Metaverse?" February 28, 2025. https://www.destinationcrm.com/Articles/ReadArticle.aspx?ArticleID=168177.

Dijck, José van. "'You Have One Identity': Performing the Self on Facebook and LinkedIn." Media, Culture & Society 35, no. 2 (2013): 199–215. https://doi.org/10.1177/0163443712468605.

Fuchs, Christian. "Power in the Age of Social Media." Heathwood Journal of Critical Theory 1, no. 1 (2015): 1–29.

Fussey, Pete, and Silke Roth. "Digitizing Sociology: Continuity and Change in the Internet Era." Sociology 54, no. 4 (2020): 659–74. https://doi.org/10.1177/0038038520918562.

General, Office of the Surgeon. "Social Media and Youth Mental Health." Page. May 28, 2024. https://www.hhs.gov/surgeongeneral/reports-and-publications/youth-mental-health/social-media/index.html.

George, Cassidy. "How Charli D'Amelio Became the Face of TikTok." Cultural Comment. The New Yorker, September 5, 2020. https://www.newyorker.com/culture/cultural-comment/how-charli-damelio-became-the-face-of-tiktok.

Goffman, Erving. "The Presentation of Self in Everyday Life." In Social Theory Re-Wired, 3rd ed. Routledge, 2023.

Hunt, Elle. “Essena O’Neill Quits Instagram Claiming Social Media ‘Is Not Real Life.’” Media. The Guardian, November 3, 2015. https://www.theguardian.com/media/2015/nov/03/instagram-star-essena-oneill-quits-2d-life-to-reveal-true-story-behind-images.

Hunter, Tatum. “Smart Glasses Record People in Public. The Most Online Generation Is Pushing Back.” The Washington Post, August 27, 2025. https://www.washingtonpost.com/technology/2025/08/27/gen-z-smart-glasses-digital-privacy-consent/.

Ibrahim, Hazem, HyunSeok Daniel Jang, Nouar Aldahoul, Aaron R. Kaufman, Talal Rahwan, and Yasir Zaki. “TikTok’s Recommendations Skewed towards Republican Content during the 2024 U.S. Presidential Race.” arXiv:2501.17831. Preprint, arXiv, May 7, 2025. https://doi.org/10.48550/arXiv.2501.17831.

“Is Having Two Identities a Lack of Integrity? | TechLi.” Accessed September 28, 2025. https://www.techli.com/zuckerberg-doesnt-understand-identity-or-integrity/3354/amp/.

Kenyon, Keith, Vitalia Kinakh, and Jacqui Harrison. “Social Virtual Reality Helps to Reduce Feelings of Loneliness and Social Anxiety during the Covid-19 Pandemic.” Scientific Reports 13, no. 1 (2023): 19282. https://doi.org/10.1038/s41598-023-46494-1.

Madrigal, Alexis C. “Before It Conquered the World, Facebook Conquered Harvard.” Technology. The Atlantic, February 4, 2019. https://www.theatlantic.com/technology/archive/2019/02/and-then-there-was-thefacebook com/582004/.

McLaverty-Robinson, Andy. “Jean Baudrillard: The Masses.” Ceasefire Magazine, October 25, 2012. https://ceasefiremagazine.co.uk/in-theory-baudrillard-12/.

Milmo, Dan, and Kari Paul. “Facebook Harms Children and Is Damaging Democracy, Claims Whistleblower.” Technology. The Guardian, October 6, 2021. https://www.theguardian.com/technology/2021/oct/05/facebook-harms-children-damaging-democracy-claims-whistleblower.

Milmo, Dan, and Kari Paul. “Facebook Harms Children and Is Damaging Democracy, Claims Whistleblower.” Technology. The Guardian, October 6, 2021. https://www.theguardian.com/technology/2021/oct/05/facebook-harms-children-damaging-democracy-claims-whistleblower.

Multipost Digital. “The Intersection of Social Media and Virtual Reality: Future Trends.” Accessed October 10, 2025. https://www.multipostdigital.com/blog/nllm9vsl1tlm8yn8e0r83rwp5rndt3.

Murthy, Dhiraj. “Towards a Sociological Understanding of Social Media: Theorizing Twitter.” Sociology 46, no. 6 (2012): 1059–73. https://doi.org/10.1177/0038038511422553.

Ortiz-Ospina, Esteban. “The Rise of Social Media.” Our World in Data, September 18, 2019. https://ourworldindata.org/rise-of-social-media.

Park, Gene. “Analysis | Why TikTokers Are Pretending to Be Robots and Saying ‘Ice Cream so Good.’” The Washington Post, July 17, 2023.

https://www.washingtonpost.com/arts-entertainment/2023/07/17/npc-pinkydoll-tiktok-live-streaming-robot/.

Park, Gene. “Analysis | Why TikTokers Are Pretending to Be Robots and Saying ‘Ice Cream so Good.’” The Washington Post, July 17, 2023. https://www.washingtonpost.com/arts-entertainment/2023/07/17/npc-pinkydoll-tiktok-live-streaming-robot/.

Patton, Desmond Upton, Jun Sung Hong, Megan Ranney, et al. “Social Media as a Vector for Youth Violence: A Review of the Literature.” Computers in Human Behavior 35 (June 2014): 548–53. https://doi.org/10.1016/j.chb.2014.02.043.

Podcastle Blog. “Who Is Addison Rae? And Why Is She So Popular?” July 30, 2024. https://podcastle.ai/blog/who-is-addison-rae/.

Simonite, Tom. “A Zelensky Deepfake Was Quickly Defeated. The Next One Might Not Be.” Tags. Wired, n.d. Accessed October 10, 2025. https://www.wired.com/story/zelensky-deepfake-facebook-twitter-playbook/.

UNM UCAM Newsroom. “Research Shows Dating Apps, Sites Are Leading to More Diverse Couples.” Accessed September 28, 2025. https://news.unm.edu/news/research-shows-dating-apps-sites-are-leading-to-more-diverse-couples.

Vogel, Erin A., Jason P. Rose, Lindsay R. Roberts, and Katheryn Eckles. “Social Comparison, Social Media, and Self-Esteem.” Psychology of Popular Media Culture (US) 3, no. 4 (2014): 206–22. https://doi.org/10.1037/ppm0000047.

Xie, Zijing. “The Influence of Social Media on Perception of Body Image and Beauty Standards on Young People.” Transactions on Social Science, Education and Humanities Research 5 (April 2024): 143–48. https://doi.org/10.62051/67rvhh97.

How Hazardous Chemicals Present in Low-Cost Products from Popular Chinese Online Commerce Shops Can Affect Human Health By Steve Kim

Abstract

Globally, Chinese e-commerce companies such as AliExpress, Shein, and Temu are rapidly expanding their popularity. This paper identifies hazardous chemicals – phthalates, formaldehyde, lead, and cadmium – in low-cost products from Chinese e-commerce and examines their potential effects on the human body. It will focus on testing clothing, toys, and household items to assess the presence and levels of harmful substances such as phthalates, lead, formaldehyde, and cadmium. The study will compare the results to international safety standards to determine whether these products comply with health and safety regulations. The goal is to highlight short-term and long-term health risks these chemicals may pose to consumers. Ultimately, the findings will help inform both consumers and policymakers about the safety concerns related to these popular low-cost online platforms.

Introduction

Over time, global online marketplaces gradually gained popularity, allowing for direct purchases by customers in different countries, leading to the "fast fashion" trend to emerge (Liu et al. 2021). "Fast fashion" refers to low-cost clothing collections that replicate current luxury fashion trends, allowing young consumers to follow the fashion trend (Annamma et al. 2012). In particular, the popularity of Chinese e-commerce shops has skyrocketed. At an extremely low price, their products are more than affordable for almost every consumer. For example, Shein, one of the leading Chinese e-commerce companies, has a C2M (consumer to manufacturer) model, allowing Shein to remove intermediaries and enabling customers to buy products at a lower cost. Shein's accessories averaged the price of $6.56, for instance, whereas other companies had about $10 on average (Chen 2023). In 2020, Chinese e-commerce transactions reached $2.29 trillion, with more than 710 million online consumers accounting for about 50% of the world's transactions ("China - eCommerce" 2025). According to data provided by Statistics Korea, Chinese e-commerce companies accounted for approximately 4.85 trillion won ($3.51 billion) of the total 8.08 trillion won ($5.85 billion) of overseas direct purchases in South Korea in 2024, a 47% increase from 2023 (Korean Statistical Information Service 2025). Depending on the companies, their products are not only limited to fashion but also include household items, toys, and other daily items. Unlike any other Chinese-made products in non-Chinese markets, purchases from these e-commerce shops deliver products directly from Chinese manufacturers to consumers' residences. These products often do not meet U.S. safety regulations due to restricted chemicals such as phthalates and formaldehyde, resulting in the sale of unsafe goods ("Chapter 4: Unsafe And Unregulated Chinese Consumer Goods: Challenges In Enforcing Import Regulations And Laws" 2024). In 2024, the Korean government attempted to ban the overseas shipping of products without Korean Certification (KC), which is a certification of compliance of products with Korean safety regulations ("KC certification for South Korea" 2025), yet failed to do so due

to its impracticality: the number of purchases from overseas commerce extremely outnumbers the capacity of the product inspection and global overseas e-commerce companies are not obligated to obey Korean safety regulations (Ku 2024). Nevertheless, various studies have found that their products contain high levels of toxic chemicals. Numerous toys have been found to contain phthalates ("One In Five Toys Bought Online Contain Harmful Phthalates" 2024), clothes with PFAS ("Most Waterproof Jackets From Amazon, Shein and Temu Contain Harmful PFAS" 2025), and other hazardous substances present in household items ("These Facial Creams Contain Unwanted Chemicals" 2025).

This paper identifies common hazardous chemicals that are present in low-cost products. The paper explains several health risks of exposure to those chemicals. Thus, this paper aims to inform mainly consumers, perhaps policymakers, of the risk of purchasing those products.

Phthalates

Phthalates are the most widely used plasticizers, composed of a variety of families of industrial compounds that increase the durability, flexibility, and workability of polymers. Phthalates are the esters of phthalic acid, also known as 1,2-dibenzene dicarboxylic acid. Phthalate esters are produced by the reaction of phthalic anhydride with an excess of branched or normal alcohols in the presence of a catalyst:

$$C_6H_4(CO)_2O + ROH \rightarrow C_6H_4(CO_2R)(CO_2H)$$
$$C_6H_4(CO_2R)(CO_2H) + ROH \rightarrow C_6H_4(CO_2R)_2 + H_2O$$

Their properties of low melting point and high boiling point allow them to be used as heat transfer fluids, carriers, and children's toys. Common plasticizers are di-2-ethylhexyl phthalate (DEHP), dibutyl phthalate (DBP), diisononyl phthalate (DiNP), diisodecyl phthalate (DiDP), and diisobutyl phthalate (DiBP) (Jørgensen et al. 2008). In addition to its function as a plasticizer, phthalates have properties that can be used as viscosity modifiers, solidifiers, stabilizers, lubricants, and emulsifiers, so they are used in electronics, paint pigments, adhesives, food containers, shampoos, perfumes, cosmetics, and pharmaceuticals.

However, plasticizer exposure has numerous possible health risks. Phthalates cause endocrine disruption when they enter the body. Specifically, phthalates act as analogs or inhibitors of steroid hormones such as estrogen and androgen that induce abnormal hormonal action or interfere with normal hormonal action. These disruptions of physiological functions lead to decreased fertility in both men and women, causing sperm damage in men, precocious puberty, premature puberty, and infertility in women. Phthalates are known to disturb not only sex hormone action but also thyroid hormone action, and cause breast and liver cancer. In addition, it has been reported that phthalate exposure during pregnancy affects fluctuations in pregnancy and fetal development. Moreover, the association between early childhood phthalate exposure and neurodevelopment, intelligence decline, and mental diseases such as Attention Deficit/Hyperactivity Disorder (ADHD) has been steadily proposed (Kim et al. 2017).

According to the U.S. Environmental Protection Agency, di-2-ethylhexyl phthalate (DEHP), diisodecyl phthalate (DiDP), diisononyl phthalate (DiNP), Butyl benzyl phthalate (BBP), diisobutyl phthalate (DiBP), dibutyl phthalate (DBP), and Dicyclohexyl phthalate (DCHP) "present an unreasonable risk of injury to human health" (Environmental Protection Agency 2025a) (Environmental Protection Agency 2025b) (Environmental Protection Agency 2025c) (Environmental Protection Agency 2025d) (Environmental Protection Agency 2025e) (Environmental Protection Agency 2025f) (Environmental Protection Agency 2025g). Thus, exposure to products that contain phthalates poses a strong danger to humans.

Formaldehyde

Formaldehyde is one of the most widely utilized chemicals throughout the world. It is a colorless gas at room temperature and pressure, typically produced by the reaction of methanol, steam, and air, with the addition of a catalyst. Formaldehyde is primarily sold as a 37-50% aqueous solution, known as formalin. It is a material used in various fields such as coal, acid-based, urea-based, melamine-based synthetic resin raw materials, adhesives, wood product manufacturing, fertilizers and pesticides, water-soluble paints, textiles, disinfectants, and preservatives (Ju et al. 2008). Nonetheless, exposure to formaldehyde holds various health risks. It can cause skin and eye irritation as well as sensitization and toxic effects at the contact site. Beyond basic irritation, formaldehyde can cause allergic contact dermatitis, sensitization, and allergic reactions, especially in children and those with pre-existing skin conditions (Garcia 2024). Moreover, according to the International Agency for Research on Cancer, there is sufficient evidence that formaldehyde is carcinogenic to humans, causing nasopharyngeal cancer, leukemia, and sinonasal cancer (International Agency for Research on Cancer 2012).

Lead

Lead is a chemical metal element, naturally found throughout the earth. It is commonly used in gasoline, paint, plumbing pipes, ceramics, solders, batteries, and cosmetics (Adarsh 2021). Due to its unique physical and chemical properties, lead is highly suitable for various applications. Yet, Lead toxicity has a destructive effect on the human body, affecting almost every function of the human body (Wani 2015).

It is considered one of the most harmful heavy metals since it induces neurodegenerative diseases, cardiovascular and developmental disorders, kidney damage, hyperirritability, and decreased bone growth in children, and irreversible damage to the nervous system (Adarsh 2021). Children absorb up to 5 times as much lead as adults, making them more vulnerable to lead poisoning, and exposure to lead can lead to various permanent effects on a child's development and behavior. In particular, it can result in reduced attention span and intelligence quotient (IQ), increased antisocial behavior, and less educational attainment (World Health Organization 2024). Inhalation, ingestion, or skin contact are common ways of exposure. When inhaled, up to 40% of lead dust is deposited in the lungs, and 95% of it enters the bloodstream (Wani 2015).

In order to substitute $PbCrO_4$ (lead chromate) pigment due to its safety concerns, using a series of inorganic-organic hybrid pigments, with a main component of inorganic materials (SiO_4, TiO_2, and sepiolite), is one possible solution. The hybrid pigments possess similar properties to $PbCrO_4$, having similar color performance, heat resistance, and photo stability, thus potentially substituting $PbCrO_4$ (Cao et al. 2017).

Cadmium

Cadmium is released as a by-product of refining zinc and other metals. It is commonly found in batteries, paints, and plastics. Through gastrointestinal and pulmonary absorption, Cadmium can cause severe damage to the human body (Nordberg et al. 1974). It has a long biological half-life in mammals, which means that Cadmium gets accumulated in mammals' bodies for a long period of time. Some laboratory records of exposure to cadmium in animals "include renal tubular damage, placental and testicular necrosis, structural and functional liver damage, osteomalacia, testicular tumors, teratogenic malformations, anemia, hypertension, pulmonary edema, chronic pulmonary emphysema, and induced deficiencies of iron, copper, and zinc." Among those, several effects have been observed in humans due to accidental exposure (Ragan et al. 1990). Furthermore, according to the World Health Organization's International Agency for Research on Cancer and the United States National Toxicology Program, Cadmium has been designated a human carcinogen. Supporting this, chronic inhalation of Cadmium to rats shows it causes pulmonary adenocarcinomas (Waalkes 2003).

Possible replacement for Cadmium pigment is $Bi_{1-x-y}Ca_xZn_yVO_{4-(x+y)/2}$ ($0 \leq x \leq 0.10$, $0 \leq y \leq 0.10$) pigments. Synthesized as novel inorganic yellow pigments, these pigments are environment and human-friendly. In addition to $BiVO_4$ being environmentally friendly, Ca and Zn being nontoxic elements, lead these pigments to be a safe and effective alternative (Masui et al. 2013).

Overseas Retail Product Inspection

The following table summarizes the results of overseas retail product inspection conducted by the Seoul Electronic Commerce Center (SECC) from January to June 2025 ("Overseas direct purchase safety inspection" 2025). More than half of the products that failed the inspection contained an illegal amount of chemicals that pose different health dangers to humans.

Table 1: Overseas retail product inspection conducted by the Seoul Electronic Commerce Center (SECC) from January to June 2025 ("Overseas direct purchase safety inspection" 2025).

Chemical	Number of products	Source/Product	Company	Detected Levels
Phthalate	~30%	Umbrellas, shoes, dolls, jeans, toys, pencils, notepads, pencil case	AliExpress, Temu	Up to 443.5 times above the legal limit
Lead	~20%	Umbrellas, shoes, blouses, toys, notepads, paints, pencil cases, pencils, accessories	AliExpress	Up to 231 times above the legal limit
Formaldehyde	~7%	Raincoats, jeans, skirts, and other clothing	AliExpress, Shein, Temu	Up to 32.55 times above the legal limit
Cadmium	~11%	Clothing, toys, pencils, notepads, pencil cases	AliExpress, Temu	Up to 5.61 times above the legal limit

Discussion and Conclusions

Hazardous chemicals are prevalent throughout industrial products. In particular, products from companies like AliExpress, Temu, and Shein are often exemplified for containing hazardous chemicals. This paper mainly focused on four chemicals: phthalate, formaldehyde, lead, and cadmium. Phthalates are industrial plasticizers that disturb endocrine function, affect fertility, fetal development, thyroid activity, and neurodevelopment, while also being linked to cancers. Formaldehyde exposure can cause skin and eye irritation, allergic reactions, and sensitization. The International Agency for Research on Cancer classifies formaldehyde as carcinogenic to humans, linking it to cancers such as nasopharyngeal cancer, leukemia, and sinonasal cancer. Lead exposure can cause neurodegenerative, cardiovascular, and developmental disorders, kidney damage, and irreversible nervous system. Children are especially vulnerable, absorbing more lead than adults, which can lead to reduced IQ, attention deficits, antisocial behavior, and long-term developmental impairments. Cadmium exposure can cause kidney, liver, bone, reproductive, and lung damage, along with anemia and hypertension. Both the WHO and U.S. agencies classify cadmium as a human carcinogen, with evidence linking chronic exposure to cancers such as pulmonary adenocarcinomas. These health risks could simply be caused by the use of products purchased from those companies. The fact that hazardous chemicals are detected in multiple products of AliExpress, Temu, and Shein raises safety concerns and suggests a certain danger in the consumption of these companies.

Although for some chemicals, there are available replacements in terms of chemical alternatives, to prevent the spread of hazardous chemicals practically, there are legal limits on those chemicals allowed to be found in products. Still, direct overseas commerce from China is relatively unregulated by national policies compared to companies that are in the nation; there are numerous products that do not comply with the laws. Since it is nearly impossible for individual countries to run an inspection for every single product from direct overseas commerce, the consumers' health risk depends on the consumers' choice.

Nonetheless, there were a few limitations of this paper. Since it is a literature review, even though the products that failed the safety inspection by SECC reveal the prevalence of hazardous chemicals across products from AliExpress, Shein, and Temu, the paper fails to address the total proportion of those unsafe products among all the products available on e-commerce platforms. Also, there are copious factors that influence exposure to chemicals from the products, other than their amount. For instance, if a certain chemical is detected in the part where it's rarely exposed, it might have less effect on humans. Therefore, it is the consumer's responsibility to be aware of what they are buying and the potential risks that follow.

Works Cited

Adarsh, N., et al. "Development of Semiconductor Based Heavy Metal Ion Sensors for Water Analysis: A Review." Sensors and Actuators A: Physical, vol. 330, 2021. ScienceDirect, https://www.sciencedirect.com/science/article/pii/S0924424721003423.

Annamma, J., et al. "Fast Fashion, Sustainability, and the Ethical Appeal of Luxury Brands." Fashion Theory, vol. 16, 2012, pp. 273–. https://www3.nd.edu/~jsherry/pdf/2012/fastfashionsustainability.pdf.

Cao, L., X. Fei, and H. Zhao. "Environmental Substitution for $PbCrO_4$ Pigment with Inorganic-Organic Hybrid Pigment." Dyes and Pigments, vol. 142, 2017, pp. 100–07. https://doi.org/10.1016/j.dyepig.2017.03.024.

Chen, Y. "Analysis of Marketing Strategies of Cross-Border E-Commerce Platforms in the United States—Shein." Highlights in Business, Economics and Management, vol. 19, 2023, pp. 478–83. https://doi.org/10.54097/hbem.v19i.11985.

"China – eCommerce." International Trade Administration, 7 Apr. 2023, https://www.trade.gov/country-commercial-guides/china-ecommerce.

Environmental Protection Agency. Risk Evaluation for Di-Isodecyl Phthalate (DIDP). Jan. 2025, https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-di-isodecyl-phthalate-12-benzene.

Environmental Protection Agency. Risk Evaluation for Dicyclohexyl Phthalate (DCHP). Jan. 2025, https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-dicyclohexyl-phthalate-dchp.

Environmental Protection Agency. Risk Evaluation for Di-Ethylhexyl Phthalate (DEHP). June 2025, https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-di-ethylhexyl-phthalate-12-benzene.

Environmental Protection Agency. Risk Evaluation for Diisononyl Phthalate (DINP). June 2025, https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-diisononyl-phthalate-12-benzene.

Environmental Protection Agency. Risk Evaluation for Dibutyl Phthalate (DBP). June 2025, https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-dibutyl-phthalate-12-benzene.

Environmental Protection Agency. Risk Evaluation for Diisobutyl Phthalate (DIBP). July 2025, https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-diisobutyl-phthalate-12-benzene.

Environmental Protection Agency. Risk Evaluation for Butyl Benzyl Phthalate (BBP). Aug. 2025, https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-butyl-benzyl-phthalate-12-benzene.

Garcia, J. “Is Formaldehyde in Clothing Dangerous?” Kherkher Garcia, 16 Apr. 2024, https://www.kherkhergarcia.com/formaldehyde-in-clothing-dangerous/.
International Agency for Research on Cancer. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. vol. 100, 2012, p. 385.
Jørgensen, Sven Erik, and Brian D. Fath. Encyclopedia of Ecology. Elsevier, 2008.
Ju, G. D., and J. J. Yu. Formaldehyde. Korea Occupational Safety & Health Agency, Mar. 2008, https://www.kosha.or.kr/_attach/old_web/newkosha/content/download/document/Formaldehyde(report).pdf.
KC Certification for South Korea. MPR Korea Certification, 7 Apr. 2025, https://www.korea-certification.com/en/kc/what-is-kc-certification/.
Kim, W., and C. G. Myung. “Maleficent Effects of Phthalates and Current States of Their Alternatives: A Review.” Korean Journal of Environmental Biology, vol. 35, no. 1, 2017, pp. 21–36. http://www.ebr.or.kr/journal/article.php?code=51156.
Korean Statistical Information Service. “Online Shopping Survey.” 4 Feb. 2025, https://kosis.kr/statHtml/statHtml.do?sso=ok&returnurl=https://kosis.kr:443/statHtml/statHtml.do?conn_path%3DI2%26tblId%3DDT_1KE1009%26orgId%3D101%26.
Ku, S. Y. “‘It’s Hard to Stop Ali and Temu’… The Government Withdrew Regulations on KC Certification.” inews24, 20 May 2024, https://www.inews24.com/view/1721182.
Liu, A., et al. “Cross-Border E-Commerce Development and Challenges in China: A Systematic Literature Review.” MDPI, 27 Dec. 2021, https://www.mdpi.com/0718-1876/17/1/4.
Masui, T., et al. “Novel and Environmentally Friendly (Bi,Ca,Zn)VO_4 Yellow Pigments.” ScienceDirect, Dec. 2013, https://www.sciencedirect.com/science/article/abs/pii/S0143720813002441.
“Most Waterproof Jackets from Amazon, Shein and Temu Contain Harmful PFAS.” Hjem, 6 May 2025, https://taenk.dk/kemi/visit-our-english-version/most-waterproof-jackets-amazon-shein-and-temu-contain-harmful-pfas.
Nordberg, Gunnar F. “Health Hazards of Environmental Cadmium Pollution.” Ambio, vol. 3, no. 2, 1974, pp. 55–66. JSTOR, http://www.jstor.org/stable/4312046.
“One in Five Toys Bought Online Contain Harmful Phthalates.” Hjem, 25 Oct. 2024, https://taenk.dk/kemi/visit-our-english-version/one-five-toys-bought-online-contain-harmful-phthalates.
“Overseas Direct Purchase Safety Inspection.” Seoul Electronic Commerce Center, 24 Jan. 2025, https://ecc.seoul.go.kr/DR2001/FN2008LS.jsp.
Ragan, H. A., and T. J. Mast. “Cadmium Inhalation and Male Reproductive Toxicity.” Reviews of Environmental Contamination and Toxicology, vol. 114, 1990, pp. 1–22. https://doi.org/10.1007/978-1-4612-3368-8_1.
“These Facial Creams Contain Unwanted Chemicals.” Hjem, 12 Feb. 2025, https://taenk.dk/kemi/visit-our-english-version/these-facial-creams-contain-unwanted-chemicals.

Unsafe and Unregulated Chinese Consumer Goods: Challenges in Enforcing Import Regulations and Laws. U.S.-China Economic and Security Review Commission, Nov. 2024, https://www.uscc.gov/sites/default/files/2024-11/Chapter_4--Unsafe_and_Unregulated_Chinese_Consumer_Goods.pdf.

Waalkes, M. P. "Cadmium Carcinogenesis." Mutation Research, vol. 533, 2003, pp. 107–20. https://doi.org/10.1016/j.mrfmmm.2003.07.011.

Wani, A. L., A. Ara, and J. A. Usmani. "Lead Toxicity: A Review." Interdisciplinary Toxicology, vol. 8, no. 2, 2015, pp. 55–64. https://doi.org/10.1515/intox-2015-0009.

World Health Organization. "Lead Poisoning." WHO, 27 Sept. 2024, https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health.

Estrogen Replacement Therapy and Alzheimer's Risk in Postmenopausal Women: A Review By Sasha Ali

Abstract

Estrogen replacement therapy can be defined as a potential treatment option for Alzheimer's Disease. ERT is theorized to negate the onset and development of Alzheimer's if implemented during the postmenopausal period in a woman's life. Previous studies have presented a multitude of results that have rendered the current status of the legitimacy of the treatment inconclusive. Estrogen depletion is hypothesized to contribute to cognitive decline through the connection of many positive feedback systems such as protein buildup and neuroinflammation to the risk of Alzheimer's. Major studies within this field have taken two main forms, observational research and randomized clinical trials. Observational studies tend to result in favor of the Critical Window Hypothesis. However, clinical studies tend to showcase evidence for no or a negative correlation. Hormone therapy research focuses on three main hormone regimens: 17β-estradiol, CEE, and CEE + progestin. The most effective therapy tested was concluded to be 17β-estradiol therapy, followed by CEE in second place. Progestin is believed to cancel out the neuroprotective effects of estrogen. The trials that showcased positive correlation often exhibited an inverse relationship between risk reduction and time. Although the overall legitimacy of using estrogen therapy to reduce the risk of Alzheimer's in postmenopausal women is still inconclusive, these findings are imperative stepping stones to understanding the true potential of Hormone Therapy.

1 Introduction

In recent years professionals have become more open-minded about the topic of hormone therapy (HT) as a possible treatment for a variety of health issues (Fillit, 2002). Postmenopausal women are at a substantially higher risk for developing Alzheimer's (AD) than at any other time in their lives (Mervosh and Devi, 2025). Because of this, it is postulated that the loss of neuroprotective estrogen after menopause could correlate with an increased risk for developing AD (Brann et al., 2007). This speculation led to the rise of "The Critical Window Hypothesis". This concept has gained prominence through recent testing, such as the 2011 UC San Francisco retrospective study, which contrasted many older studies by showing evidence for a lowered risk (Tokar, 2011). Currently, HT is not a recommended treatment option for AD because of inconclusive testing, so we must understand previous data to grasp what can be done to retain a more desirable, clear conclusion on this topic (Dye et al., 2012). This paper will review the findings in this field of research and each study's relevance to validating or disproving the critical window hypothesis (Maki, 2013).

2 Background

In 2010, there were 35.6 million Alzheimer's patients living with dementia, two-thirds of these patients being women (Mervosh and Devi, 2025). The number of AD patients has only

increased over time, especially in women exceeding 80 years old (Mervosh and Devi, 2025). The troubling increase in the number of AD patients warranted an array of recent studies that focused on a new approach, HT (Fillit, 2002). It is theorized that estrogen could play a neuroprotective role in the brain which in turn protects mechanisms that cause neurocognitive decline (Brann et al., 2007; Prokai-Tatrai and Prokai, 2024). The critical window hypothesis theorizes that there is a pivotal point of action in a woman's life, during postmenopause, where if administered Estrogen Replacement Therapy (ERT) it can substantially reduce the risk and speed of the three progressive stages of AD (Maki, 2013).

Hormone Replacement Therapy (HRT) is the use of various forms of estrogen either by itself or with progestins to most commonly treat menopausal symptoms (Yaffe et al., 1998; Ali et al., 2023). Menopause is a physiologic phenomenon that affects women most directly through their vagina, ovaries, bones, arteries, and more. It occurs because of a natural decline in ovarian function that comes with age, leading to the production of less and less estrogen as time goes on (Prokai-Tatrai and Prokai, 2024). AD is a neurodegenerative disorder that occurs when there is a buildup of amyloid plaques and neurofibrillary tangles which lead to the cells of the brain shrinking and dying (Ahmad et al., 2022).

Estrogen deficiency is linked to an increased risk of AD through several internal mechanisms (Brann et al., 2007; Ahmed et al., 2022):

- The buildup of neurotoxic amyloid-beta (Aβ) plaques
- Unregulated microglia and astrocyte cell function leading to neuroinflammation
- Reduced metabolic activity in the brain (glucose utilization)

3 Methods

Observational studies showed a trend in finding supporting evidence of the neuroprotective role of ERT against AD (Seshadri et al., 2001). In contrast to this, studies featuring randomized clinical trials have shown less clear findings (Dye et al., 2012). Observational studies may be affected by many biases. For example, women who decide to take ERT for long periods of time may be healthier, affluent, or have different biological clocks (Fillit, 2002). These factors and more could all very possibly contribute to the margin of error of a study. A common subject of criticism within the methods ERT and AD is the lack of controls present (Depypere et al., 2016). For example, many observational studies test varied ERT regimens instead of a unilateral, specified form of ERT (Maki, 2013). In clinical trials, the group of women being studied can also be biased due to unrelated health conditions frequent among the women. It's imperative to reform the methods in which we study a subject to ensure the most accurate findings. Although it's up to interpretation and context to determine which method of study is more accurate, randomized clinical trials are generally agreed to be the most trustworthy (Dye et al., 2012).

3.1 Affirming Studies

The Baltimore Longitudinal Study of Aging found that ERT was linked to reduced risk

for AD (Kawas et al., 1997). Two notable limitations to the takeaway of this study are that the subjects' duration of use varied and the age of menopause is a variable factor. The study featured a sample of 514 women with no other requirements listed.

The Manhattan Study of Aging found that ERT was associated with significant risk reduction for AD while testing a sample of 1124 women. In this study, it was found that the women who took estrogen for longer than a year reported the lowest risk (Tang et al., 1996).

Paganini-Hill and Henderson conducted a study in which ERT was found to significantly reduce the risk for the development of AD. An inverse relationship was observed, meaning that the longer exposed to ERT, the lower the risk for AD. Most studies that reported evidence for ERT protecting against cognitive decline tend to demonstrate this relationship. This study specifically found that those on ERT for seven or more years have the lowest risk (Dye et al., 2012).

Using neuroimaging technology Silverman compared the cerebral metabolic activity associated with three hormone plans. These regimens each give insight into how hormone imbalance caused by gonadal hormone depletion affects brain function. 17β-estradiol (E2), isolated CEE, and CEE + progestin were all tested and observed in this study. The results showed that the E2 group showed significantly better results in verbal memory, higher metabolism rate, and reception to language and auditory association than the other test groups (Silverman et al., 2011).

3.2 Non-Affirming Studies

A large study was conducted by the Women's Health Initiative Memory Study (WHIMS) with a total of 7479 postmenopausal women enrolled. 4532 women were involved in the actual trials which tested conjugated equine estrogen (CEE) with medroxyprogesterone (MPA) against a placebo. Even though the trial was discontinued due to unforeseen health risks, some data was still collected that showed that women who received the CEE and MPA therapy actually showed greater cognitive decline compared to the placebo test group. It was concluded that the risk had actually doubled compared to the placebo group (Craig et al., 2005).

Another randomized controlled study found that women receiving CEE and MPA together for specifically four months showed that the women receiving HT had mild declines in verbal memory compared to the placebo group (Maki, 2013). The study conducted by Silverman also found evidence for the negative effects HT can have. The specific CEE + progestin therapy showed lower metabolism rates in long-term memory storage compared to the isolated CEE therapy group. This study suggests that therapies that include progestin may diminish the potentially positive effects of estrogen in HT (Silverman et al., 2011).

In a study by Joffe et al., it was found that E2 was not associated with an improvement in verbal memory. This contrasts with the study by Silverman et al which reports that rather than E2 improving memory, it actually just enhanced the ability to process information. This creates the illusion that they are showing signs of improved memory when the subject is actually just more capable of processing information effectively (Dye et al., 2012).

4 Discussion

This field of study can be traced back to the 50s and has long been debated (Fillit, 2002). Each of the academic discussions, studies, and papers surrounding this topic plays a vital part in understanding why we stand where we are today on this topic. The inconclusive label on the study of ERT in relation to AD shows how significant it is to continue to innovate in this field (Ali et al., 2023; Depypere et al., 2016). The results of these numerous studies show several results. Some findings, such as showing that estrogen does affect AD risk, were more general (Seshadri et al., 2001; Yaffe et al., 1998). Some were more niche, such as establishing how E2 affects cognitive function through the synthesis of information rather than the capacity to memorize (Brann et al., 2007; Prokai-Tatrai and Prokai, 2024). From this information, you can infer that HT can have an undeniably significant role in the body, whether it is negative or not depends on the context. In the context of AD, HT is extremely relevant because it is a field of study full of possibilities and potential (Mervosh and Devi, 2025).

Although many current approaches to studying AD and HT include many vital flaws such as bias and lack of controls, each study is still relevant because it provides a stepping stone of knowledge that the next scientist can utilize to continue to deepen our understanding of the subject (Depypere et al., 2016). It's important to advocate for more research surrounding HT for the safety of women and for the sake of redefining the millions of lives of those affected by AD for the better (Study Suggests Estrogen to Prevent Alzheimer's, 2023). Further research is necessary to refine our understanding of this topic so that we can approach this controversial topic with nuance (Maki, 2013). There are also many other sub-categories within this field of research such as sexual health concerns, early menopause concerns, and personalized hormone therapy approaches that have been barely touched upon (Ali et al., 2023). The inconclusive label on ERT and AD should be handled by more research, instead of being discouraged by the less-than-clean-cut findings so far. The uncertainty is what makes it so necessary that we study this topic further.

5 Conclusion

ERT is a topic of study that aims to understand the correlation between estrogen deficiency and the risk of AD development (Brann et al., 2007). The ways in which ERT has been studied show room for improvement (Dye et al., 2012). Numerous biases and inconsistencies have been observed within the trials and studies performed centered on this topic (Ali et al., 2023). Of the many studies performed, none have enough weight to establish a clear conclusion on the legitimacy of ERT to treat AD (Maki, 2013). Some notable findings include that E2 is likely to improve the rate at which we process information (Prokai-Tatri and Prokai, 2024) and that when a positive correlation is shown an inverse relationship between time and risk is present (Seshadri et al., 2001; Fillit, 2002). The inconclusive results of this field of research should warrant reform within how ERT is studied and speak to the need for more research efforts (Study Suggests Estrogen to Prevent Alzheimer's, 2023; Mervosh and Devi, 2025).

Works Cited

[1] Ahmad, Md Afroz, et al. “Neuroinflammation: A Potential Risk for Dementia.” International Journal of Molecular Sciences, U.S. National Library of Medicine, 6 Jan. 2022, pmc.ncbi.nlm.nih.gov/articles/PMC8775769/.

[2] Ali, Noor, et al. “The Role of Estrogen Therapy as a Protective Factor for Alzheimer’s Disease and Dementia in Postmenopausal Women: A Comprehensive Review of the Literature.” Cureus, U.S. National Library of Medicine, 6 Aug. 2023, pmc.ncbi.nlm.nih.gov/articles/PMC10480684/#sec1.

[3] Brann, Darrell W., et al. “Neurotrophic and Neuroprotective Actions of Estrogen: Basic Mechanisms and Clinical Implications.” Steroids, U.S. National Library of Medicine, May 2007, pmc.ncbi.nlm.nih.gov/articles/PMC2048656/.

[4] Brann, Darrell W., et al. “Neurotrophic and Neuroprotective Actions of Estrogen: Basic Mechanisms and Clinical Implications.” Steroids, U.S. National Library of Medicine, May 2007, pmc.ncbi.nlm.nih.gov/articles/PMC2048656/.

[5] Craig, Michael C., et al. “Biological Effects of Gonadal Hormone Replacement on Cognitive Function in Postmenopausal Women.” The Lancet Neurology, U.S. National Library of Medicine, Feb. 2005, https://pubmed.ncbi.nlm.nih.gov/15721829/.

[6] Depypere, H., et al. “Alzheimer’s Disease, Apolipoprotein E and Hormone Replacement Therapy.” Maturitas, Elsevier, 29 Sept. 2016, www.sciencedirect.com/science/article/abs/pii/S0378512216302262.

[7] Dye, Richelin V., et al. “Hormone Replacement Therapy and Risk for Neurodegenerative Diseases.” International Journal of Alzheimer’s Disease, U.S. National Library of Medicine, 2012, pmc.ncbi.nlm.nih.gov/articles/PMC3324889/#B12.

[8] Fillit, Howard M. “The Role of Hormone Replacement Therapy in the Prevention of Alzheimer's Disease | Dementia and Cognitive Impairment | Jama Internal Medicine | Jama Network.” JAMA Network, 2002, jamanetwork.com/journals/jamainternalmedicine/fullarticle/213175.

[9] Kawas, Claudia, et al. “A Prospective Study of Estrogen Replacement Therapy and the Risk of Developing Alzheimer’s Disease: The Baltimore Longitudinal Study of Aging.” Neurology, U.S. National Library of Medicine, June 1997, https://pubmed.ncbi.nlm.nih.gov/9191758/.

[10] Maki, Pauline M. “Critical Window Hypothesis of Hormone Therapy and Cognition: A Scientific Update on Clinical Studies.” Menopause (New York, N.Y.), U.S. National Library of Medicine, June 2013, pmc.ncbi.nlm.nih.gov/articles/PMC3780981/#R29.

[11] Mervosh, Nicholas, and Gayatri Devi. “Estrogen, Menopause, and Alzheimer’s Disease: Understanding the Link to Cognitive Decline in Women.” Frontiers, Frontiers, 7 Aug. 2025, www.frontiersin.org/journals/molecular-biosciences/articles/10.3389/fmolb.2025.1634302/full.

[12] Prokai-Tatrai, Katalin, and Laszlo Prokai. “The Impact of 17β-Estradiol on the

Estrogen-Deficient Female Brain: From Mechanisms to Therapy with Hot Flushes as Target Symptoms." Frontiers in Endocrinology, U.S. National Library of Medicine, 8 Jan. 2024, pmc.ncbi.nlm.nih.gov/articles/PMC10800853/.

[13] Seshadri, Sudha, et al. "Postmenopausal Estrogen Replacement Therapy and the Risk of Alzheimer's Disease | Dementia and Cognitive Impairment | Jama Neurology | Jama Network." JAMA Network, 2001, jamanetwork.com/journals/jamaneurology/fullarticle/778809.

[14] Silverman, Daniel H. S., et al. "Estrogen and Brain Aging in Women: The Impact of Hormone Therapy on Cerebral Metabolism." Neurobiology of Aging, Elsevier, 2011, https://www.sciencedirect.com/science/article/abs/pii/S0306453010002064.

[15] "Study Suggests Estrogen to Prevent Alzheimer's Warrants Renewed Research Interest." WCM Newsroom, 23 Oct. 2023, news.weill.cornell.edu/news/2023/10/study-suggests-estrogen-to-prevent-alzheimer%E2%80%99s-warrants-renewed-research-interest.

[16] Tang, Ming-X., et al. "Effect of Oestrogen during Menopause on Risk and Age at Onset of Alzheimer's Disease." The Lancet, Elsevier, 17 Aug. 1996, https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(96)03356-9/fulltext.

[17] Tokar, Steve. "Estrogen Therapy's Link with Dementia Risk Depends on Age When Taken, Study Finds." UC San Francisco, 29 Feb. 2011, www.ucsf.edu/news/2011/02/98174/estrogen-therapys-link-dementia-risk-depends-age-when-taken-study-finds.

[18] Yaffe, Kristine, et al. "Estrogen Therapy in Postmenopausal Women." JAMA Network, 4 Mar. 1998, jamanetwork.com/journals/jama/article-abstract/187297.

Effect of Saving Rates on Pension Policies By Vihaan Agarwal

Abstract

This paper looks at how national savings rates shape pension systems across ten countries with different economies and social structures. By comparing case studies—from India and the United States to Greece and Singapore—it explores how people save, how much they save, and how that influences government pension policies. Some countries rely heavily on pay-as you-go systems, while others focus more on individual savings and investment-based plans. The paper also considers broader economic factors like ageing populations, fiscal pressure, and the role of domestic savings in long-term economic growth. What emerges is a clear pattern: countries with higher savings rates tend to have more sustainable pension systems, while those with lower rates often face challenges that lead to reforms or financial strain. The study highlights how savings behaviour, both at the household and national level, plays a key role in shaping the future of retirement policies.

Introduction

Pension policies are a major economic issue for any country, and the relationship between a nation's national savings rate and its pension policies is a crucial part of every country's economic policy-making. The manner in which citizens save money, especially in countries where populations are aging, could have major implications as an ageing population could strain a country's social security systems. This requires governments to implement policies that would be able to support and aid their populations. Thus, individual financial behaviour and national policy frameworks are closely related. This relationship has gained heightened significance in recent decades as demographics shift and people experience longer lifespans. In such a scenario, understanding the interplay between private financial responsibility and state support becomes central to addressing long-term sustainability of retirement income systems. Additionally, the increasing complexity of global financial markets adds another layer of consideration, as access to and knowledge of financial instruments can influence saving patterns and, in turn, policy structures. The following study will seek to examine the effect of different saving rates on pension policies and different pension schemes in countries.

Historical Patterns and Regional Contrasts

A look at historical evidence suggests that countries that have a higher household saving rate have developed policies distinctly different from those where the average household saving rate is lower. This is because the burden of spending that people will be able to bear will change drastically based on how much they have saved. The differences between the policies are seen when examining the differences in policies implemented in East Asian countries and those of the West. While people living in East Asian nations typically have a higher household savings rate, those living in Western nations have a lower average in comparison. This results in different systems being instituted. Thus, the pension systems of East Asian nations place greater emphasis

on individual responsibility and funded schemes. In contrast, many Western economies have historically relied more heavily on pay-as-you-go systems and state-funded pension provisions. These divergent approaches reflect not only economic necessities but also cultural attitudes toward savings and retirement planning.

The Feedback Loop Between Savings and Policy

The nexus between savings behaviour and pension policy affects the former through several channels. In one direction, a higher national savings rate is usually combined with a greater ability to self-fund in old age, which can imply a lower necessary scope of state pension provision. In the other direction, a developed savings culture is often associated with more sophisticated financial markets and relates to more complex and sophisticated pension policy options like private pension schemes and investment-based retirement products. Finally, the aggregate national savings determines the capital formation and potential economic growth of a country, which in turn affects the resources available for pension system funding. Moreover, policy frameworks can act as incentives or disincentives for saving. For instance, generous state pension schemes might reduce the perceived need for personal savings, while tax benefits on retirement accounts might encourage higher savings. Therefore, the relationship is not unidirectional but symbiotic, where savings patterns influence policy decisions, while pension policies themselves might influence saving behaviour. This relationship is important for policy makers, who have to navigate its complexities while designing pension reforms. If not considered properly, it could lead to an overburdened pension system that is incapable of catering to the needs of retirees. This paper seeks to analyse how national savings rates relate to pension policies across countries. By analyzing this relationship, the paper will aim to identify patterns that could better inform policy decisions and help in the development of more robust retirement and social security systems. The paper will explore key questions, including, how varying levels of national savings rates correlate with different approaches to pension policy? What role do cultural and socio-economic factors play in this relationship? The paper seeks to further the discussion around saving rates, the GDPs of nations, and pension policies. **Global**

Perspectives on Pension Systems and Savings Behaviour:

Having explored the theoretical nexus between national savings rates and pension policy, it becomes necessary to ground this understanding in real-world contexts. This is because the pension schemes are employed and the retirement savings structures vary greatly from country to country based on the economy of the region, the demographics there, and the culture's appreciation for planning for finances. Drawing from a variety of case studies, we can gain insight in how savings behaviour and pension in practice come together. The following section presents an overview of pension systems and savings patterns across a range of nations, highlighting both common challenges and distinct policy approaches.

Methodology

This study adopts a qualitative, comparative case study methodology, drawing on secondary data sourced from government publications, international organizations, like the IMF, and financial databases.

Ten countries have been selected for analysis, representing a range of geographic regions, economic development levels, and pension system models. These include both developed and developing economies with varying approaches to retirement planning and national savings behaviour. The selected countries are: India, the United States, the United Kingdom, Greece, New Zealand, Finland, Australia, Switzerland, Ireland, and Singapore.

Each case study focuses on three core variables: (1) the structure and funding model of the national pension system, (2) household or national savings rates, and (3) pension spending as a percentage of GDP. Where relevant, recent economic trends and policy reforms have been considered.

The study does not aim to establish causality but to explore correlations and patterns that may inform policy discussions. Quantitative indicators are used to contextualize qualitative analysis, ensuring a more grounded comparison across nations. This approach allows for a nuanced understanding of how economic capacity, cultural norms, and institutional frameworks shape the interaction between savings behaviour and pension policies.

Table showing the savings rates of countries

Countries	SAVING RATE
US	4.60%
UK	11.10%
India	18.40%
Greece	-4%
Finland	3%
Australia	5.90%
New Zealand	1.40%
Ireland	12.70%
Singapore	58.46%
Switzerland	23.40%

Table showing the GDP's of countries

Countries	GDP (in billion dollars)
US	29160
UK	3089
India	3549.9
Greece	217.75
Finland	280.826
Australia	1675
New Zealand	248.69
Ireland	551.55
Singapore	498.98
Switzerland	870

The US

In the United States, the Federal Employees Retirement System is a retirement plan available to federal government employees. It offers benefits from 3 sources: A Basic Benefit Plan, Social Security, and the Thrift Savings Plan. Two of the three parts that make up FERS — Social Security and the Thrift Savings Plan — can be carried over to an employee's next job if they leave the federal government before retirement. However, for non-federal employees, Social Security serves as the primary government-backed safety net.

There are also private plans that are available to employees. The US-private sector offers 401 (k) plans, where employees are able to contribute a portion of their wages. These contributions are matched by employers. The funds collected are managed by private accounts. However, unlike traditional pension plans, there's no guaranteed payments as part of the 401 (k) plans. While the government incentivizes participation in these plans, it does not play an active role in them. The money contributed is typically invested in a coterie of funds, including target-date funds and mutual funds. People are free to withdraw funds from their 401 (k) accounts once they reach retirement age. The amount being withdrawn is not fixed. It is totally up to the person whose retirement fund it is to decide how much and when to withdraw the funds, which in turn depends on how much the person contributed in the first place.

In the year 2024, the US government's total federal outlays are projected to be $6.8 trillion, which is around 23.9% of the country's $28.78 trillion GDP. The personal savings rate for the US is at 4.60% as of October 2024, which is significantly lower than the long-term average of 8.45%.

India

The Employees Provident Fund is the primary government-backed retirement scheme where both employee and employer contribute an equal amount. This currently stands at 12% of the employee's salary. It offers a guaranteed annual interest rate that's higher than the saving rates offered at banks. The National Pension Scheme is another government-backed tool. The NPS is voluntary, with the money being invested in equity, government bonds, and government securities. There are also plans like the Atal Pension Yojna, aimed at the informal sector.

India had a household savings percentage of 22.7% of GDP in the Financial Year 2021, but this has since declined as per the latest data to 18.4% in the Financial Year 2023. In the year 2024, the GDP of India is estimated at $3.95 trillion. The country spends about 3.3% of its GDP on employee pensions. While Indians have a generally high amount of savings, the recent data, especially post Covid, shows that more people in India are putting their money towards investments and the stock market. However, the percentage of savings is still high. The total share of people covered under India's National Pension Scheme and Atal Pension Yojna actually went up from 1.2% to 3.7% between 2016-2017 and 2021-2022. Data shows that the National Pension Scheme in 2023 had 8.9 trillion rupees, going up by a significant amount compared to last year. Despite this, India's pension assets are comparatively small compared to other economies, reflecting the still developing labour market in the country.

UK

The State Pension scheme is the primary government-backed retirement instrument in the country. The scheme is funded through National Insurance contributions, where employees need to contribute to the scheme for at least 10 years or make voluntary payments to make up shortfalls. In most cases, the money is directly cut from an employee's paycheck and the employer will also contribute an amount towards the pension scheme.

The UK has a pay-as-you-go system, meaning that the money contributed by employees currently working is used to pay the pensions of those that have already retired. In such a system, the first generation of employees who retired and received benefits did not need to make contributions towards the system to receive its benefits. Unlike many other countries that do not have such a pay-as-you-go system, the UK does not invest the money received as part of pension contributions. Instead, as the name suggests, the money coming in every year is used directly to make pension pay outs to the workers that have already retired. In the year 2024, the GDP of the UK is at an estimated $3 trillion, with $167.6 billion in projected pension spending. The pension market in the UK is growing steadily at an annualized rate of 7%, and people's savings are playing a significant role in contributing towards this growth. This uptick in savings has bolstered pension contributions, helping the Local Government Pension Scheme, the largest defined benefit pension scheme in the UK, to grow its assets to $425 billion.

Switzerland

The Old Age and Survivors Insurance is the country's primary government-backed

pension system (10). It is funded via mandatory contributions by both the employee and the employer. It is the first pillar of a three-pillar system, where the other two pillars are made up of schemes that are private and voluntary in nature. These include the Occupational Benefits Insurance and Private Pensions plan.

In the year 2024, the estimated GDP for Switzerland is $938.46 billion. The current conversion rate for the country's pension pay outs is at 6.8% (10), meaning that for ever CHF 100,000 in retirement assets a person has, they will receive an annual pension of CHF 6,800. In cases where a person retires early, there is a 0.15-0.25% reduction in the conversion rate — in the opposite case, if a person works past retirement age, their conversion rate is bumped up by a similar degree. In the year 2023, Switzerland achieved a 5.1% average rate of return of pension assets (12).

Greece

The National Social Security Pension is the country's main pension instrument, providing payments to all employees who have contributed to it. The pension is paid regardless of how long or short a period of time employees have contributed to the scheme. However, pay outs will vary depending on time, pensionable earnings, and other factors. The full monthly pension amount is €384 ($418.5) (13). The estimated GDP of Greece in 2024 is $252.732 billion, with 16% of the GDP expected to be spent on pensions.

In the year 2024, Greece has a gross savings rate of 10.9%. However, the household savings rate of the country was at -4% (14) in 2022. This means that people in Greece were spending more than their disposable income allowed them to, either by dipping into money they had previously saved or by borrowing. The lack of savings has been partly responsible for the pension crisis in the country (15).

Reforms have been instituted as the pension system was under threat, due to factors like an ageing population and reduced labour force participation that threaten social security. Policy changes such as consolidating (16) the pension system into what it currently is have been implemented. However, with saving rates still significantly low, the pension system continues to be stressed despite the reforms.

New Zealand

NZ Superannuation is the primary pension scheme of the country. It is government funded, based on both total income and asset tests. There are fixed rates of payments under the plan. As per the NZ Super plan, people above 65 years of age can start receiving payments. Single people with dependent children can receive up to $519 each, while couples living together can receive up to $400 each week. There are also other schemes like KiwiSaver, which can supplement retirement income for New Zealand retirees after the age of 65. It is the fastest growing investment asset in the country, with over $100 billion NZD in assets (17).

New Zealand is projected to have a GDP of $252,24 billion in 2024, with around 5% of its GDP expected to go towards pensions. The average household saving in New Zealand in

2023 was $856 million, with the household saving ratio, which compares household savings to net disposable income, being at 1.4% in 2023 (18).

Australia

The country has an Age Pension plan that is non-contributory and totally public-funded. There are fixed payment amounts. However, payments under the scheme may vary based on asset tests. It is projected to have a GDP of $1745 billion in 2024. The pension contribution is expected to be around 2.9-4.5% of the GDP.

Savings play a major role in the pension pay outs, with Australia having superannuation assets worth AU$3.5 trillion (19) in March 2022, the fourth largest such corpus in the world. For most Australians, the largest chunks of savings are locked away till the age of 65. The latest data released by the government of Australia showed that the mean superannuation balance across the whole population was $164,000, while the median was a little under $58,000 (20).

Ireland

The country has a state pension plan based on Pay Related Social Insurance contributions. Both the employee and employer contribute to this. Even self-employed people and those receiving rental payments must contribute to the PRSI scheme. Ireland has a three pillar system (21), where the PRSI serves as the first and primary pillar. The country also has Funded occupational pension plans, which serve as the second pillar, accepting contributions from both individuals and employers. The third pillar is made up of private savings plans, which includes personal pension plans and private savings accounts. Ireland is projected to have a GDP of $560.566 billion in 2024, with an expected 4.5% of GDP likely to go towards the payment of pensions. Ireland's household savings rate was at 10.19% (22) during the Q4 2023.

Poland

The primary pension instrument of the country is the Social Insurance Institution (ZUS), which is funded by contributions from both the employee and the employer. Apart from ZUS, the government has also introduced Employee Capital Plans (PPK) (23). While the PPK plan is optional, it is encouraged by the government, which also contributes to it — adding to the employee and employer contributions. The country also has Open Pension Funds, which are private pension funds, which were mandatory till 2014 (24). The estimated GDP of Poland in 2024 is $845 billion. Poland has a pension expenditure rate of 11% of its GDP.

Singapore

The Central Provident Fund (25) is the main pension instrument of the country and is backed by the government. Both the employee and employer contribute to this fund, which is the primary safety net for the country's residents. People are required to contribute 40% of their wages up to a monthly salary ceiling of S$6,000 (26). The Central Provident Fund has two types of accounts: the first being the Ordinary Account (OA), while the other is the Special Account

(SA). The amount of interest accrued in the OA is 2.5%, while the amount of interest given in the SA is 4% (27). The two accounts also serve separate purposes, with the OA being used for short-term needs like rent, schooling etc. The SA is used for retirement needs and investments in retirement-related financial products. In addition to this, there is also the Supplementary Retirement Scheme, a voluntary plan to help boost savings beyond the CPF. The estimated GDP of Singapore in 2024 is $530.71 billion, with Singapore's pension assets funds to GDP being around 42.1%, based on 2020 data.

Finland

Earnings-related Pension is the primary pension instrument of the country. It is funded by contributions from both the employee and the employers and is a pay-as-you-go scheme. Self-employed persons must also contribute to it. Payouts are based on contributions accrued over employee's lifetimes. The country also has a National Pension scheme to supplement the Earnings-related Pension scheme. Other than supplementing, the scheme also provides social security benefits to those who are not benefiting from the Earnings-related Pension scheme. Finland's pension scheme is partially funded (28) with a pre-funded scheme covering about a quarter of earnings-related pension outlays. The pre-funding is collective and the amount of The pension received is not affected by this. The remainder, which is 75% of outlays, are funded by a pay-as-you-go system. The projected GDP of Finland for 2024 is $306.06 billion, with a pension expenditure of 12.8% of its GDP. Meanwhile, the savings percentage of Finland keeps fluctuating, ranging between 0.6% (29) in 2023 to 3.0% in June 2024 (30).

Results

A comparative analysis of ten countries—India, United States, United Kingdom, Greece, New Zealand, Finland, Australia, Switzerland, Ireland, and Singapore—reveals key patterns in how savings behaviors relate to pension system structures. The findings are based on secondary data covering pension scheme types, national savings rates, GDP figures, and pension expenditures.

1. Pension Scheme Types and Funding Structures
   - Pay-as-you-go systems are dominant in countries like the UK, Greece, and Finland. These rely on current workers' contributions to fund retirees' pensions. • Mixed or funded systems are employed in countries like Switzerland, India, and Ireland, where mandatory contributions are combined with private or voluntary pension options. • Heavily funded schemes are seen in Singapore and Australia, where savings are primarily channelled through government-mandated personal accounts or employer supervised superannuation funds.

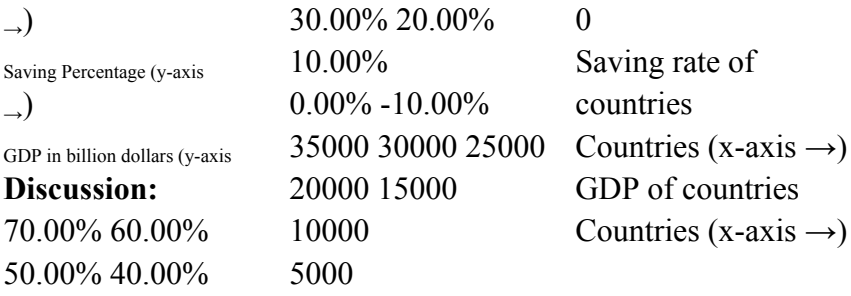
2. Household/National Savings Rates
   - Singapore has the highest reported saving rate at 58.46%.

- Switzerland and India follow at 23.4% and 18.4% respectively.
- The UK and Ireland have moderate rates (11.1% and 12.7%).
- The US, Australia, Finland, and New Zealand fall into the low-savings range (1.4%–5.9%).
- Greece has a negative household savings rate of -4%, indicating dissaving.

3. Pension Expenditure as Percentage of GDP
- Greece (16%), Finland (12.8%), and Poland (11%) have the highest pension spending as a share of GDP.
- Countries like India and Australia spend relatively less (around 3–4.5% of GDP). • Singapore's pension fund-to-GDP ratio is high (42.1%) but reflects a different funding model rooted in mandatory individual savings.

4. GDP Size and Economic Capacity
- The US has the largest GDP ($29.16 trillion), followed by India ($3.95 trillion) and the UK ($3.09 trillion).
- Smaller economies like Greece ($252.7 billion), New Zealand ($252.2 billion), and Finland ($306 billion) faces relatively higher pension burdens proportionate to GDP. 5.

Key Observed Patterns
- Countries with higher savings rates tend to have more diversified or funded pension systems (e.g., Singapore, Switzerland).
- Nations with lower savings rates or negative household savings (e.g., Greece, New Zealand) often rely on pay-as-you-go schemes and exhibit greater fiscal strain. • Pension system sustainability tends to align with either high formal savings or a robust multi-pillar model combining public and private provisions.



As is seen from the overview of countries listed above, most nations have a combination of public and private pension schemes that rely strongly on the savings percentage of the nation. The reason for this is that a higher saving percentage will lead to lesser reliance on pensions later on. Higher savings percentages will also allow for greater contributions towards such schemes from disposable incomes. Thus, the pension policies of nations are significantly related to the household's saving percentages.

From a macroeconomic standpoint, the national savings rate is intrinsically linked to

investment, capital formation, and long-term economic growth. In economies with higher savings rates, a greater pool of domestic capital becomes available for productive investment, reducing dependence on foreign borrowing. This, in turn, strengthens fiscal stability and can free up state resources to be channelled into social protection programs like pensions. Conversely, low national savings can hinder capital accumulation, reduce potential GDP growth, and increase fiscal pressure to maintain pension obligations—especially as dependency ratios rise. Moreover, savings behaviour influences current account balances. A nation with a high savings rate and relatively lower consumption may run current account surpluses, which can be used to invest in sovereign wealth funds or bolster pension reserves. On the other hand, countries with persistent deficits and low household savings often face challenges funding pension liabilities without resorting to increased taxation or borrowing. In this way, the macroeconomic implications of national savings extend well beyond individual behavior and directly affect the sustainability and design of pension systems.

In nations like the UK there have been increased debates around the pay-as-you-go system (31) due to factors like an ageing population sparks fears that current contributions won't be able to handle outflows. Factors like Brexit have also played a role. The government has, thus, encouraged greater personal savings and private/workplace pension schemes to alleviate the burden on the state pension system. In nations like India, people tend to save more. However, these are largely informal savings and the overall savings percentage remains low, thereby leading to the implementation of additional pension schemes like the NPS to bolster retirement schemes. Greece is a prime example of what can happen when there's a generous pension system but the savings percentage is low. The low saving percentage was the primary reason, alongside an ageing population, that caused a major financial and pension crisis in the 2010s. This resulted in a major overhaul of the Greek pension system, which included policies merging pension funds, raising the retirement age, reducing early retirement, as well as taxing pension benefits to deal with shortfalls. Finally, when looking at a country like Finland, we see a nation with one of the most comprehensive pay-as-you-go schemes. With an ageing population and a high old-age dependency ratio, Finland has enacted policies that ensure contributions and benefits reflect these demographic and socio-economic shifts through their robust pension policy schemes.

Thus, through these examples we can see that the savings of a nation, alongside other factors such as an ageing workforce and population, play a major role in the formation of policies. This is particularly prominent in nations like the UK and Finland, which have pay-as-you-go systems where the funds coming in are used immediately instead of being invested through market and bond instruments, as is the case in the pension systems of the US and India. Thus, we see changes in their policies, including incentivizing private pension schemes that can supplement incomes at retirement age. However, even in nations that do not have pay-as-you-go schemes, savings are an imperative part of pension contributions.

Works Cited

1. Fernando, Jason. "401 (k): What It Is, How It Works, Pros, and Cons." Investopedia, 5 Sept. 2024, www.investopedia.com/terms/1/401kplan.asp#toc-how-does-your-401k earn-money.
2. "US Personal Saving Rate Monthly Analysis: Personal Income and Outlays | YCharts." YCharts, ycharts.com/indicators/us_personal_saving_rate#:~:text=US%20Personal%20Saving %20Rate%20is,long%20term%20average%20of%208.45%25.
3. Kundu, Rhik. "Indian household savings may have rebounded in FY24, says Crisil." Mint, 21 May 2024, www.livemint.com/economy/indian-household-savings-may have-rebounded-in-fy24-says-crisil-11716294805584.html.
4. "India: value of assets under management in NPS 2023 | Statista." Statista, 30 Aug. 2024, www.statista.com/statistics/1027896/india-value-of-assets-under-management in-national-pension-scheme/#:~:text=In%20financial%20year%202023%2C%20the,when%20compared% 20to%20other%20economies.
5. Mohanty, Deepak. "Perspectives on the PensionSector in India." PFRDA WORKING PAPER SERIES, PFRDA (WPS):2022-23 (1), The Pension Fund Regulatory and Development Authority, 2022, www.pfrda.org.in/myauth/admin/showimg.cshtml?ID=2159#:~:text=The%20rate%20 of%20returns%20in,old%2Dage%20social%20security%20benefits.
6. Government Digital Service. "Workplace pensions." GOV.UK, 26 Jan. 2015, www.gov.uk/workplacepensions#:~:text=How%20they%20work,tax%20relief%20from %20the%20government.
7. The Pensions Policy Institute, and Jackie Wells. Pension scheme assets – how they are invested and how and why they change over time. Pensions Policy Institute, 2024, www.pensionspolicyinstitute.org.uk/media/c00dra0k/20240909-ppi-pension-scheme assets-main-report-final.pdf.
8. Azad, Sid, et al. "Capturing growth in the evolving UK savings and retirement market." McKinsey & Company, 6 Mar. 2023, www.mckinsey.com/industries/financial-services/our-insights/capturing-growth-in the-evolving-uk-savings-and-retirement-market.
9. Mason, Neil. First 100 days of government: support the Local Government Pension Scheme | PLSA. www.plsa.co.uk/Policy-and-Research/Topics/Election 2024/Article/First-100-days-of-government-support-the-Local-Government-Pension Scheme.
10. "The three-pillar system: a simple explanation." AXA Schweiz | the Three-Pillar System: A Simple Explanation, www.axa.ch/en/pension/pension-system.html.
11. Finpension_Admin. "Pension conversion rate: all information." Finpension, 2 Oct. 2024, finpension.ch/en/knowledge/pension-conversion

rate/#:~:text=The%20current%20conversion%20rate%20of%20the%20pension%20fund%20is%206.8,CHF%20100%2C000%20in%20retirement%20assets.
12. Pension Funds Study 2023: The health of pension funds was put to the test in 2022. www.zkb.ch/en/home/asset-management/pensions/pension-funds-study/current study.html#:~:text=Pension%20funds%20achieved%20an%20average,%2Dyear%20average%20was%203.5%25.&text=The%20best%20funds%20achieved%20a,an%20average%20of%202.44%25).
13. Ministry of Labour and Social Affairs. “Primary pension - Ministry of Labour and Social Affairs.” Ministry of Labour and Social Affairs, 27 Apr. 2022, ypergasias.gov.gr/en/social-security/pensions/primary pension/#:~:text=Pension%20amount&text=The%20full%20amount%20is%20set,in%20Greece%20have%20been%20completed.
14. Chrysolora, Eirini. “Greeks ate into savings in 2022.” kathimerini.gr, 23 Nov. 2023, www.ekathimerini.com/economy/1225510/greeks-ate-into-savings-in 2022/#:~:text=Savings%20in%20Greece%20moved%20into,reverting%20to%20negative%20last%20year.
15. Kangur, Alvar, et al. “Reforming the Greek Pension System.” IMF eLibrary, International Monetary Fund, 16 July 2021, www.elibrary.imf.org/view/journals/001/2021/188/article-A001-en.xml#:~:text=Excessive%20pension%20spending%20was%20one,euro%20area%2C%20after%20Italy).
16. Altiparmakov, Nikola and Serbian Fiscal Council. THE 2022 GREEK PENSION REFORM. 2022, www.cerp.carloalberto.org/wpcontent/uploads/2022/04/WP_208.pdf.
17. New Zealand retirement system ranked 14th in Mercer CFA Institute Global Pension Index 2024. www.mercer.com/en-nz/about/newsroom/mercer-cfa-institute-global pension-index 2024/#:~:text=%E2%80%9CKiwiSaver%20is%20the%20fastest%20growing,decumulation%20strategies%2C%E2%80%9D%20Whitelock%20said.
18. Household saving steady in the September 2023 quarter | Stats NZ. www.stats.govt.nz/news/household-saving-steady-in-the-september-2023-quarter. 19. Wikipedia contributors. “Superannuation in Australia.” Wikipedia, 10 Nov. 2024, en.wikipedia.org/wiki/Superannuation_in_Australia#:~:text=As%20of%2030%20March%202022,is%20in%20defined%20contribution%20funds.
20. O’Sullivan, Harry. “How much does the average Australian save?” Savings.com.au, 29 Aug. 2024, www.savings.com.au/savings-accounts/average-savings australia#:~:text=Household%20Savings%20Ratio,-%2D4%25%20%2D2&text=Seasonally%20adjusted.,0.2%25%20in%20September% 20'23.
21. “Pension pillars | Practical Law.” Practical Lawuk.practicallaw.thomsonreuters.com/5-518-0705?transitionType=Default&contextData=(sc.Default)#:~:text=The%20three%20pi

llars%20are%3A,pensions%20and%20individual%20savings%20accounts.
22. CSO. Household Saving Q4 2023 - Central Statistics Office. 11 Mar. 2024, www.cso.ie/en/releasesandpublications/ep/p-hs/householdsavingq42023.
23. Janas, Jakub. “CEE country report 2024: Poland’s auto-enrolment system - five years on.” IPE, 19 Jan. 2024, www.ipe.com/country-reports/cee-country-report-2024-polands-auto-enrolment-system-five-years-on/10070808.article.
24. ACCRUED-TO-DATE PENSION ENTITLEMENTS IN SOCIAL INSURANCE: FACT SHEET. July 2024, ec.europa.eu/eurostat/documents/7158500/12335606/PL_T2900_factsheet.pdf/7ff4693d-83fb-f721-d98e483949b54fc4?t=1613387910877#:~:text=1)%20Open%20Pension%20Funds%20(OFE,participation%20in%20OFE%20was%20voluntary.
25. Asher, Mukul G. “Chapter 12. Singapore’s Pension System: Challenges and Reform Options.” IMF eLibrary, https://doi.org/10.5089/9781616359508.071.ch012. 26. Asher, Mukul G. Compulsory Savings in Singapore: An Alternative to the Welfare State. www.ncpathinktank.org/pdfs/st198.pdf.
27. Koh, Benedict S. K. Singapore’s Social Security Savings System: A Review and Some Lessons for the United States. By Pension Research Council of the Wharton School of the University of Pennsylvania and Singapore Management University, report, 2014, pensionresearchcouncil.wharton.upenn.edu/wp-content/uploads/2015/09/WP2014-18-Koh.pdf.
28. “Pension Assets and Contributions - Finnish Centre for Pensions.” Finnish Centre for Pensions, www.etk.fi/en/work-and-pensions-abroad/international comparisons/financing-and-investments/pension-assets-andcontributions/#:~:text=In%20Finland%2C%20the%20statutory%20earnings,comparatively%20smaller%20in%20these%20countries.
29. Households’ saving rate was close to zero in the second quarter of 2023 | Statistics Finland. stat.fi/en/publication/cl8lonfsyrb2h0cvzthxgngoe.
30. Households’ saving rate on level with the previous quarter in April to June 2024 | Statistics Finland. stat.fi/en/publication/cln2sod4p2dj60bvzkb6nfgk9#:~:text=to%20June%202024-,Households'%20saving%20rate%20on%20level%20with%20the%20previous,in%20April%20to%20June%202024&text=According%20to%20Statistics%20Finland%2C%20households,now%20significantly%20higher%20than%20previously.
31. Smith, Sarah. Should the UK Switch From a Pay-as-you-go to a Funded Pension Scheme? ifs.org.uk/sites/default/files/output_url_files/fp184.pdf.

Contradictions of a Colonial Legacy:
A Contrapuntal Reading of Etel Adnan's Sitt Marie Rose By Norah Grigoresco

Etel Adnan's Sitt Marie Rose acts as both a moving, first-hand account of the Lebanese civil war, as well as a work of postcolonial literature that brings to light the correlation between the violence experienced and Lebanon's colonial history (Adnan, 1977). Written in 1977, the novella focuses on the kidnapping and murder of a young woman, Marie Rose Boulos, who defies sectarian divisions by working alongside Palestinian refugees. Her death is described as both a tragedy felt throughout the community, and as a political symbol of the country's fragmentation throughout the war. Edward Said's Culture and Imperialism, published in 1993, is a philosophical work which extends earlier ideas from Orientalism, a book which argues that cultural representation of the Middle East is purposefully distorted by Western media, by proposing a method of contrapuntal reading to highlight the often discreetly placed colonial ideas woven into literary works (Said, 1993). His approach emphasizes reading while keeping in mind both the dominant imperial history, as well as the marginalized stories that are often side-lined (Said). Taken together, Adnan's novel and Said's theory highlight how individual stories and narratives cannot be separated from broader histories of colonialism. Reading Sitt Marie Rose from Said's lens allows readers to truly comprehend the colonial structures that have shaped Lebanon to be the way it is today.

Analyzing Sitt Marie Rose through Said's contrapuntal lens reveals how the impacts of colonialism on Lebanese society are particularly evident in the contradictions that Adnan exposes, contradictions which were created and intensified by the sectarian divisions institutionalized under colonial rule. Whether it be between identity and societal role, speech and silence, and within the language that describes violence and place, these contradictions demonstrate that the Lebanese Civil War cannot be fully understood without comprehending the complex colonial structures that split apart the nation.

Edward Said's concept of contrapuntal reading, as stated in Culture and Imperialism (1993), provides readers with a methodology that is perfect for analyzing texts rooted in colonial history. Said specifically defines this contrapuntal reading as the practice of reading literary works while taking into account both the dominant, tending to be imperial, narratives while also keeping in mind the suppressed and marginalized narratives that interact with them. In doing so, the reader is able to decipher the power structures and resistance that is encoded within cultural works. Furthermore, this approach allows for the reader to continue to analyze how these colonial systems impact identities, spaces and conflicts in a postcolonial society, even when the subjects are now perceived as independent.

Applying a contrapuntal reading to Adnan's Sitt Marie Rose is valuable, as the novella in itself is an act of resistance against the lingering colonial structures that makeup Lebanese society, by revealing the very contradictions born from colonialism. Through these contradictions, Adnan is able to challenge the dominant ideologies that are held up by sectarian structures, and

illustrate how they continue the cycle of violence in Lebanon while splitting a people and a nation apart.

In the following sections of this paper, I will apply this contrapuntal reading to analyze three main contradictions within Sitt Marie Rose: the contradictions between appearances and societal roles, the presence and absence of dialogue, and the poetic language that Adnan herself uses to describe violence. In doing so, I hope to make clear how reading Sitt Marie Rose through Said's contrapuntal framework helps uncover the deep and lingering impacts of colonialism on Lebanese society, specifically by splitting a people and therefore creating a nation full of inherent contradiction. In the end, my work will reveal that the Lebanese Civil War cannot be fully understood without acknowledging the colonial structures that came before.

To understand how colonialism informs the contradictions embedded in Adnan's work, it is essential to begin with the French colonial presence in the region, as well as the sectarian frameworks they enacted. After the collapse of the Ottoman Empire after World War 1, the League of Nations gave way to the French Mandate over both Lebanon and Syria in 1920, officially placing Lebanon under French rule until its eventual independence in 1943. The French mandate system greatly privileged members of the Lebanese Maronite Christian community. They did this through the promotion of a confessional political system, aligning the way the government was created with French geopolitical interests. The following French policies essentially codified sectarian identities into politics, splitting power along religious lines, and therefore creating hierarchies that were entrenched into the social and economic structures (Makdisi and Sadaka, 60-62).

This infrastructure, which was created to maintain French influence, therefore formed the path along which tensions would explode during the Lebanese Civil War. The confessional system, in privileging certain groups such as Maronite Christians, excluded others, notably the Muslims, leading to widespread inequality and injustice. Additionally, the flow of Palestinian refugees following the Nakba in 1948 only added pressure to these tensions. While many Maronite Christians feared the influx of Palestinians would destabilize the country, Lebanese Muslims greatly supported the cause, causing a wider rift. As widening economic and political inequalities continued throughout the years, several militias began forming along both sides, eventually leading up to the trigger of the war: the bus attack in Ain el-Rummaneh. On April 13, 1975, after an attempted assassination of a leader of the Christian Phalangist Party, Phalangist gunmen ambushed a bus and killed 27 Palestinians in retaliation (Makdisi and Sadaka, 63). This sparked the rapid escalation into the Civil War, and it is with that image that Adnan begins Sitt Marie Rose.

One of the most striking areas in which the contradictions of Adnan's Sitt Marie Rose manifests is in how appearance and identity clash with one's role in society. Through the character of Marie Rose, as well as those who surround her, Adnan creates a tension between visuals and ideology that directly mirrors the fragmentation of a postcolonial Lebanon.

Marie Rose is one of the greatest examples of this, as Adnan sets her up to be a woman who destabilizes the limits set by both colonial and sectarian ideology. Everything from her

appearance, demeanor and background fit the French vision of what a “civilized” Lebanese woman should be: Christian, educated, articulate, white-passing. Yet, her political alignment directly contradicts these expectations. This contradiction, especially her solidarity with the Palestinian refugees, leads to the main conflict in the book. As Olivia Harrison points out, Adnan’s story redefines affiliation as a choice, as opposed to being inherited, therefore challenging sectarian identity, and imagining new bonds that span division (Harrison, 2009).

For example, Adnan’s description of Marie Rose’s appearance as beautiful: “For an Arab, it’s rare, she has blue eyes” (Adnan, 30). This statement points out how European beauty standards, such as blue eyes and fairer skin, signal privilege and alignment with the values the Christian Lebanese community seeks to uphold especially as they consider themselves closer to the French than other Arabs. The admiration tied to her Westernized appearance is used as colonial validation, yet Marie Rose actively violates that in her self-declaration for supporting the Palestinian factions. This is represented in the militia's thought process, as Adnan writes, “Like the presence of this woman, taken at random at a roadblock, who should, according to the norms, be a part of his lan, his flesh and blood...he would have to fight the dissident Christians to save the real Christians” (Adnan, 75). By turning over to the ‘other’ side, Marie Rose throws away all the privilege garnered by how she looks, making her a complex enemy to the militia. These contradictions depict both Foster and Said’s key idea that colonial norms will forever persist within the postcolonial elite, as the militia here are directly seen internalizing and outputting the very ideas the French first brought with them. Marie Rose becomes an anomaly by refusing to conform.

Language and both its use and absence throughout the book act as a sort of battle ground, in the war through which they point out how sectarian forces get to control who is heard and who is silenced. Adnan’s use of characters who cannot speak-- particularly the deaf-mute students-- alludes to the experience of all youths throughout Lebanon who are not offered a voice and are forced instead to passively grow up on the violence. Silence first appears as a condition. A condition which enables the continuation of unchecked violence. As Thomas Foster writes, Adnan’s fragmented style reproduces “circles of repression,” where silence and speech become intertwined as tools used to dominate an oppressed people (Foster, 1995). When the children’s thoughts are first echoed, they state “There’s no noise in this world. That’s why the war doesn’t stop. Nobody wants to stop it. Far away the big powers are too busy, and besides, they never think about us. So we just keep it up. In silence...the Arabs are all silent” (Adnan, 43). Through this quote, it is seen not only how colonial powers reshaped local conflict but then abandoned the regions in that very state, it also points to how the “silence” in itself is contrapuntal. It echoes the colonial silencing of colonized peoples, while also pointing out how post-independence societies internalize and remain stuck due to that silencing. The war therefore continues both because of existing hatred, but also because of passive submission, because “big powers” have normalized silent suffering. This highlights Adnan’s point of cultural numbness to violence, which is later described in the children’s own experiences.

The quote “she doesn’t like violence. Neither do we, because we can’t take part in it” (Adnan, 30). reveals how violence has become the new form of speech, rebirthed from constant colonial and sectarian trauma. Identity now only becomes possible through violent exclusion, and continues to be idolized by younger generations as they now grow up with a craving for war to finally be able to be seen as a part of Lebanese society.

The rapport between speech and silence here mirrors Said’s point that imperialism requires a sort of blindfold to justify itself. In Sitt Marie Rose, that blindness is institutionalized through education and ideology, resulting in generations of students who are desensitized and even molded for war, echoing words without truly grasping their understanding. Adnan, in contrapuntally layering silence and speech, allows the reader to see through the oppressor’s spoken ideology, as well as behind the scenes into the silent pain of the oppressed.

Beyond dialogue and action, Adnan’s use of poetic and metaphorical language to describe Lebanon’s landscape plays a crucial role in her contrapuntal resistance to both colonial and sectarian violence. The land is not neutral, rather, Adnan turns the country into a living and suffering presence, one shaped by the violence continuously played out on its land. The country therefore becomes both a witness and a victim, holding the traumas enacted on it. This technique of description therefore allows Adnan to challenge colonial ideas of territory to be claimed and divided.

In one passage early on with the novel, Adnan oddly describes the war as something almost beautiful: “The Middle East lives its destiny. No sound seems trivial or ordinary. The power of terror is totalitarian. Bullets crack and resonate in the amphitheatre that is Beirut. The location is perfect. The sound of the guns is echoed off the great stretched surface of the sea. Thunder mixes with the rhythmic sounds of war which purge Beirut” (Adnan, 12-13). Here, war takes on both a theatrical and real form at the same time. Beirut, called an “amphitheatre” for violence, becomes a place of performance, pointing to how ritualized the violence has now become. This passage aestheticizes war. By describing it through rhythm and spectacle: the bullets which “resonate” like music, the sea echoing the songs back, Adnan insinuates some form of choreography to the conflict. By draping the violence in words of beauty, the land becomes animated, the land speaking with “rhythmic sounds of war,” giving Lebanon itself a voice in the face of violence. The contrast with the voice of the country becomes even more striking in the face of the absence of sound by the deaf-mute children. This juxtaposition establishes Adnan’s view of Lebanon as both a scarred yet resilient country, the war not only acted upon it but wholly being a part of Lebanon’s identity itself.

The word “purge” has a haunting aspect to it, as it describes violence as a sort of cleansing act, as though Beirut would become pure at the end of the war. This word recalls imperialist logic, which often justified intervention as a way to ‘cleanse’ and ‘modernize’ non-European lands, calling back to the “White Man’s Burden.” Said’s contrapuntal reading ties into these notions perfectly, as it points out all of the political undertones hidden within Adnan’s language, how destiny and purification are ideas that are deeply imbedded with colonial implications.. The sentence “the Middle East lives its destiny,” is ironic, pointing to the Western forces that have set

the region on the path to conflict. Therefore, this sentence masks the role of imperialism, a common orientalist trope.

Later, Adnan continues this idea of a violated landscape in stating, “She gathered the manners and customs, the flaws and vengeance, the guilt and debauchery of the whole world into her own belly. Now she has thrown it all up, and that vomit fills all her spaces” (Adnan, 20). The “she” in this passage being Lebanon, is described as a feminine symbol that has been overwhelmed. The almost grotesque descriptions surrounding the swallowing and the vomit, portrays the nation as ill due to the consequences of not only the violence, but the colonial legacies and cultural conflict. The “whole world” which she has consumed points to the fact that the war in Lebanon cannot be isolated from the global history of war, arms, and displacement--all legacies of colonialism. The act of throwing up in itself shows the depiction of how Lebanon is now currently expelling all the external ideologies it has internalized, through the form of war and societal collapse.

Finally, Adnan brings an image forward of violence and reconciliation, as she writes, “I want to say forever and ever that the sea is beautiful, even more so since the blood washed down by the greedy rain opened reddening roads into the sea. It’s only in it, in its immemorial blue, that the blood of all is finally mixed” (Adnan, 98). The blood of everyone, regardless of their sect or side, is “finally mixed,” in the war, painting the sea as a site of collective grief and rest. The "immemorial blue” comes in sharp contrast with the red blood of the war, pointing to how nature will forever sustain a neutrality at the end of the carnage. This metaphor serves as a critique of all the divisions and contradictions imposed, pointing to how artificial and violently imposed they are, as in death everyone is reunited with nature just the same.

Through these poetic metaphors used to depict violence and landscape, Adnan goes beyond describing war, she fully rewrites the geography of Lebanon in a language of resistance and grief. The voice is not unified, but fractured by years of conflict, a parallel to Adnan’s own disjointed style of narration. The landscape alone holds all these voices and opinions, but at the same time develops its own voice, continuously reshaped by war, a witness to the constant destruction and violence. Both physically, through the wounds of war that affect the geography, and emotionally, through the grief and memory that will forever linger, Lebanon has been changed due to the effects of the remnants of colonialism. Yet, as demonstrated through Adnan’s metaphors, even scarred, Lebanon will forever remember and carry its people.

Overall, Etel Adnan’s Sitt Marie Rose goes beyond simply being a story of war, but instead serves as a political and poetic critique of the legacies of colonialism and the fragmentation it has left behind. Through a contrapuntal reading based on Edward Said’s work, this paper has taken apart how Adnan has weaved contradiction into every single layer of text, and how each of these contradictions are deeply rooted in the structure left behind French colonialism.

In the end, a contrapuntal reading will not reduce the Lebanese Civil War as simply an aftermath of colonialism, but will instead demonstrate how colonialism helped build the

framework that was then played out by local dynamics. Through this argument, the reader is able to see that colonialism is not a scapegoat, but rather a foundation that the war responded to. One possible counterargument to reading Sitt Marie Rose through Edward Said's contrapuntal lens is the critique that this approach overemphasizes colonial influence. This therefore could strip the Lebanese of their local agency, and white-wash their history as it takes away the complexity of local history, politics and also accountability. I agree that Lebanon's war has been motivated by several factors, whether they be sectarian rivalries, militias, class divisions and Palestinian displacement. Therefore, taking all these intricacies and putting them solely on colonial history can downplay the role the Lebanese people had in their own conflict.

It is definitely not unreasonable to think that way. However, in reading Adnan's novel contrapuntally, local forces are definitely not ignored. Instead, it highlights the deep entanglement with colonial legacy, situating it within a broader historical context. In the very quote, "There's no noise in this world. That's why the war doesn't stop. Nobody wants to stop it. Far away the big powers are too busy, and besides, they never think about us. So we just keep it up. In silence...the Arabs are all silent" (Adnan, 43). Adnan implicates both global powers and the very region. The "big powers" are guilty due to their lack of concern, completely abandoning the region. But Adnan also expresses inward criticism, pointing to a self-destructive tendency Arabs hold in remaining silent when speaking up is crucial. This two-edged critique is a perfect encapsulation of Said's contrapuntal method, as the ability to critique both imperial and local effects simultaneously is crucial.

Additionally, Adnan's highlighting of sectarian divisions, especially in how she depicts the militia men as echoing colonial rhetoric while simultaneously defending their own Christian faction, adds to this notion. This rhetoric portrays the idea that colonial effects did not completely disappear, but instead found a new form within Lebanese society. As critic Prabha Manuratne notes in "The Traitor as a Figure of Betrayal in Etel Adnan's Sitt Marie-Rose," Marie Rose's disloyalty to her own sect becomes both a political and moral challenge to the guidelines colonialism has helped define ("The Traitor as a Figure of Betrayal," 2010). As Said argues, colonialism persists in the way societies imagine themselves, which is expressed through the roles Adnan's characters inhabit, of nationalist, traitor, refugee, victim, all institutionalized by a broader colonial context.

This analysis contributes to the field of postcolonial studies as it reinforces the idea that postcolonial literature not only documents history, but subverts the dominant narrative in an attempt to truly pick apart and make visible what history tries to erase. In the end, this novel offers no happy ending, but it does leave the reader with a profound truth: violence from war is never separate from the violence of the system that shaped it.

Works Cited

Adnan, Etel. Sitt Marie Rose. Translated by Georgina Kleege, Post-Apollo Press, 1982.

Foster, Thomas. “Circles of Oppression, Circles of Repression: Etel Adnan’s Sitt Marie Rose.” PMLA, vol. 110, no. 1, 1995, pp 59-74. Cambridge University Press.

Harrison, Olivia C. “Resistances of Literature: Strategies of Narrative Affiliation in Etel Adnan’s Sitt Marie Rose.” Postcolonial Text, vol. 5, no.1, 2009.

MAKDISI, SAMIR, and RICHARD SADAKA. “The Lebanese Civil War, 1975–90.” UNDERSTANDING CIVIL WAR: Evidence and Analysis, edited by Paul Collier and Nicholas Sambanis, World Bank, 2005, pp. 59–86. JSTOR, http://www.jstor.org/stable/resrep02484.7.

Manuratne, Prabha.“The Traitor as a Figure of Betrayal in Etel Adnan’s Sitt Marie-Rose.” Suspect Belongings: Essays on Exile, Identity, and Postcolonial Literature, 2010.

Said, Edward W. Culture and Imperialism. Knopf, 1993.

Broadly Neutralizing Antibodies: Our Future By Mannas Malik

Abstract

This paper looks into how broadly neutralizing antibodies can aid in the design of next generation HIV vaccines. It looks to showcase their potential in overcoming the current problems plaguing today's HIV vaccines. Currently, an effective HIV vaccine has proven difficult to find despite many years of research. This is due to the fact that HIV has many special traits that help it evade traditional vaccines, including high sequence diversity and an extremely fast mutation rate. This paper uses a literature review in order to draw its conclusions. Relevant and up to date studies focusing on the applications and functions of bNAbs were carefully reviewed to aid with the paper. A focus was placed on identifying common trends between sources in order to pick out the most reliable information. The paper's findings suggest that bNAbs can neutralize a variety of HIV strains, thus making them extremely well suited to be the base of the next generation of vaccines. While limitations like cost and technology do exist, these can be overcome by collaboration and unity between companies and nations. To conclude, bNAb based vaccines offer an extremely promising future for the field of HIV research, but some practical barriers must be overcome to make this a reality.

Introduction

Creating an effective and safe vaccine for the Human Immunodeficiency Virus (HIV) has eluded scientists despite endless years of effort[12]. Due to its ability to evade standard immune defense mechanisms, HIV creates rare challenges for those trying to develop a vaccine[1]. Among the most significant barriers to development of an actual working vaccine is HIV's high mutation rate[2]. This allows it to rapidly modify surface proteins and not be efficiently recognized by the host's immune system[3]. Added to this difficulty is the virus's highly glycosylated envelope glycoprotein (Env), which is shrouded in a cloud of sugars that hides critical epitopes and limits antibody access[4]. These mechanisms make HIV extremely persistent in the body and highly resistant to most forms of neutralization[5]. This makes typical vaccine strategies such as those used in influenza and polio broadly useless[6].

In the last few years, a new strategy to fight HIV has been invented that is proving to be highly promising. It is based on using broadly neutralizing antibodies (bNAbs) to fight HIV[7]. These antibodies were first identified in a small percentage of patients who were infected for long periods of time with HIV[8]. After being researched, it was discovered that they had the ability to neutralize a variety of strains[9]. Unlike strain-specific antibodies traditionally employed in medicine, bNAbs target conserved areas of the HIV Env that are mostly unchanged across variants[10]. This breadth and potency makes bNAbs a great candidate to be the base of the next generation of vaccines[11].

The discovery of bNAbs has completely shifted the direction of HIV vaccine research as a whole[12]. Scientists are now attempting to understand how these antibodies naturally develop and what features give them their unique neutralizing activity, with the final goal of finding out how to recreate this process through vaccination in non-infected individuals[13]. This extensive focus on antibodies has produced a number of developments. These developments include new immunogen designs, germline-targeting strategies, and mRNA-based delivery systems that are all aimed at guiding the immune system's natural generation of bNAbs.

This research paper explains how broadly neutralizing antibodies are teaching and remodeling HIV vaccine development. The paper will begin by defining bNAbs and explaining how they vary from conventional strain-specific antibodies[14]. It will then go on to outline their mechanisms and structural targets, and how they interact with conserved regions on the HIV protein to avert entry[15]. The paper will then address the immunological challenges in inducing bNAbs through vaccination, including the needs for high levels of somatic hypermutation and exceptionally long antibody loops[16]. The paper will then address current vaccine strategies for surmounting these challenges, including sequential immunization regimens and mRNA delivery[17]. The research will lastly consider practical and ethical limits on these bNAb based approaches, including production expenses and dangers of experimental trials in vulnerable populations[18].

Lastly, by analyzing both the scientific breakthroughs and the controversies that remain, this paper will attempt to provide an insight into how bNAbs are spearheading the search for an effective HIV vaccine—one capable of ending a global pandemic once and for all[19].

Methods

This paper draws on information from an extensive literature review. Many relevant studies in the field were closely examined, and an emphasis was placed on recurring information. This was done in order to ensure the highest levels of accuracy. Additionally, all sources were checked for validity and that they are peer reviewed. The main databases used were PubMed and Google Scholar, and all papers focused on were peer reviewed.

What Are Broadly Neutralizing Antibodies?

Broadly neutralizing antibodies (bNAbs) are a highly specialized subset of antibodies that have the ability to neutralize a wide array of strains, including those relevant to HIV[20]. Routinely used in vaccines, strain-specific antibodies target variable regions of proteins and are only effective against one strain[21]. bNAbs, however, are capable of recognizing conserved regions of a virus that are shared by many strains, which makes them effective against far more than one strain[22]. It is this ability that allows bNAbs to overcome the strain diversity issue posed by HIV, thereby making them central to the development of next generation HIV vaccines[23].

To add to their rarity, bNAbs are not common in individuals with HIV. They naturally arise only in about 10–20% of people with the virus, and only after several years of chronic infection[24]. Their rarity is due to the exceptionally complex maturation process required for their

creation[25]. Most antibodies undergo limited somatic hypermutation, which can be thought of as minimal random changes in their genetic code that improve their ability to bind to antigens[26]. In contrast to this, bNAbs often undergo extensive hypermutation, with more than 30% deviation from their original gene sequences in some instances[27]. This extended maturation process allows bNAbs to acquire high affinity to antigens as well as breadth, but makes them difficult to induce through vaccination[28].

There have been several seminal studies that have enabled the discovery and characterization of bNAbs. One of the first broadly neutralizing antibodies, b12, was identified in the late 1990s and was found to bind the CD4 binding site of the envelope glycoprotein (gp) 120 (gp120) of HIV[29]. Dozens of bNAbs have since been isolated through methods such as single B cell sorting and high throughput neutralization screening[30]. Some examples are VRC01, which binds the CD4 binding site, and 2F5, which binds to portions of the gp41 membrane-proximal external region (MPER)[31]. These bNAbs have been shown to neutralize a vast majority of HIV strains, highlighting their potency[32]. These bNAbs possess characteristics that make them ideal templates for vaccines. Firstly, they possess breadth, meaning they can neutralize a vast number of genetically different strains of HIV[33]. They are potent, as they neutralize viruses at very low concentrations[34]. They recognize conserved epitopes, or parts of the HIV Env protein that are functionally important and hence less likely to mutate[35]. Several such epitopes are buried under the glycan shield or in recessed pockets, making it a rare occurrence for the immune system to access them without a considerable amount of antibody maturation[36].

These remarkable features of bNAbs have caused them to become a cornerstone of current HIV vaccine efforts[37]. Understanding how they develop, what they target, and how they function can potentially reveal valuable information regarding how a vaccine might elicit the same responses within uninfected individuals[38]. These antibodies truly appear to contain the secret to paving the path towards an actual vaccine, if their development can be replicated[39].

Mechanisms of Action and Targets of Broadly Neutralizing Antibodies

By binding to viral envelope glycoproteins which allow viral entry to cells, bNAbs neutralize HIV strains[40]. The Env protein is made up of multiple parts and has multiple binding sites which the virus can use as entry points[11]. Env proteins vary wildly and have high levels of glycosylation, which makes it hard for the immune system to generate memory towards and thus target[24]. However, bNAbs work by targeting conserved regions of the Env which are important to functions of the virus and therefore cannot tolerate mutations. This allows bNAbs to efficiently fight heterogeneous HIV strains[1].

Steric hindrance is one of the main ways bNAbs neutralize HIV. By binding tightly to epitopes on the Env protein, bNAbs physically block the virus from interacting with cell surface receptors[29]. This blockage prevents viral entry and thus stops infection[28]. For example, antibodies like VRC01 neutralize targets by binding to the gp120 CD4 T cell receptor site, which essentially serves to hide the site of entry from the virus[3]. Other bNAbs have other methods such as binding to membrane proximal regions and preventing membrane fusion[13].

Other than receptor blocking, bNAbs possess antiviral properties due to their Fc-effector actions[14]. After recognizing an antibody's Fc-region via Fc receptors of immune cells, antiviral mechanisms are triggered[19]. These mechanisms include antibody-dependent cellular cytotoxicity (ADCC) and antibody-dependent cellular phagocytosis (ADCP)[35]. Effector actions result in clearance of infected cells and virions from the host, complementing the neutralization functions of antibodies[16]. Research has shown that some bNAbs have mobilized these immune mechanisms, likely significantly contributing to their protective action *in vivo*[21].

Structural biology studies have enabled us to recognize the very precise binding sites and conformations of bNAbs on the HIV Env[12]. High resolution techniques like X-ray crystallography and cryo-electron microscopy have located bNAb epitopes to specific regions of the Env trimer[23]. These investigations recognize the specific features of the Env protein targeted by bNAbs, like recessed or glycan-warded conserved patches, which most antibodies cannot access[27]. Recognizing them, however, has enabled researchers to design immunogens to more closely mimic such open sites and induce bNAbs in vaccination[11].

In fact, most bNAbs themselves have distinctive structural characteristics[1]. For example, they tend to have very long heavy chain complementarity-determining region 3 (CDR3) loops, which are important antigen-binding regions of the antibody[3]. Long loops can potentially penetrate the tight glycan shield surrounding Env to gain access to conserved epitopes[20]. Additionally, bNAbs undergo a good deal of somatic hypermutation, which is the accumulation of genetic changes to refine and perfect antibody affinity to an antigen[28]. These kinds of features make bNAbs very unusual and very difficult to elicit naturally, as the immune system would not generally produce such highly mutated or structurally divergent antibodies without very extensive antigen experience[34].

Challenges in Eliciting Broadly Neutralizing Antibodies through Vaccination

Although it has been promising, vaccine-induced broadly neutralizing antibodies are one of the more formidable challenges of HIV research[33]. Unlike the majority of pathogens in which protective antibodies are induced reproducibly by conventional vaccines[15], bNAb induction is inhibited by multiple immunological and virological barriers[1]. One of the primary concerns centers on the huge levels of somatic hypermutation to produce bNAbs[17]. Most vaccines rely on naïve B cells to produce antibodies with relatively low levels of mutation[2]. These, however, contrast with bNAbs from HIV-infected individuals, which have 30% or more sequence divergence from their germline origin genes after years of chronic infection[27]. Widespread mutation implies an evolved process of affinity maturation by multiple rounds of affinity maturation within germinal centers of lymph nodes[28]. Mimicking this process by immunization has its challenges as it requires an immune process to undergo lengthy, highly specific evolutionary increments, a process not favorable to standard immunization regimens[40].
The other key challenge lies in the availability of the correct naïve B cell progenitors to be transformed into bNAb-producing cells[21]. Germline-targeting approaches try to circumvent this by designing vaccine immunogens to specifically engage and stimulate such restricted precursor

B cells [22]. These B cells, however, occur at very low frequencies and possess low affinities to the initial immunogens themselves[33]. Furthermore, some bNAbs possess structural characteristics not typical of or desirable within the naïve antibody repertoire, e.g., extremely lengthy CDR3 loops or non-consensus glycan recognition modalities[12]. That implies that there might be intrinsic limits to the immune system's ability to generate bNAbs, limiting the natural efficiency of the process[30].

The extremely glycosylated character of the HIV Env itself is a second barrier[35]. While its large glycan shield which blocks immune detection of virus simultaneously blocks access to conserved epitopes, bNAbs have found ways to traverse or survive glycans. However, vaccine immunogens themselves need to be accurately designed to expose such epitopes for recognition and a response-allowing conformation[24]. Recapitulation of the native Env trimer structure is also essential, since soluble monomeric gp120 protein used in early vaccine attempts failed to induce bNAbs by virtue of conformational disparity from the native viral spike[23].

Additionally, HIV's exceptionally high genetic diversity and mutability make it a moving target[1]. The vaccine needs to induce broadly recognizing, high-activity antibodies to protect against universally circulating strains[13]. That places another demand on vaccine design to induce bNAbs against highly conserved sites and not strain-specific locations, the latter of which can be more easily mutated[21].

In addition, immune tolerance mechanisms can inhibit bNAbs production[27]. Formation of some bNAbs may possess self- or unrelated-antigen binding ability, also referred to as poly- or autoreactivity[15], which can lead to autoimmunity[16]. This is admittedly somewhat ironic, as protection from self-reactivity by the immune system may, by error, inhibit development of some best anti-HIV antibodies[18]. Altogether, all these obstacles render current vaccine strategies inadequate to produce bNAbs[34]. Sophistication of maturation of the required antibodies, lack of precursor cells, Env structural hurdles, and immunoregulatory mechanisms all need to be overcome in new vaccine technologies[29]. Research is currently extremely busy developing new devices to produce vaccine solutions by virtue of advanced immunogen construction and step-by-step immunization protocols, which seek to guide the immune machinery through specific pathways of development required to produce broadly neutralizing antibodies[32].

Strategies for bNAb-based Vaccine Design

Identification of bNAbs has revolutionized HIV vaccine development by shifting focus away from generic to more nuanced, structure-directed, and immune-centric strategies in vaccine design[23]. bNAbs are extremely rare but potent antibodies, which are found in some individuals after several years of chronic HIV infection[1]. The overall goal of bNAb-based vaccine design is to trigger this process of maturation by immunizing, rather than waiting several years to observe what occurs following exposure to the virus itself[14]. Towards this, scientists have used a range of strategies, including germline-targeting immunogens, serial immunization regimens, mRNA-mediated delivery, and engineering of native-like HIV envelope (Env) proteins[27].

One of the main obstacles to bNAb induction after vaccination is the lack of enough qualified precursor B cells to become bNAb-producing cells[13]. These generally low-affinity naïve

B cells are not readily mobilized by vaccination, nor by any immunity stimulation method[29]. Germline-targeting strategies have thus been developed to overcome this obstacle[2]. They include the design of immunogens to bind to and engage the elusive yet correct precursor B cells, precisely[34]. One breakthrough came in the form of researchers coming up with the eOD-GT8 immunogen, with the aim of targeting the VRC01-class of bNAbs-precursors binding to HIV envelope CD4 binding site[1]. In the first-in-human clinical trial, IAVI G001, nearly all participants had the correct precursor B cell activation, demonstrating, to our knowledge, that vaccination was able to trigger the very first step of bNAb development[33].

However, germline-targeting is just the tip of the iceberg[40]. bNAbs typically arise after innumerable decades of unrestrained somatic hypermutation during a chronic infection state not readily replicable by a single immunogen[17]. To educate B cells in this intricate process of maturation for bNAb manufacture, researchers have resorted to serial immunization[26]. In this case, a prudent set of serial immunogens, any of which progressively molds the antibody response, is administered in a stepwise manner[18]. Precursor B cells are mobilized by an early-stage immunogen, while intermediate-stage immunogens guide them through rounds of affinity maturation, and terminal-stage immunogens train them to bind conserved HIV epitopes with high potency and specificity[19].

This approach has succeeded in animal systems[28]. Immunologists, for example, have serially vaccinated genetically engineered mice with a set of immunogens recapitulating the natural HIV course, successfully evolving antibody sequences towards effective lineages[21]. These results have been transferred to primate models and have begun to be evaluated in early-phase trials in humans[6]. These results indicate it's conceivable to engineer the antibody response to generate bNAbs, but precise vaccination schedule and immunogen design is required[23].

Another novel strategy includes the use of mRNA technology for vaccine delivery of HIV vaccine antigens[14]. The COVID-19 vaccine's success has proven the ability for mRNA vaccines to drive strong and specific immunities, and it is now being used to express targeted immunogens against HIV[34]. To give an example, Moderna, in collaboration with the National Institutes of Health (NIH) and International AIDS Vaccine Initiative (IAVI), has begun testing its mRNA-1644 vaccine in order to initiate the process of bNAb maturation by targeting germline B cells[2]. mRNA vaccines achieve this by depositing the genetic code of targeted-immunogens directly inside human cells, through which proteins are constructed to drive immunity[39]. There are some benefits to the process, including rapid manufacturing and reformulation of vaccine candidates[11], ability to code many immunogens in one formulation option[27], and ability to have immunization protocols sequences[21].

Even with all such advantages, mRNA vaccines are not without issues[1]. These vary from stability of the mRNA molecule to efficient delivery into the correct immune cells, to long-term safety—given that multiple doses could potentially be administered to prime antibody maturation. Preliminary indications, though, are that mRNA technology does present an effective means to deliver the complex immunogen sequences crucial to bNAb-based vaccines[33].

In parallel to such advances, engineering of HIV env proteins to be more native in form and to more aggressively stimulate the immune response has been undertaken[12]. Initial vaccine candidates were monomeric gp120-based, which were not effective in revealing crucial epitopes in native conformations. Novel approaches have resulted in native-like Env protein trimers, some of which, such as the SOSIP trimer, closely resemble native pre-fusion forms of the HIV spike[28]. These stable trimers have conserved components of a virus, which can often be targeted by bNAbs[36].

Some of the innovations involve glycan engineering to uncover previously hidden conserved epitopes with simultaneous presentation of various Env trimers by nanoparticles, with the goal of boosting B cell activation. These technologies allow for the improved ability of the immune system to detect and respond to difficult-to-target areas of the virus[14], and when used along with germline-targeting and serial immunization, are crucial in determining successful bNAb responses[38].

Best of all, however, is to combine all of these tools within a multicomponent vaccine regimen format[3]. One such format can be initiated by an mRNA-based delivery of a germline-targeting immunogen to engage rare precursor B cells, and repeated boosts of immunogens to initiate the maturity trajectory[38]. These can be delivered as genetically engineered Env trimers in combination with suitable adjuvants that enhance the immune system response[7]. While such regimens require careful design and trial, they appear to be the closest path to eliciting the much-desired broadly neutralizing antibody protection[4].

Limitations and Ethical Concerns of Broadly Neutralizing Antibodies

While bNAbs wait to transform the science of HIV vaccine research, application of bNAb strategies is simultaneously balanced by an agenda of daunting challenges[18]. These range from scientific, to logistical, to economic, to ethical. While identification of bNAbs is a scientific advancement, bringing bNAbs to a widely distributed and effective vaccine formulation is an ambitious and formidable endeavor[21]. One must stipulate what is within the reach of current technology to create a roadmap for future research and to commit to doing so in an ethically and internationally compliant manner[33].

Among the greatest challenges is the biological imperative to produce bNAbs by vaccination[34]. Mimicking to some extent this process by vaccination is biologically unnatural[13]. Most individuals' immune systems are not primed to produce bNAbs, and their B cell repertoires can be deprived of the precursor cells which produce bNAbs outright[23]. Even when early precursor activation can be attained by germline-targeting immunogens, little can be forecast to follow on this course, and it cannot be ensured to produce protective antibodies predictably in all individuals[9].

A second limitation of bNAbs is immune response strain specificity[19]. In spite of the breadth of bNAbs, no bNAb has been reported to neutralize all HIV strains[39]. Thus, combinations of bNAbs are necessary to achieve adequate coverage[32]. This complicates vaccine development and production in the sense that it would need to induce several lineages of bNAb simultaneously

or sequentially, each of which would need its own distinct set of individual immunogens[17]. Such complex regimens of immunization pose gargantuan scientific and logistical hurdles, particularly in HIV's most affected regions, where healthcare infrastructure is less than optimal.

Technologically, all the delivery technologies critical to bNAb-based vaccines are still experimental to date[34]. mRNA vaccines are newer technologies, hardly tested to this date beyond short-term safety. Furthermore, mRNA vaccines' cold-chain supply and ultra-cold refrigeration requirements to avoid loss of stability are significant barriers to global and equitable access[27]. These types of technical requirements threaten the development of a two-tiered system with affluent countries alone gaining in the latest HIV prevention technologies, further deepening global health inequities[21].

Economic limitation is no less daunting. Research and development of bNAb-based vaccines demand huge investments, high-end laboratories, and protracted timelines[33]. Production also commands huge investments, primarily if it entails more than a single engineered immunogen or nanoparticle platform[12]. For mass application in low-income nations, cost per dose must be decreased by bounds and leaps[37]. Large-scale, long-term trials to establish safety and efficacy of bNAb-eliciting vaccines must be conducted too, but trials cost millions and take years[36].

The most difficult issues, however, are ethical in nature[13]. Most HIV vaccine trials take place in high prevalence nations, virtually all of sub-Saharan Africa and Southeast Asia[32]. These are simply the individuals who would most benefit from effective vaccines and who would otherwise be least privileged in education, access to health care, and socioeconomic status[27]. Trials involving individuals in such settings pose fundamental issues regarding informed decision-making, exploitation, and medical fairness[20]. Individuals need to be sufficiently informed of the experimental nature of bNAb-based vaccines, its dangers, and the likelihood that individuals themselves may not individually benefit from trial participation[9]. True autonomy of decision-making is undermined if trial participation might offer individuals access to health care from which they would not have otherwise benefited[33].

Also, trials of vaccines need to be designed not to replace or pre-empt existing prevention interventions[29]. Ethically, all volunteers in trials need to be provided with the amount of HIV prevention we currently have, which is condoms, PrEP and education, and so on[23]. That creates a dilemma: if we have effective prevention methods to provide for our trial volunteers, it is more difficult to measure the incremental value of our test vaccine, trials go more slowly, but shortchanging on standard care would be unethical[12]. Researchers have to walk a tightrope, then, and balance good science with good care[31].

Another area of moral consideration is long-term consequences from antibody-based immunity[36]. Some vaccine platforms require multiple vaccinations at intervals, which leads to individuals who have variable, partial, or waning immunity. This could lead to people endangering themselves if they are under the assumption that they have absolute immunity, as they may not obtain supplementary booster injections or will rely upon waning immunity to preclude infection re-occurrence when it no longer provides any such immunity[13]. Furthermore,

should a few individuals respond to vaccination by producing effective bNAb, but not others, questions surrounding fairness and justice exist: who receives further-follow-up care? Who pays for further doses? What should occur should severe, rare, undesired effects occur in settings where sophisticated medical facilities are not available[30]?

Moreover, the extremely rapid rate of scientific advancement in this area has kept it ahead of general understanding and knowledge[19]. Misinterpretation or misinformation can possibly damage trust in vaccine science and clinical trials more generally, particularly among populations predisposed not to trust in Western therapeutic technologies as a product of histories of abuse[27]. Scientists and public health officials should prioritize frank discussion and trust-formation at all levels of vaccine research, especially when research involves disadvantaged or marginalized populations[21].

Although bNAb-based vaccines represent some of the largest advances in HIV prevention research to date, they await unprecedented restrictions and moral complications[12]. Scientific challenges including heterogeneity of the immune system, delivery, and number of immunogen requirements must be overcome simultaneously with global accessibility issues, cost-effectiveness, and protections from exploitation by research participants[33]. These very promising technologies can be pushed to the brink of universal, safe, effective, and accessible HIV vaccines by nothing short of deliberation between innovation, equality, and moral restriction[7].

Conclusion

Broadly neutralizing antibodies have revolutionized HIV vaccine research by infusing new energy into the decades-long quest for an effective barrier against one of the most lethal viruses in human history[14]. Unlike conventional strain-specific antibodies, bNAbs have a never-before-seen ability to identify and neutralize broad groups of HIV strains by binding to conserved regions of the virus coat glycoprotein[23]. For their record-breaking breadth and potency, bNAbs are one of the highest-priority target focuses for vaccine discovery research trying to overcome HIV's high mutation rate, glycan shielding, and immune evasive tactics[35]. What has been learned in bNAb research has changed our knowledge base and has led cutting-edge vaccine design technologies to potentially offer lasting, broad-spectrum protection.

Here, the features of bNAbs have been discussed in detail as they can neutralize highly heterogeneous viral variants and are reliant on intricate maturation processes including heavy and extensive somatic hypermutation and structurally unique features such as long CDR3 loops[19]. bNAbs' mechanisms for HIV neutralization—such as steric hindrance inhibition of HIV entry and by Fc-mediated effector functions to permit clearance of infected cells—highlight their multi-faceted action in immune protection[28]. Structural biologists have presented important findings into bNAbs' extremely specific binding sites on the HIV Env trimer, and it is now possible for researchers to design immunogens to copy such susceptible epitopes to induce similar antibody replies through vaccination[32].

Despite such improvements, elicitability problems caused by vaccine bNAbs remain daunting[13]. Induction of bNAbs by natural infection generally takes years of continuous infection and hence cannot readily be replicated in early-stage research facilities[15]. The novelty of bNAbs such as extensive mutation and low precursor B cells calls for new vaccine technologies capable of traversing the immune system through long development phases[21]. Technologies such as germline-targeting immunogens, serial immunization paradigms, and new mRNA-based delivery platforms advance and iterate within early-stage trials as it stands[7]. Early-stage trial breakthroughs such as IAVI G001 and Moderna's mRNA vaccine programs foretell advancement but also scientific- and logistically driven challenges[36].

The next steps in the field may benefit from multi-epitome vaccines. These target many epitopes of the virus simultaneously, which leads to more success. Furthermore, they can prime multiple types of B and T cells to bolster the immune system, which has long term benefits for the host. They are also cheaper to implement than many other methods, making them a realistic candidate as well as an effective one.

In bNAb-based vaccine design, there are parallel issues of limitation and ethically responsible considerations[1]. Biological hurdles to replicating bNAb production, multi-antigen vaccine immunization regimens, and high expense and technical complexity of newer vaccine technologies present pragmatic hurdles to universal application—especially to low-resource settings most impacted by HIV[33]. Ethical issues unique to clinical trials with vulnerable populations demand open, educational processes of consent and fairness in access to care and equipment of prevention[30]. Balance between vigorous scientific inquiry and consideration of participant and community well-being must be brokered to enable responsible future efforts to develop an HIV vaccine[18].

In years to come, the application of bNAbs to vaccine design against HIV is simultaneously a matter of scientific progress and a call to sustained collaborative action[32]. Basic research must push forward knowledge of bNAb development, enhance immunogen design, and identify the best vaccine delivery mechanisms[31]. Beyond this, surmounting economic and moral challenges by way of international collaboration, capacity building, and policy intervention will be essential to bridging gaps between scientific possibility and real application[27]. As the worldwide scientific community confronts these challenges, the prospect of eventually developing an effective vaccine against HIV to not only protect against but widely and long-term prevent disease appears ever more within our grasp[12]. In short, bNAbs have revolutionized the strategy towards HIV vaccine development by demonstrating how to neutralize a variety of viruses and immune escape[21]. They guided research away from conventional to novel vaccine constructions with the best immune system tools[33]. The bNAb research is not only advancing HIV vaccine research and general immunological research, but is hopefully translatable to vaccine construction against other quickly changing pathogens. Research conducted now on bNAb-directed vaccines represents a determinant step forward to ending the HIV/AIDS pandemic and attaining global health equity[36].

Works Cited

1.Upadhyay, C.. (2025, January 30). Progress and Challenges in HIV-1 Vaccine Research: A Comprehensive Overview. https://doi.org/10.3390/vaccines13020148

2.Burton, D. R., & Hangartner, L. (2016). Broadly neutralizing antibodies to HIV and their role in vaccine design. Annual Review of Immunology, 34(1), 635–659. https://doi.org/10.1146/annurev-immunol-041015-055515

3.Griffith, S. A., & McCoy, L. E. (2021). To BNAB or not to BNAB: Defining broadly neutralising antibodies against HIV-1. Frontiers in Immunology, 12. https://doi.org/10.3389/fimmu.2021.708227

4.Haynes, B. F., Wiehe, K., Alam, S. M., Weissman, D., & Saunders, K. O. (2023). Progress with induction of HIV broadly neutralizing antibodies in the Duke Consortia for HIV/AIDS Vaccine Development. Current Opinion in HIV and AIDS, 18(6), 300–308. https://doi.org/10.1097/coh.0000000000000820

5.Haynes, B. F., Wiehe, K., Borrow, P., Saunders, K. O., Korber, B., Wagh, K., McMichael, A. J., Kelsoe, G., Hahn, B. H., Alt, F., & Shaw, G. M. (2022). Strategies for HIV-1 vaccines that induce broadly neutralizing antibodies. Nature Reviews Immunology, 23(3), 142–158. https://doi.org/10.1038/s41577-022-00753-w

6.Julg, B., Walker-Sperling, V. E. K., Wagh, K., Aid, M., Stephenson, K. E., Zash, R., Liu, J., Nkolola, J. P., Hoyt, A., Castro, M., Serebryannyy, L., Yanosick, K., Speidel, T., Borducchi, E. N., Murzda, T., Maxfield, L., Arduino, R., McDermott, A. B., Gama, L., … Barouch, D. H. (2024). Safety and antiviral effect of a triple combination of HIV-1 broadly neutralizing antibodies: a phase 1/2a trial. Nature Medicine. https://doi.org/10.1038/s41591-024-03247-5

7.Landais, E., & Moore, P. L. (2018). Development of broadly neutralizing antibodies in HIV-1 infected elite neutralizers. Retrovirology, 15(1). https://doi.org/10.1186/s12977-018-0443-0

8.Mahomed, S. (2024). Broadly neutralizing antibodies for HIV prevention: a comprehensive review and future perspectives. Clinical Microbiology Reviews, 37(2). https://doi.org/10.1128/cmr.00152-22

9.Mahomed, S., Pillay, K., Hassan-Moosa, R., Galvão, B. P. G. V., Burgers, W. A., Moore, P. L., Rose-Abrahams, M., Williamson, C., & Garrett, N. (2025). Clinical trials of broadly neutralizing monoclonal antibodies in people living with HIV – a review. AIDS Research and Therapy, 22(1). https://doi.org/10.1186/s12981-025-00734-8

10.Schiffner, T., Phung, I., Ray, R., Irimia, A., Tian, M., Swanson, O., Lee, J. H., Lee, C. D., Marina-Zárate, E., Cho, S. Y., Huang, J., Ozorowski, G., Skog, P. D., Serra, A. M., Rantalainen, K., Allen, J. D., Baboo, S., Rodriguez, O. L., Himansu, S., … Schief, W. R.

(2024). Vaccination induces broadly neutralizing antibody precursors to HIV gp41. Nature Immunology, 25(6), 1073–1082. https://doi.org/10.1038/s41590-024-01833-w

11.Schommers, P., Kim, D. S., Schlotz, M., Kreer, C., Eggeling, R., Hake, A., Stecher, M., Park, J., Radford, C. E., Dingens, A. S., Ercanoglu, M. S., Gruell, H., Odidika, S., Dahlhaus, M., Gieselmann, L., Ahmadov, E., Lawong, R. Y., Heger, E., Knops, E., … Klein, F. (2023). Dynamics and durability of HIV-1 neutralization are determined by viral replication. Nature Medicine, 29(11), 2763–2774. https://doi.org/10.1038/s41591-023-02582-3

12.Sok, D., Laserson, U., Laserson, J., Liu, Y., Vigneault, F., Julien, J., Briney, B., Ramos, A., Saye, K. F., Le, K., Mahan, A., Wang, S., Kardar, M., Yaari, G., Walker, L. M., Simen, B. B., St John, E. P., Chan-Hui, P., Swiderek, K., … Poignard, P. (2013). The effects of somatic hypermutation on neutralization and binding in the PGT121 family of broadly neutralizing HIV antibodies. PLoS Pathogens, 9(11), e1003754. https://doi.org/10.1371/journal.ppat.1003754

13.Tsolaki, A. C., Tsolaki, M., Pandria, N., Lazarou, E., Gkatzima, O., Zilidou, V., Karagianni, M., Iakovidou-Kritsi, Z., Kimiskidis, V. K., & Bamidis, P. D. (2019). Web-Based Intervention Effects on Mild cognitive impairment based on apolipoprotein E genotype: Quasi-Experimental Study. Journal of Medical Internet Research, 22(5), e14617. https://doi.org/10.2196/14617

14.Huang, & Wang. (2025, June 9). A potent and broad CD4 binding site neutralizing antibody with strong ADCC activity from a Chinese HIV-1 elite neutralizer. Cell Discovery https://doi.org/10.1038/s41421-025-00808-x

15.Yu, L., & Guan, Y. (2014). Immunologic basis for long HCDR3s in broadly neutralizing antibodies against HIV-1. Frontiers in Immunology, 5. https://doi.org/10.3389/fimmu.2014.00250

16.Bale, S. D., Badman, S. T., Bonnell, J. W., Bowen, T. A., Burgess, D., Case, A. W., Cattell, C. A., Chandran, B. D. G., Chaston, C. C., Chen, C. H. K., Drake, J. F., De Wit, T. D., Eastwood, J. P., Ergun, R. E., Farrell, W. M., Fong, C., Goetz, K., Goldstein, M., Goodrich, K. A., ... Wygant, J. R. (2019). Highly structured slow solar wind emerging from an equatorial coronal hole. Nature, 576(7786), 237–242. https://doi.org/10.1038/s41586-019-1818-7

17.Bertrandt, J., Anyżewska, A., Łakomy, R., Lepionka, T., Szarska, E., Tomczak, A., Gaździńska, A., Bertrandt-Tomaszewska, K., Kłos, K., & Maculewicz, E. (2022). Assessment of energy expenditure of police officers trained in Polish police schools and police training centers. International Journal of Environmental Research and Public Health, 19(11), 6828. https://doi.org/10.3390/ijerph19116828

18.Byrareddy, S. N., Kallam, B., Arthos, J., Cicala, C., Nawaz, F., Hiatt, J., Kersh, E. N., McNicholl, J. M., Hanson, D., Reimann, K. A., Brameier, M., Walter, L., Rogers, K., Mayne, A. E., Dunbar, P., Villinger, T., Little, D., Parslow, T. G., Santangelo, P. J., ... Ansari, A. A. (2014). Targeting α4β7 integrin reduces mucosal transmission of simian

immunodeficiency virus and protects gut-associated lymphoid tissue from infection. Nature Medicine, 20(12), 1397–1400. https://doi.org/10.1038/nm.3715
19.Cho, J. H., & Feldman, M. (2015). Heterogeneity of autoimmune diseases: pathophysiologic insights from genetics and implications for new therapies. Nature Medicine, 21(7), 730–738. https://doi.org/10.1038/nm.3897
20.Clinical case of a patient undergoing radium-223 treatment following treatment with abiraterone acetate and enzalutamide. (2018, June 1). Exp Oncol. https://pubmed.ncbi.nlm.nih.gov/29949528/
21.Enomoto, K., Fukumoto, S., Mori, S., Nozaki, F., Hara, Y., & Tada, K. (2021). Survival With Surgery Is Superior to Survival Without Surgery in Breast Cancer Patients Aged 85 years or Older: A Retrospective Study. The American Surgeon, 87(11), 1746–1751. https://doi.org/10.1177/00031348211054067
22.Erratum. (2019). Brazilian Journal of Biology, 80(1), 234. https://doi.org/10.1590/1519-6984.er219204
23.Fang, Z., Jiang, W., Liu, P., Xia, N., Li, S., & Gu, Y. (2025). Targeting HIV-1 Immune Escape Mechanisms: Key advances and challenges in HIV-1 vaccine design. Microbiological Research, 299, 128229. https://doi.org/10.1016/j.micres.2025.128229
24.Gafni, O., Weinberger, L., Mansour, A. A., Manor, Y. S., Chomsky, E., Ben-Yosef, D., Kalma, Y., Viukov, S., Maza, I., Zviran, A., Rais, Y., Shipony, Z., Mukamel, Z., Krupalnik, V., Zerbib, M., Geula, S., Caspi, I., Schneir, D., Shwartz, T., ... Hanna, J. H. (2013). Derivation of novel human ground state naive pluripotent stem cells. Nature, 504(7479), 282–286. https://doi.org/10.1038/nature12745
25.Maji, A., Singh, A., Mohanty, A., Maji, P. K., & Ghosh, K. (2019). Ferrocenyl palladacycles derived from unsymmetrical pincer-type ligands: evidence of Pd(0) nanoparticle generation during the Suzuki–Miyaura reaction and applications in the direct arylation of thiazoles and isoxazoles. Dalton Transactions, 48(45), 17083–17096. https://doi.org/10.1039/c9dt03465j
26.Meng, Y., Zhong, J., Lv, Y., & Zou, W. (2022). Research progress on HIV-1 immune escape mechanisms. Aids Reviews, 24(3). https://doi.org/10.24875/aidsrev.21000068
27. Musacchia, G., Hu, J., Bhutani, V. K., Wong, R. J., Tong, M., Han, S., Blevins, N. H., & Fitzgerald, M. B. (2019). Frequency-following response among neonates with progressive moderate hyperbilirubinemia. Journal of Perinatology, 40(2), 203–211. https://doi.org/10.1038/s41372-019-0421-y
28. Nel, C., & Frater, J. (2024). Enhancing broadly neutralising antibody suppression of HIV by immune modulation and vaccination. Frontiers in Immunology, 15. https://doi.org/10.3389/fimmu.2024.1478703
29.Nunes-Alves, C. (2015). Taking advantage of quorum sensing. Nature Reviews Microbiology, 13(5), 252. https://doi.org/10.1038/nrmicro3477

30.Seeholzer, L. F., Seppo, M., Stern, D. L., & Ruta, V. (2018). Evolution of a central neural circuit underlies Drosophila mate preferences. Nature, 559(7715), 564–569. https://doi.org/10.1038/s41586-018-0322-9
31.Spearman, P. (2006). Current progress in the development of HIV vaccines. Current Pharmaceutical Design, 12(9), 1147–1167. https://doi.org/10.2174/138161206776055859
32.Sprent, J. (2017). T cell–B cell collaboration. Nature Reviews. Immunology, 17(9), 532. https://doi.org/10.1038/nri.2017.62
33.Swanson, O. M., Zhang, Q. E., Van Itallie, E., Tian, M., Brown, A. R., Harris, C., Kapingidza, A. B., Rhodes, B., Smith, L. M., Venkatayogi, S., Cronin, K., Frazier, M., Parks, R., Bar, M., Jiang, C., Beem, J. S. M., Cheng, H., Davis, J., McGovern, K., ... Azoitei, M. L. (2025). An engineered immunogen activates diverse HIV broadly neutralizing antibody precursors and promotes acquisition of improbable mutations. Science Translational Medicine, 17(780). https://doi.org/10.1126/scitranslmed.adr2218
34.Thiagarajan, N., Subhas, A. V., Southon, J. R., Eiler, J. M., & Adkins, J. F. (2014). Abrupt pre-Bølling–Allerød warming and circulation changes in the deep ocean. Nature, 511(7507), 75–78. https://doi.org/10.1038/nature13472
35.Visan, I. (2014). Too much of a good thing. Nature Immunology, 16(1), 12. https://doi.org/10.1038/ni.3070
36.Walsh, S. R., & Seaman, M. S. (2021). Broadly neutralizing antibodies for HIV-1 prevention. Frontiers in Immunology, 12. https://doi.org/10.3389/fimmu.2021.712122
37.Wells, A. D., & Morawski, P. A. (2014). New roles for cyclin-dependent kinases in T cell biology: linking cell division and differentiation. Nature Reviews. Immunology, 14(4), 261–270. https://doi.org/10.1038/nri3625
38.Wiehe, K., Saunders, K. O., Stalls, V., Cain, D. W., Venkatayogi, S., Beem, J. S. M., Berry, M., Evangelous, T., Henderson, R., Hora, B., Xia, S., Jiang, C., Newman, A., Bowman, C., Lu, X., Bryan, M. E., Bal, J., Sanzone, A., Chen, H., ... Haynes, B. F. (2024). Mutation-guided vaccine design: A process for developing boosting immunogens for HIV broadly neutralizing antibody induction. Cell Host & Microbe, 32(5), 693-709.e7. https://doi.org/10.1016/j.chom.2024.04.006
39.Williams, R. A. M., Smith, T. K., Cull, B., Mottram, J. C., & Coombs, G. H. (2012). ATG5 Is Essential for ATG8-Dependent Autophagy and Mitochondrial Homeostasis in Leishmania major. PLoS Pathogens, 8(5), e1002695. https://doi.org/10.1371/journal.ppat.1002695
40. Yang, C. C., & Clemens, J. Q. (2020). Lower urinary Tract symptoms: Advances in Women's Urologic Health from MAPP and LURN. Urology, 150, 223–226. https://doi.org/10.1016/j.urology.2020.04.024

High Metallicity in Early Galaxies By Ethan Ding

Abstract

This study investigates the presence of high metallicity in early galaxies using simulation data from TNG50 at redshifts z = 15, 12, 10, 8, 6, 2, 1, 0.5, and 0. Analysis of Specific Star Formation Rate (sSFR), Stellar Mass, Gas Metallicity, and Star Metallicity reveals that measurably enriched galaxies already exist at z = 15, with more massive galaxies systematically exhibiting higher metallicities and star formation rates. Gas Metallicity consistently exceeds Star Metallicity in most early galaxies, with this offset decreasing over cosmic time. These findings suggest rapid metal enrichment occurs preferentially in massive, actively star-forming systems within the first 650 Myr after the Big Bang.

1. Introduction

Recent JWST observations find non-zero metallicities in $z \gtrsim 8$–10 galaxies — on the order of a few to a few tens of percent of solar ($12+\log(O/H) \approx 7$–8), subject to calibration and solar abundance choice. (Curti et al. 2023; Heintz et al. 2023; Nakajima et al. 2023). The surprising aspect relates to the timing of enrichment—these galaxies show measurable metallicity within 300-500 Myr after the Big Bang, much earlier than standard models predicted. (Hsiao et al. 2024) This challenges theoretical frameworks that expected more gradual metallicity buildup and longer timescales for the transition from pristine Population III to enriched Population II star formation.

Possible explanations for rapid early enrichment include:

- Enhanced star formation efficiency in early galaxies
- Top-heavy initial mass functions producing more metals per unit stellar mass
- Efficient gas recycling keeping metals within galaxies
- Pre-enrichment from Population III stars

This paper uses simulation data from TNG50. TNG50 is a cosmological hydrodynamical simulation that simulates a 50 Mpc^3 box with 2160^3 gas cells, achieving a median spatial resolution of ~100-140 parsecs in star-forming regions across cosmic time. As part of the IllustrisTNG project, TNG50 combines large cosmological volume with high resolution to

resolve internal galactic structures including spiral arms, bulges, and nuclear bars. The simulation contains approximately 100 Milky Way analogs, one massive galaxy cluster (~10^{14} M⊙), and dozens of group-sized halos. TNG50's galaxy formation model includes magnetohydrodynamics, stellar and supermassive black hole feedback, chemical enrichment tracking nine elements (H, He, C, N, O, Ne, Mg, Si, Fe), and radiative processes, covering the redshift range from cosmic reionization (z ~ 6) through cosmic noon (z ~ 2) to the present day. (Nelson et al. 2019; Pillepich et al. 2019)
This work analyzes simulation snapshots to identify and characterize metal-enriched galaxies in the early universe.

2. Data and Methods

2.1 Simulation Data

Analysis uses 9 snapshots from cosmological simulations:

- Snapshot 001: z = 15 (271 Myr after Big Bang)
- Snapshot 002: z = 12 (370 Myr after Big Bang)
- Snapshot 004: z = 10 (475 Myr after Big Bang)
- Snapshot 008: z = 8 (640 Myr after Big Bang)
- Snapshot 013: z = 6 (932 Myr after Big Bang)
- Snapshot 033: z = 2 (3285 Myr after Big Bang)
- Snapshot 050: z = 1 (5878 Myr after Big Bang)
- Snapshot 067: z = 0.5 (8587 Myr after Big Bang)
- Snapshot 099: z = 0 (13803 Myr after Big Bang)

2.2 Key Parameters Analyzed

SubhaloMassType: Stellar Mass (M⊙/h), the total mass of all member particle/cells which are bound to this Subhalo, separated by type. Particles/cells bound to subhaloes of this Subhalo are NOT accounted for.

SubhaloStarMetallicity: Star Metallicity (log(Z*/Z⊙)), the mass-weighted average metallicity (Mz/Mtot, where Z = any element above He) of the star particles bound to this Subhalo, but restricted to stars within twice the stellar half mass-radius.

SubhaloSFR: Star Formation Rate (M⊙/yr), the sum of the individual star formation rates of all gas cells in this subhalo. sSFR, Specific Star Formation Rate, has a unit of 1/yr.

SubhaloGasMetallicity: Gas Metallicity (log(Zgas/Z⊙)), the Mass-weighted average metallicity (Mz/Mtot, where Z = any element above He) of the gas cells bound to this Subhalo, but restricted to cells within twice the stellar half mass radius.

SubhaloVmax: Maximum circular velocity (km/s), the maximum value of the spherically-averaged rotation curve. All available particle types (e.g. gas, stars, DM, and SMBHs) are included in this calculation.

SubhaloHalfmassRad: Half-mass radius (ckpc/h, comoving kiloparsecs per Hubble constant), the comoving radius containing half of the total mass (SubhaloMass) of this Subhalo.

3. Results

3.1 Star Formation Rate and Mass-Metallicity Relation

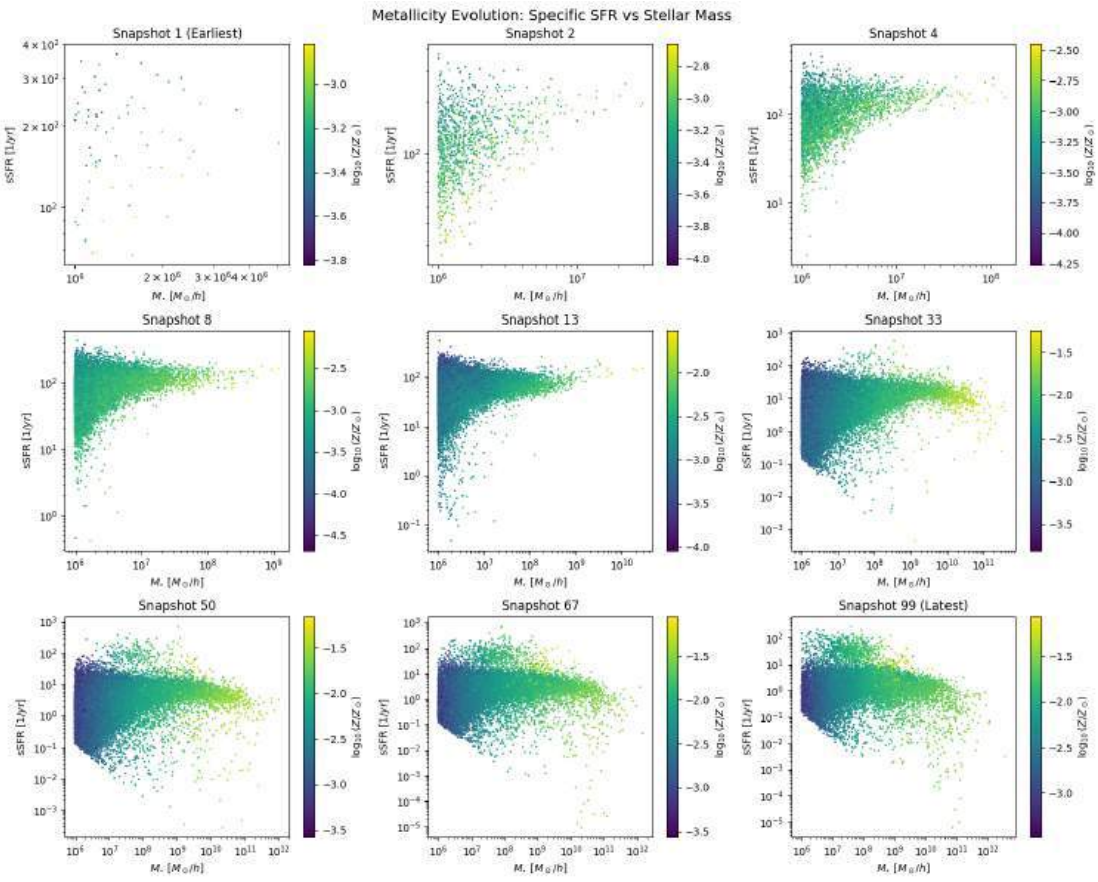


Figure 1. Specific Star Formation Rate (sSFR) vs. Stellar Mass across redshifts, color-coded by metallicity

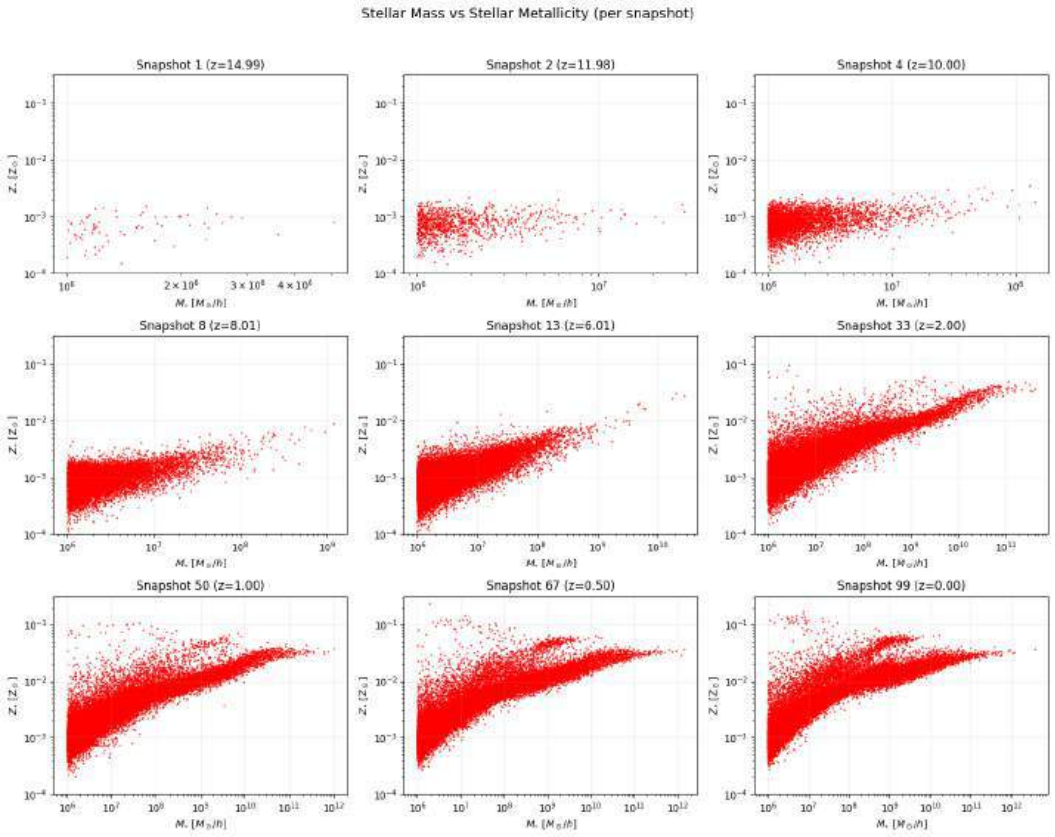
Figure 1 shows the relation between sSFR and Stellar Mass on logarithmic scales, with points colored by metallicity. Yellow indicates values closer to $\log(Z/Z\odot) = 0$, while purple indicates more negative values.

For snapshots 001, 002, 004, and 008, galaxies with low Stellar Mass values show sSFR ranging widely from 10 to above 10^2/yr. As Stellar Mass increases, the dots become less dense and concentrate near sSFR ~ 10^2/yr. As the redshift decreases, the sSFR value in which the dots

concentrate near at shifts downward, from about 80/yr in snapshot 013 to about 1/yr in snapshot 099.

Moving from snapshot 001 to snapshot 013, the number of galaxies increases significantly. The sSFR values show increasingly scattered distributions. Earlier snapshots (001 and 002) contain relatively more purple dots (low metallicity) than yellow compared to other snapshots which contains much higher ratio of yellow dots to purple dots, though the total galaxy count is much lower. This demonstrates that while high-metallicity systems are rarer at early times compared to at later times, they do exist at z = 15.

Figure 2. Stellar Mass vs. Star Metallicity, showing correlation at different redshifts



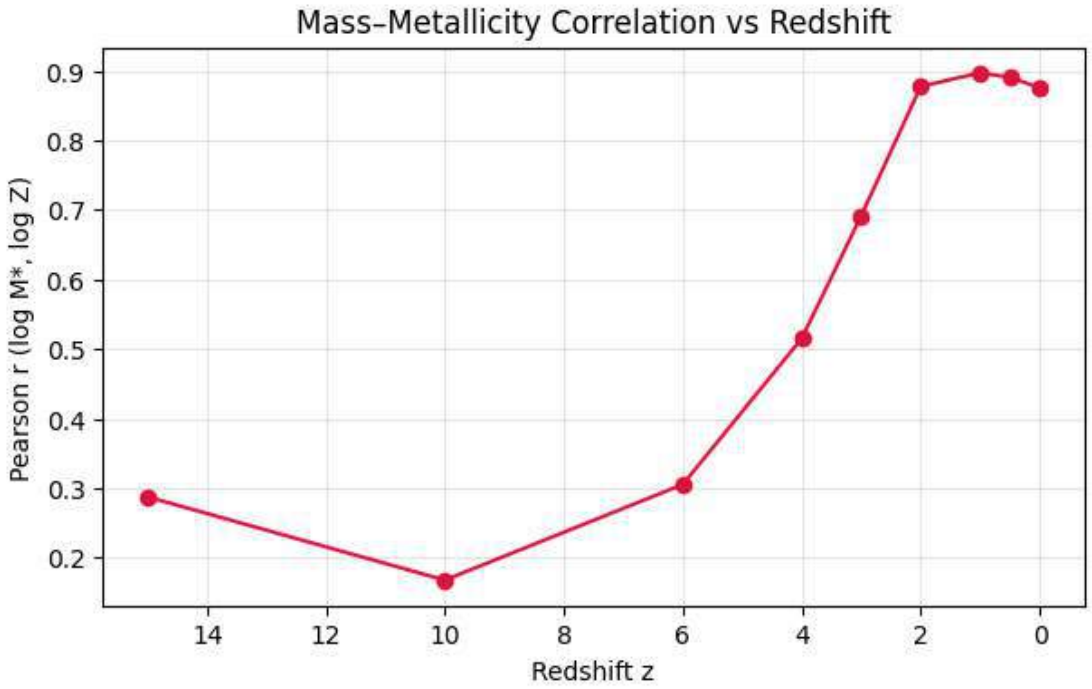


Figure 3. Evolution of the Mass–Metallicity Relation across redshifts

Figure 2 shows Stellar Mass vs Star Metallicity on logarithmic scale. For snapshot 001 and 002, Star Metallicity remains mostly independent of Stellar Mass. Figure 3 shows the Mass-Metallicity Correlation across different redshifts. For figure 2 and 3, starting from snapshot 004, a clear trend appears: Star Metallicity becomes increasingly positively correlated with Stellar Mass.

This positive correlation between Star Metallicity and Stellar Mass can be explained by the difference in gravitational strength of galaxies. Galaxies with higher Stellar Mass have stronger gravity, allowing them to retain more heavy elements released during supernova, whereas galaxies with lower Stellar Mass are more likely to lose heavy elements, resulting in higher metallicity in galaxies with greater Stellar Mass.

3.2 Galaxy Structure Evolution

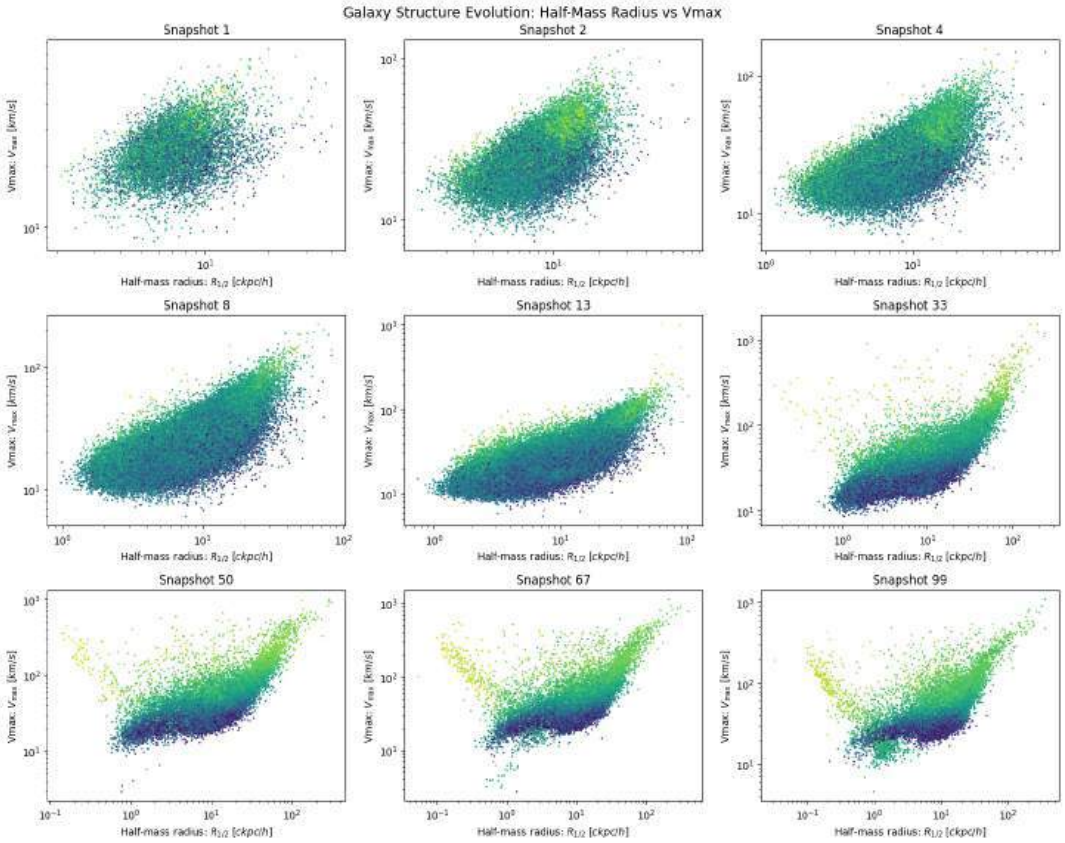


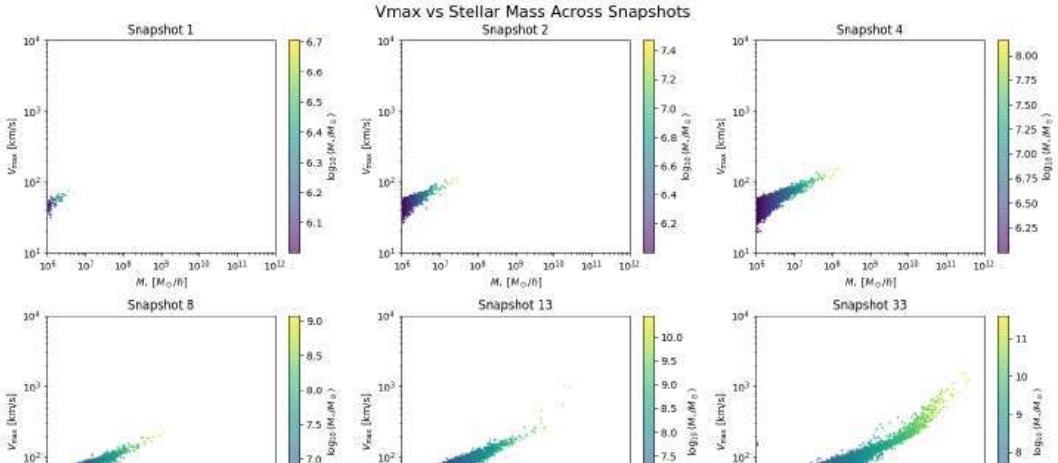
Figure 4. Half-mass Radius vs. Maximum Circular Velocity, colored by metallicity

Figure 4 displays the evolution of galaxy structure through Half-mass radius vs Maximum Circular Velocity for 9 snapshots. The color in the plots represents metallicity. Yellow represents higher metallicity, while purple represents lower metallicity. From the plots, higher Maximum Circular Velocity galaxies tend to have higher metallicity.

At low Half-mass radius values (around 1 ckpc/h), Maximum Circular Velocity is about 25 km/s. In all plots, the general trend is that Half-mass radius and Maximum Circular Velocity are positively correlated.

Starting from snapshot 2, and becoming more pronounced toward lower redshifts, a clear trend emerges: galaxies with higher Maximum Circular Velocity tend to exhibit higher metallicities, as indicated by the plots, where yellow colors correspond to higher metallicity values.

Figure



5. Relationship between Maximum Circular Velocity, Stellar Mass, and metallicity

Figure 5 shows that Maximum Circular Velocity is positively correlated with Stellar Mass, which in turn correlates with metallicity, but metallicity appears independent of Maximum Circular Velocity at fixed Stellar Mass, indicating an indirect relationship mediated by Stellar Mass.

The positive correlation between Stellar Mass and Maximum Circular Velocity shows that more massive galaxies can sustain higher rotational velocity. However, since metallicity and Maximum Circular Velocity aren't directly correlated to each other, it shows that metallicity is primarily driven by the stellar component rather than the dynamical properties of the halo. This implies that metal enrichment is more closely related to star formation processes and feedback mechanisms within the galaxy than to the overall halo dynamics.

3.3 Gas versus Stellar Metallicity Evolution

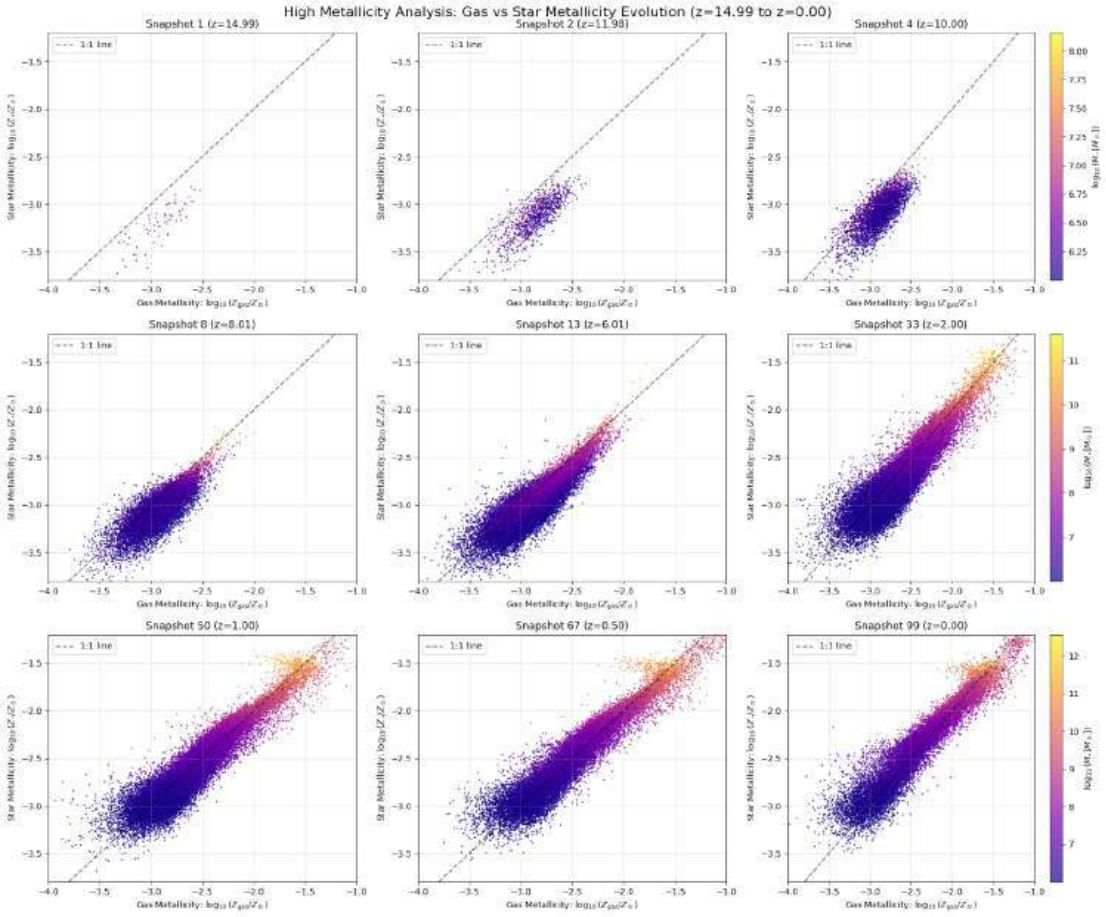


Figure 6. Star Metallicity vs. Gas Metallicity for nine snapshots, color-coded by stellar mass

Figure 6 shows Star Metallicity (log(Z*/Z⊙)) vs Gas Metallicity (log(Zgas/Z⊙)) for 9 snapshots, colored by log(M*[M⊙]) with purple indicating lower values and yellow higher values. As redshift decreases, galaxies approach the 1:1 line.

From snapshot 001 to 033, the galaxy population grows rapidly. In the early snapshots (001–008), most galaxies lie just below the 1:1 line, showing that gas metallicity is higher than star metallicity. Over time, from snapshot 001 to 099, the points move upward, and more galaxies align with the 1:1 line. In all plots, the general trend is that Star Metallicity and Gas Metallicity are positively correlated. Notably, at snapshot 050, 067 and 099, a cluster of galaxy datapoints appear on the 1:1 line with higher Gas Metallicity and Star Metallicity values than most other data points.

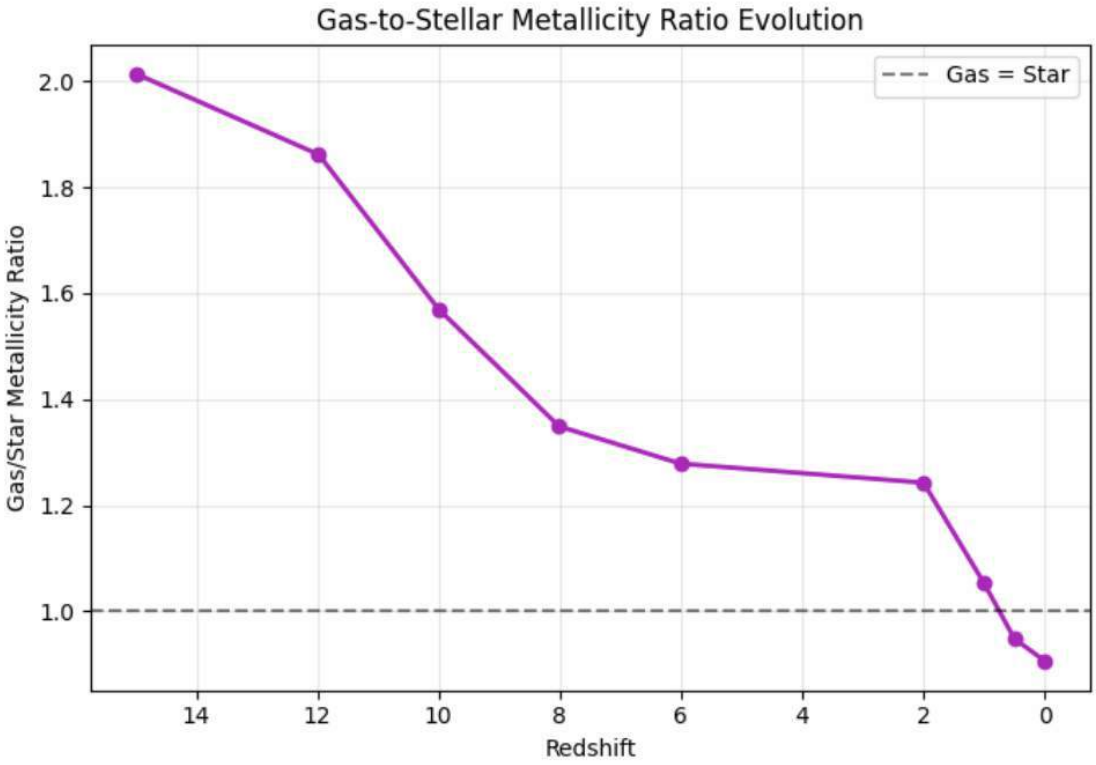


Figure 7. Evolution of the Gas-to-Stellar Metallicity Ratio across redshifts

Figure 7 shows the median Gas Metallicity to Star Metallicity ratio of the 9 snapshots. The dotted line is where Gas Metallicity equals Star Metallicity. As redshift decreases from 15 to 0, the Gas-to-Stellar Metallicity ratio declines from >2 to <1, showing that stars become increasingly metal-enriched over time.

4. Discussion

4.1 Early Metal Enrichment Mechanisms

The presence of galaxies with relatively high metallicities ($\log(Z/Z\odot) > -3$) even at $z = 15$ demonstrates that metal production begins almost immediately after first star formation. The systematic offset with Gas Metallicity exceeding Star Metallicity suggests ongoing enrichment - stars might retain their formation metallicity while gas continues to be enriched. The convergence toward the 1:1 line from $z = 15$ to $z = 0$ and the smaller dispersion of snapshot 099 compared to snapshot 004 near the 1:1 line suggests that galaxies gradually approach an equilibrium state in which stellar and gas-phase metallicities are approximately equal.

4.2 sSFR and Stellar Mass

The large scatter in sSFR at fixed Stellar Mass, particularly at early times, implies substantial galaxy-to-galaxy variations in star formation history, potentially explaining the diversity in observed high-redshift metallicities.

5. Conclusions

Analysis of galaxy simulations from z = 15 to z = 0 reveals that high-metallicity galaxies exist at all redshifts studied, though they become more common and reach higher metallicities at later times. Stellar Mass correlates with metallicity, with galaxies having higher Stellar Mass and lower sSFR tending to have higher metallicity. Gas Metallicity exceeds Star Metallicity, and this offset decreases over time as systems approach equilibrium, with a small portion of galaxies at z = 0 showing slightly inverted ratios. The galaxy population with Stellar Mass greater than 10^6 M⊙/h grows dramatically from z = 15 to z = 6, with the metallicity distribution shifting toward higher values and showing increasing sSFR-dependence.

Acknowledgements

I am deeply grateful to my mentor, Richard Stiskalek, for his invaluable guidance and support throughout this research project. His expertise in cosmological simulations and insightful feedback on data analysis and interpretation were essential in refining the methodology and results of this study.

I also extend my sincere thanks to the Lumiere Research Scholar Program for providing an exceptional platform that connected me with my mentor, facilitated regular progress monitoring through structured check-ins and resources, and enabled me to pursue research.

Works Cited

Curti, M., et al. 2023, "The chemical enrichment in the early Universe as probed by JWST via direct metallicity measurements at z ~ 8", MNRAS, 518, 425

Heintz, K. E., et al. 2023, "The gas and stellar content of a metal-poor galaxy at z=8.496 as revealed by JWST and ALMA", A&A, 679, A2

Nakajima, K., et al. 2023, "JWST Census for the Mass-Metallicity Star Formation Relations at z = 4-10", ApJS, 269, 33

Hsiao, T. Y., et al. 2024, "Dilution of chemical enrichment in galaxies 600 Myr after the Big Bang", Nature Astronomy, 8, 230

Nelson, D., et al. 2019, "The IllustrisTNG simulations: public data release", Computational Astrophysics and Cosmology, 6, 2

Pillepich, A., et al. 2019, "First results from the TNG50 simulation: the evolution of stellar and gaseous disks across cosmic time", MNRAS, 490, 3196

Characteristics of MHL Programs for Adolescents in School Setting By Hannah Rhim

Introduction

In recent decades, mental health challenges among adolescents have become increasingly prevalent, with an estimated 10–20% of young people worldwide experiencing mental health disorders (Seedaket et al., 2020). This growing concern highlights the need for accessible, early interventions that can help adolescents recognize mental health issues, understand treatment options, and seek appropriate support. One approach is improving mental health literacy (MHL), which encompasses knowledge of mental health disorders, ability to recognize symptoms, knowledge of professional help, and willingness to seek help when needed (Jorm et al., 1997). School environments play an important role in providing opportunities to this approach of improving mental health literacy because it is an institution closest to adolescence during development. It can serve as a place for promoting mental health literacy and early intervention. However, the effectiveness of school-based MHL programs varies significantly depending on factors such as program design, implementation, and broader educational context. In addressing these factors, this literature review will explore the current state of research on school based MHL initiative, factors that influenced success, and areas for further development.

MHL is defined as knowledge of how to prevent mental disorders, ability to recognize developing disorders, knowledge of help-seeking options and treatments available, knowledge of self-help strategies for milder problems, and first aid skills to help others impacted by mental health problems (Jorm, 1012). MHL is needed in different settings throughout all ages including school, work, community welfare centers, and more because MHL programs need context specific; MHL intervention for one profession, like a teacher, will not work the same for another profession, like a police. But in the span of 2016 to 2019 in the United States, visits in emergency departments with the principal diagnosis being related to mental health among ages 0-17 years increased from 784.1 per 100,000 population to 869.3 per 100,000 population and in the last decade before 2019, suicidal behaviors among highschoolers have increased more than 40% (2022 National Healthcare Quality, 2022). Additionally, during adolescence, social, cognitive, and emotional domains change, leading to adolescents experiencing frequent and intense emotions that put them at a higher risk to develop mental illnesses.

Research on adolescents' baseline knowledge provides important context for understanding intervention needs. A survey of 193 middle school students found significant knowledge gaps, with only 25% knowing that overly energetic behavior is a symptom of bipolar disorder and only 9% certain that schizophrenia does not involve multiple personalities (Wahl et al., 2012). Most students (65%) were uncertain whether mental illness has biological causes, and less than half (37%) believed medication is useful in treatment. Despite these gaps, attitudes were generally positive, with over 90% agreeing that people with mental illness deserve respect, though social distance measures revealed reluctance to interact closely with peers who have mental illness (Wahl et al., 2012). With this rising rate and lack of knowledge, MHL is a priority to keep adolescents knowledgeable about the possibilities of developing a mental illness and

how to seek treatment. States commonly require 180 days of 5 to 6 hours of school per year which can add up to 900 to 1080 hours per year. And with most adolescents attending some form of educational institutions, it is crucial to review MHL programs in school settings.

Each MHL program designs are distinctive and measurement tools to assess mental health literacy are unique to each study, making conclusions challenging to generalize about different factors of MHL programs. Furthermore, much studies were done in Western Countries, lacking geographical diversity, and didn't measure the cost-effectiveness of interventions, which can impact real-world implementation and policy decisions regarding MHL programs. Therefore, synthesis of literature to identify key factors that contribute to an effective MHL interventions/programs methodologically, culturally, and economically is crucial.

Methods

A search was conducted using Google Scholar to identify relevant studies on MHL programs in school settings. The key search terms included "Mental Health Literacy," "Adolescents," and "Schools." Inclusion criteria were studies that focused on adolescents, were implemented in school settings, and were published in English. These studies were then categorized into three groups based on the design and delivery method of the MHL programs.

Results

School-based mental health literacy programs vary in design and implementation approaches. While these programs consistently improve mental health knowledge, their effectiveness in reducing stigma and promoting help-seeking varies significantly across different contexts and settings. Methodological limitations, including brief follow-up periods and lack of standardized measures, constrain meaningful cross-study comparisons.

MHL Program Types and Delivery Methods

School-based MHL programs can be categorized into three major formats: curriculum-integrated programs, standalone interventions, and contact-based interventions. Curriculum-integrated programs are embedded into existing school curricula and typically delivered by trained classroom teachers. The Guide, a comprehensive Canadian program with six structured modules covering stigma, symptom recognition, and help-seeking strategies, is a widely studied example (McLuckie et al., 2014). When delivered by trained educators during regular health classes, The Guide has demonstrated significant improvements in student knowledge and attitudes (McLuckie et al., 2014).

Standalone interventions, such as Australia's HeadStrong and Norway's "Mental Health for Everyone", are implemented outside regular school curriculum. These programs are generally shorter in duration and delivered by external facilitators or researchers (Seedaket et al., 2020). While they report improvements in MHL components, they face challenges with long-term sustainability.

Contact-based interventions involve direct interactions between individuals who have lived experience of mental illness and these interactions between experienced individuals and adolescents showed promise in reducing stigma when combined with educational content (Sampaio et al., 2022).

Multimodal Strategies and Innovations

Traditional MHL programs often rely primarily on informational sessions focusing on symptom recognition and treatment awareness but more definitions have expanded to specifically include stigma reduction. Originally, mental health literacy was targeted towards professional groups, population subgroups, or disorders but with growing media, mass campaigns became possible which allowed a higher coverage of people including middle to low income countries. With this, innovative approaches increasingly incorporate interactive elements, such as group discussions, multimedia presentations, experiential workshops, and personal storytelling (Sampaio et al., 2022).

A growing trend in MHL program design is the integration of positive mental health promotion, which focuses on obtaining and maintaining good mental health, alongside traditional mental illness education, which focuses on mental disorders and risk factors (Sampaio et al., 2022). When adolescents aged 15-21 years were studied for mental well being, the regression model accounted for 41% of the variance in adolescents' mental well-being, positive MHL being a significant explanatory variable (Sampaio et al., 2022).

Contextual Influences on Program Implementation

The effectiveness of school-based MHL programs also varies significantly depending on the educational context in which they are implemented. Programs have been delivered in both well-resourced urban schools and under-resourced rural schools, including those in low- and middle-income countries (Kutcher et al., 2015). For instance, The Guide was successfully implemented across four Canadian school boards involving over 400 Grade 9 students, resulting in sustained improvements in knowledge and attitudes at a two-month follow-up (McLuckie et al., 2014). In contrast, the culturally adapted The African Guide: Malawi version (AGMv) demonstrated viability in resource-constrained settings, with educators in 35 schools participating in three-day workshops that led to significant improvements in mental health knowledge ($d = 1.16$) in and attitude ($d = 0.79$) (Kutcher et al., 2015). While these findings suggest that MHL programs can be effective in diverse settings, urban and better-resourced schools typically demonstrate higher program fidelity and stronger outcomes compared to rural or low-income schools. Key facilitating factors include supportive leadership, adequate training resources, and integration into routine schedules (Demissie et al., 2017).

Outcome Ef ectiveness: Mental Health Knowledge, Stigma, and Help-Seeking

School-based MHL interventions demonstrate varying degrees of success across three primary outcome domains: mental health knowledge, stigma reduction, and help-seeking

behaviors. A systematic review found that while these programs consistently improve mental health knowledge among adolescents, their effectiveness in reducing stigma and improving help-seeking behaviors is more limited (Ma et al., 2022). The Guide reported large effect sizes in knowledge gains (d = 0.90) with effects sustained over time (McLuckie et al., 2014), and the AGMv program showed significant stigma reduction among educators (d = 0.79) (Kutcher et al., 2015). However, improvements in help-seeking outcomes are much less consistent. A systematic review by Mae et al. (2022) found no strong evidence for MHL program effectiveness in improving help-seeking outcomes. This included general attitudes towards help-seeking, personal intentions to seek help, knowledge of when and how to seek help, confidence to seek help, and actual help-seeking behaviors (Ma et al., 2022).

Another program, Breaking the Silence curriculum was evaluated with193 students across four schools. The program consisted of six core components delivered over three class sessions and led to significant improvements in knowledge, attitudes, and social distance preferences among students compared to control groups (Wahl et al., 2011). Improvements were sustained at a six-week follow-up (Wahl et al., 2011). Examples of improvements include increased recognition that famous people have experienced mental illness (from 39% to 90% agreement) and better understanding of medication as treatment (from 40% to 77% agreement), though some misconceptions persisted (Wahl et al., 2011).

Factors Influencing Program Ef ectiveness

Several design and delivery factors appear to influence program success. For example, programs integrated into existing school curricula and delivered by trained classroom teachers consistently yielded stronger results in mental health knowledge and stigma reduction (McLuckie et al., 2014; Ma et al., 2022). Interactive learning formats incorporating group discussions, multimedia presentations, and experiential activities were more likely to produce positive outcomes compared to purely didactic approaches (Sampaio et al., 2022). Programs extensively varied in duration from single 20 minute sessions to multiple 40 minute sessions but there was no clear pattern of effectiveness found. Of the 27 studies reviewed, only 3 studies examined results beyond post-test follow-up; 2 studies showed knowledge persisted over time and 1 study showed knowledge decay at 6-month follow-up. Of the 8 studies with follow-up data on attitude, 4 studies showed sustained improvements (Wei et al., 2013).

Discussion and Limitations

Insert overview paragraph about MHL programs being a promising strategy to address the growing MH needs of adolescents. Describe what your review focused on and briefly mention what was helpful (curriculum-integrated programs and delivered by trained classroom teachers). Can also add that programs had strong outcomes in diverse settings which is a sign of them being adaptable interventions. [insert intro sentence about the field facing a critical challenge which is what you mention at the end of this paragraph translating knowledge gains into meaningful changes in help-seeking behavior]

The limited effectiveness in improving help-seeking behaviors represents a significant challenge, suggesting that knowledge alone may be insufficient to drive behavioral change and that interventions may need to address additional barriers such as service accessibility and social support (Ma et al., 2022).

Several methodological limitations constrain the current evidence base. Many studies rely on inconsistent or non-standardized outcome measures, limiting direct comparisons and reducing generalizability of findings (Ma et al., 2022). Furthermore, the predominant reliance on self-report measures and short follow-up periods weakens the strength of conclusions, as these tools fail to capture actual behavioral outcomes or long-term retention (Wahl et al., 2011). [Insert concluding sentence about how there are few studies that go on to measure MH service use] Sample-related limitations are also evident. Many studies involve small sample sizes, geographic homogeneity, often excluding marginalized populations such as low income students, ethnic minorities, students with disabilities, and those who don't attend education institutions. These omissions limit the inclusivity and applicability of findings across diverse adolescent populations. [add sentence about more representative research is needed to ensure relevance of interventions and effectiveness across diff cultural, socioeconomic, and geographic context.]Recent developments in the field point to an important conceptual shift in how MHL is defined and taught. Traditional programs have focused on a deficit-based model which differs from positive mental health literacy, which encompasses understanding how to obtain and maintain good mental health (Sampaio et al., 2022). This paradigm shift toward asset-based health promotion recognizes mental wellness as an independent focus and may provide a more appealing and comprehensive approach to adolescent mental health education.Despite these challenges, overall findings of this review reinforce the value of school-based mental health literacy programs to address adolescent mental health challenges. With the right structure, training, and contextual support, such intervention can significantly improve students' understanding of mental health and reduce stigmatizing beliefs. , with evidence consistently supporting curriculum-integrated programs delivered by trained teachers as most effective for improving student knowledge and reducing stigma. However, the field faces significant challenges in translating knowledge gains into meaningful improvements in help-seeking behaviors. The success of programs like The Guide in diverse contexts demonstrates potential for scalable, culturally adapted interventions, but realizing this potential requires addressing methodological, implementation, and policy challenges. Future research should prioritize standardized outcome measures, longitudinal follow-up studies, and interventions addressing complex barriers to mental health service utilization. With continued research, policy support, and implementation refinement, school-based MHL programs can serve as critical tools for promoting mental health awareness and reducing stigma among young people.

Works Cited

Demissie, Zewditu, et al. "Demographic Differences in District-Level Policies Related to School Mental Health and Social Services—United States, 2012." Journal of School Health, vol. 87, no. 7, 2017, pp. 527–534. Wiley Online Library, https://doi.org/10.1111/josh.12524.

Kutcher, Stan, et al. "Improving Malawian Teachers' Mental Health Knowledge and Attitudes: An Integrated School Mental Health Literacy Approach." Global Mental Health, vol. 2, 2015, e1, pp. 1–10. Cambridge University Press, https://doi.org/10.1017/gmh.2014.8.

Ma, Zhiyuan, et al. "School‐Based Mental Health Literacy Interventions to Promote Help‐Seeking in Children and Adolescents: A Systematic Review." Child and Adolescent Mental Health, vol. 27, no. 3, 2022, pp. 209–222. Wiley Online Library, https://doi.org/10.1111/camh.12533.

McLuckie, Alan, et al. "Sustained Improvements in Students' Mental Health Literacy with Use of a Mental Health Curriculum in Canadian Schools." BMC Psychiatry, vol. 14, 2014, article no. 379. BioMed Central, https://doi.org/10.1186/s12888-014-0379-4.

Sampaio, Francisco et al. "Mental Health Literacy: It Is Now Time to Put Knowledge into Practice." International journal of environmental research and public health vol. 19,12 7030. 8 Jun. 2022, doi:10.3390/ijerph19127030

Seedaket, Saranya, et al. "Improving Mental Health Literacy in Adolescents: Systematic Review of Supporting Intervention Studies." Tropical Medicine & International Health, vol. 25, no. 9, 2020, pp. 1055–1066. Wiley Online Library, https://onlinelibrary.wiley.com/doi/full/10.1111/tmi.13449.

Wahl, Otto F., et al. "Knowledge and Attitudes about Mental Illness: A Survey of Middle School Students." Psychiatric Services, vol. 63, no. 7, 2012, pp. 649–654.
https://doi.org/10.1176/appi.ps.201100505.

Wahl, Otto F., et al. "Changing Students' Attitudes about Mental Health Conditions: NAMI Ending the Silence." Stigma and Health, vol. 1, no. 1, 2016, pp. 35–42. https://doi.org/10.1037/sah0000011.

Wei, Yifeng, et al. "The Effectiveness of School Mental Health Literacy Programs to Address Knowledge, Attitudes and Help Seeking among Youth." Early Intervention in Psychiatry, vol. 7, no. 2, 2013, pp. 109–121. Wiley Online Library, https://doi.org/10.1111/eip.12010.

Ojio, Y., Yonehara, H., Taneichi, S., Yamasaki, S., Ando, S., Togo, F., Nishida, A. and Sasaki, T. (2015), In-school mental health literacy. Psychiatry Clin Neurosci, 69: 572-579. https://doi.org/10.1111/pcn.12320 Simkiss, Nicola J et al. "Improving mental health literacy in year 9 high school children across Wales: a protocol for a randomised control treatment trial (RCT) of a mental health literacy programme across an entire country." BMC public health vol. 20,1 727. 19 May. 2020, doi:10.1186/s12889-020-08736-z

Deep Learning for Seismic Phase Picking: A Transfer Learning Approach

By Avik Chervirala

Abstract

Accurate seismic phase picking is critical for earthquake detection, source characterization, and hazard monitoring. Traditional automated methods, such as STA/LTA detectors, often perform poorly under high-noise conditions common in volcanic regions. Recent advances in deep learning have produced models such as PhaseNet, EQTransformer, and GPD, which achieve human-level performance in tectonic contexts. However, their generalization to volcanic seismicity, especially long-period (LP) events associated with magmatic processes, remains limited. This study investigates the use of transfer learning to adapt pretrained PhaseNet models available in the SeisBench framework for heterogeneous volcanic datasets. Using waveform records from volcanic regions such as Hawaii and Northern California, I evaluate the baseline performance of PhaseNet and fine-tuning strategies to improve phase picking under varying noise and frequency conditions were evaluated and explored. Results demonstrate that transfer learning significantly improves P- and S-phase arrival detection, reducing mean absolute error and enhancing robustness to emergent LP phases. Findings suggest that transfer learning bridges the gap between global pretrained models and region-specific datasets, thereby contributing to the development of more accurate and generalizable monitoring tools for volcano seismology.

1. Introduction

Earthquakes and volcanic processes generate seismic waves that travel through the Earth. The accurate identification of the arrival times of these waves, a process known as seismic phase picking, forms the cornerstone of earthquake detection and location. The time difference between the P- and S-wave arrivals (S−P time) is directly proportional to the distance between the event's source and the recording station. By precisely picking these arrival times at multiple stations, seismologists can triangulate an event's location and depth.

Seismic phase picking of these two forms of waves form the cornerstone of earthquake detection and location procedures. Manual picking by analysts, though accurate, is time-consuming and increasingly impractical given the exponential growth of seismic data. Early automated techniques, including the short-term average/long-term average (STA/LTA) method (Allen, 1978), improved efficiency but remained sensitive to noise and required extensive parameter tuning. Template-matching approaches (Gibbons & Ringdal, 2006; Chamberlain et al., 2017) advanced detection by exploiting waveform similarity, yet they are limited to known event families.

In the last decade, deep learning has transformed seismology, with convolutional and attention-based models achieving accuracy on par with expert analysts (Mousavi et al., 2020; Zhu & Beroza, 2019). State-of-the-art models such as PhaseNet, EQTransformer, and DeepPhasePick (Soto & Schurr, 2021) demonstrate strong performance across tectonic datasets.

Nonetheless, generalization remains a persistent challenge: pretrained models often degrade when applied to "out-of-distribution" seismicity characterized by different noise levels, geology, or instrument responses (Teney et al., 2022; Wenzel et al., 2022).

Accurately forecasting volcanic eruptions is a critical challenge in natural hazard science, where improved monitoring techniques can directly save lives. Seismic monitoring is a cornerstone of this effort, as the movement of magma and fluids beneath a volcano generates distinct ground vibrations. However, volcanic seismicity presents unique diagnostic challenges. While some volcano-tectonic (VT) earthquakes share impulsive onsets with regular tectonic events, the most informative signals for forecasting, long-period (LP) earthquakes, are far more elusive.

The two primary types of waves used are Primary (P) waves and Secondary (S) waves. LP earthquakes, which are directly associated with magma or fluid movement, exhibit emergent onsets and depleted high-frequency content (Chouet & Matoza, 2013; Matoza & Roman, 2022). These unique characteristics reduce the effectiveness of automated detection models trained on tectonic datasets (Zhong & Tan, 2024). Since LP events are particularly diagnostic of magmatic processes that precede an eruption, developing reliable automated phase pickers is essential for robust hazard assessment (Acocella et al., 2023; White & McCausland, 2019). Enhancing our ability to rapidly and accurately detect these signals would provide volcano observatories with crucial real-time data, improving the timeliness and reliability of eruption warnings.
Transfer learning offers a potential solution by leveraging pretrained models while adapting them to specialized datasets. Prior work has shown that fine-tuning global models can enable robust monitoring at data-scarce volcanoes (Lapins et al., 2021). Building upon this foundation, we investigated how PhaseNet, a widely adopted U-net-based seismic phase picker, can be adapted to heterogeneous volcanic datasets using transfer learning strategies. Specifically, we test its baseline performance on volcanic data from Hawaii and Northern California and evaluate improvements after fine-tuning.

2. Methodology

2.1 Data Exploration

Seismic datasets and pretrained models were accessed through the SeisBench framework (Woollam et al., 2022). The dataset used here aligns with the global volcanic waveform compilation of Zhong & Tan (2024), which contains over 330,000 waveforms recorded at volcanoes in Alaska, Hawaii, Northern California, the Cascades, and Japan. Data from Hawaiian and Northern Californian volcanoes was used, including both VT and LP earthquakes. All waveforms are accompanied by manually picked P and S arrivals from regional observatory catalogs (USGS, NCEDC, NIED).

Preprocessing steps included:

- Bandpass filtering to remove extreme noise.

● Trace normalization by removing the mean and scaling to unit amplitude. ● Segmentation into fixed windows (typically 60s, with picks centered). ●

Conversion to SeisBench tensors for model input.

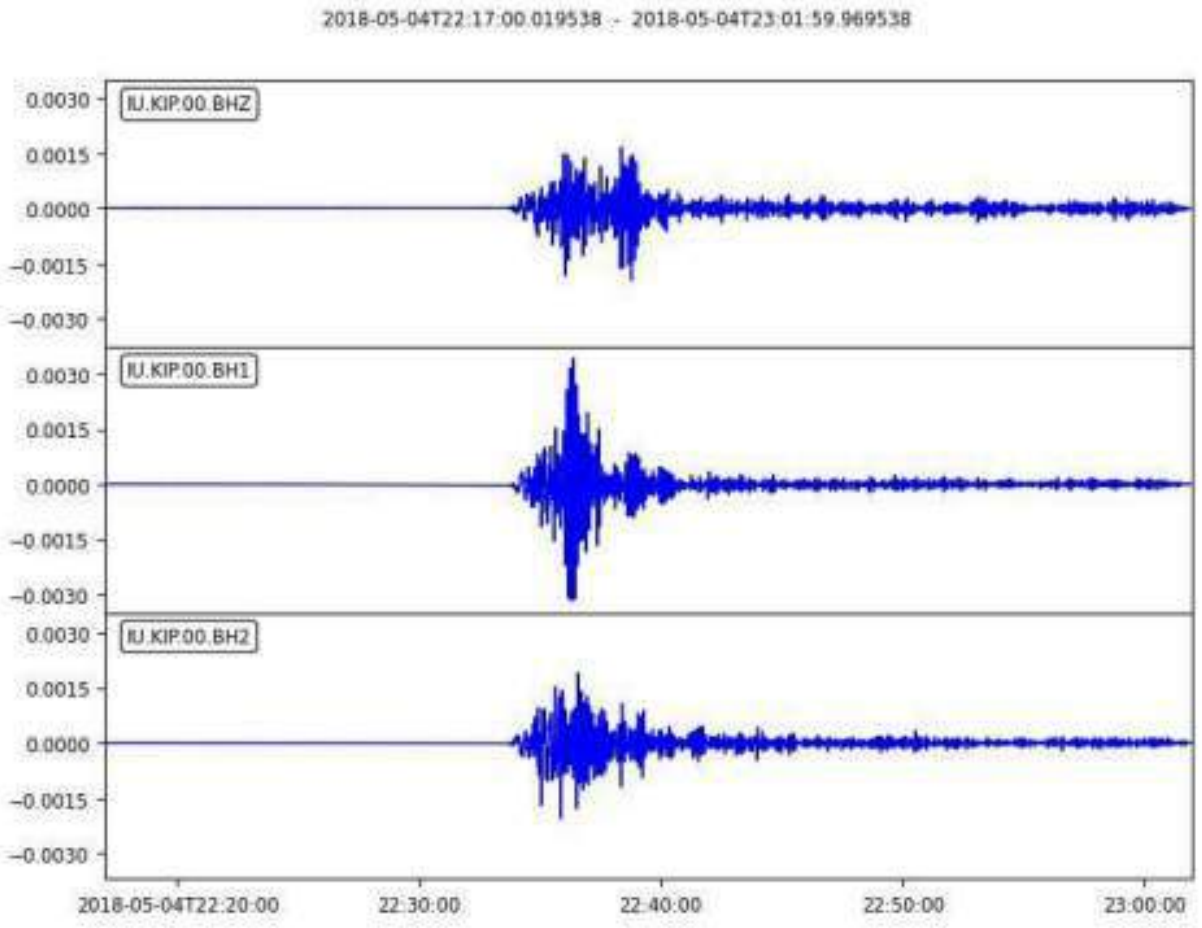


Figure 1. Example of a seismic waveform recorded at a Hawaiian station. The event exhibits clear P and S arrivals but is contaminated by volcanic tremor. Such events highlight the challenges of phase picking under high noise.

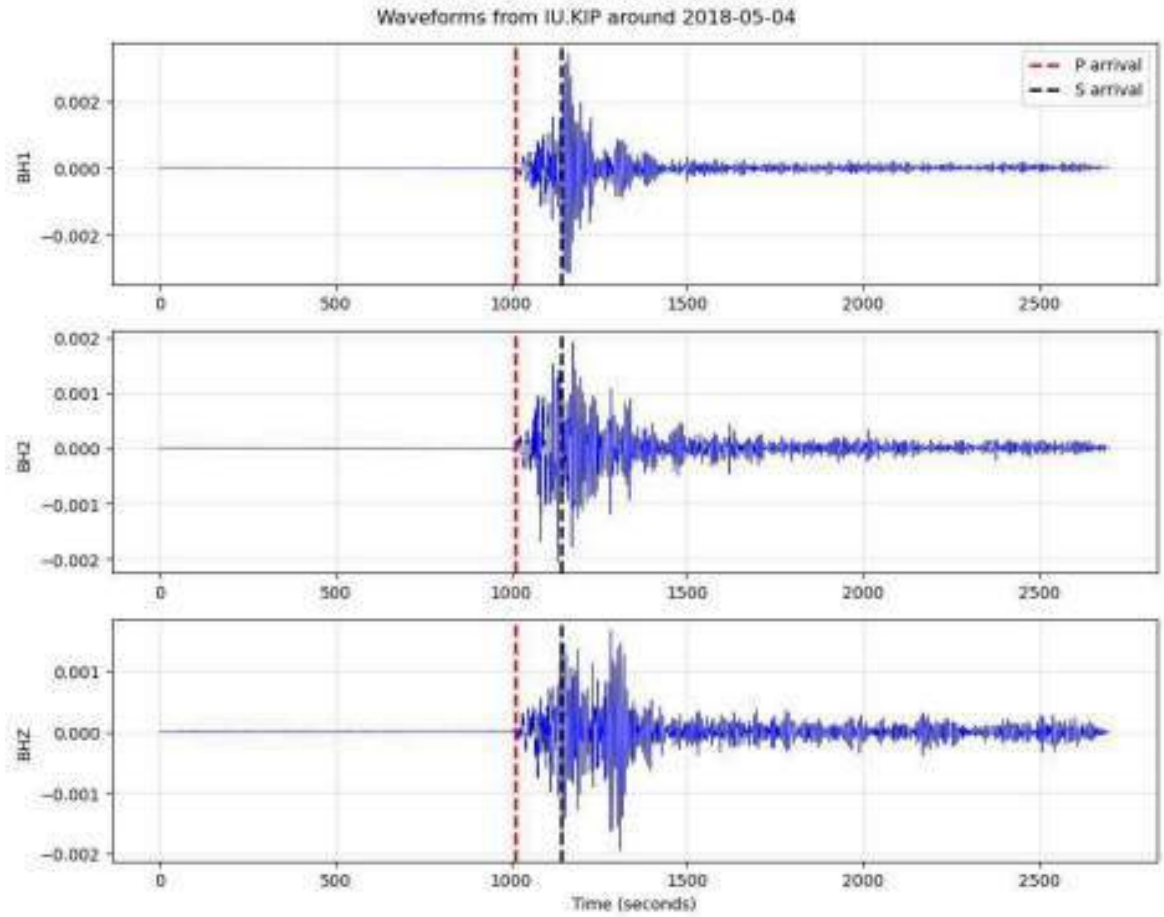


Figure 2. Catalogued P- and S-phase picks for the Hawaiian event in Figure 1. Manual analyst picks are marked, serving as ground truth labels for evaluation of automated methods.

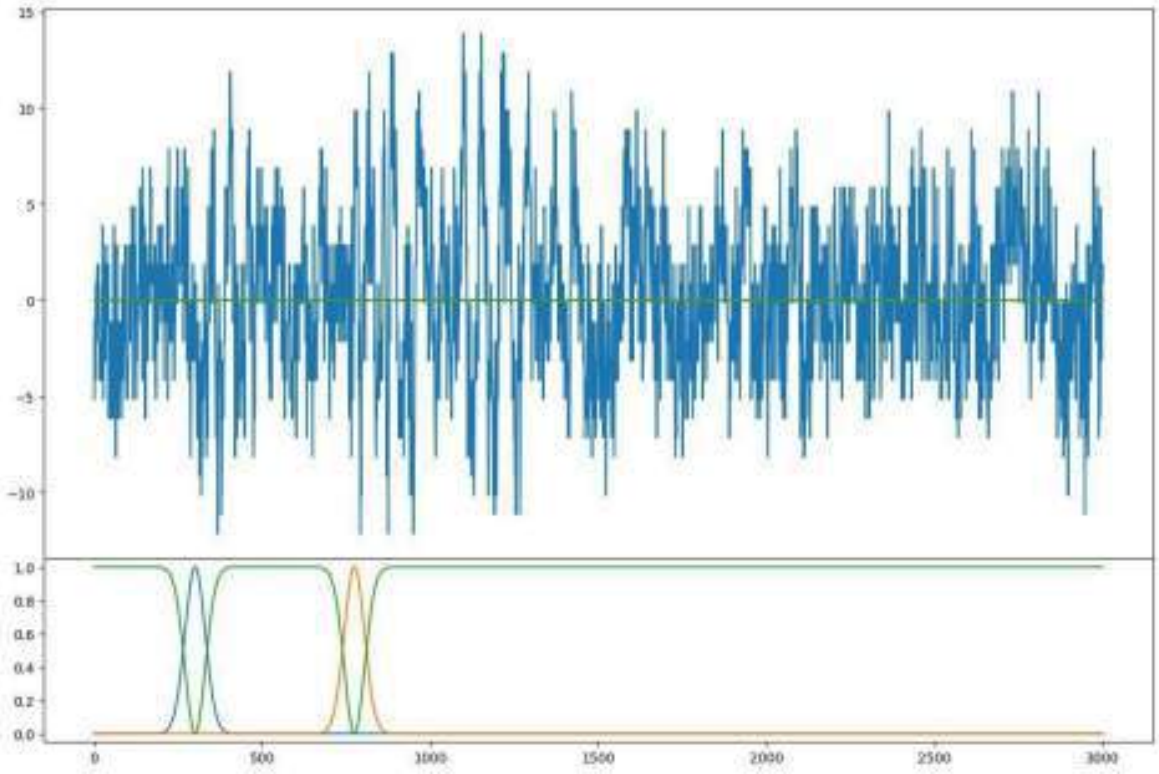


Figure 3. Example of P and S phases from a volcanic earthquake. The impulsive P onset is followed by an emergent S arrival, reflecting local geological heterogeneity.

2.2 Model Inference

PhaseNet (Zhu & Beroza, 2019) was selected as the baseline model due to its U-net structure, which has demonstrated high accuracy in tectonic contexts. Pretrained weights included in SeisBench were used and evaluated directly on volcanic data to assess generalization.

Transfer learning was then applied by fine-tuning the model on a subset of volcanic events using PyTorch. The fine-tuning strategy included:

- Initializing weights from the pretrained PhaseNet model.
- Freezing early convolutional layers to preserve low-level feature extraction. ● Fine-tuning deeper layers with a reduced learning rate (0.0005).
- Applying data augmentation (random shifts, noise injection, waveform mixing) as per Zhong & Tan (2024) to increase robustness.

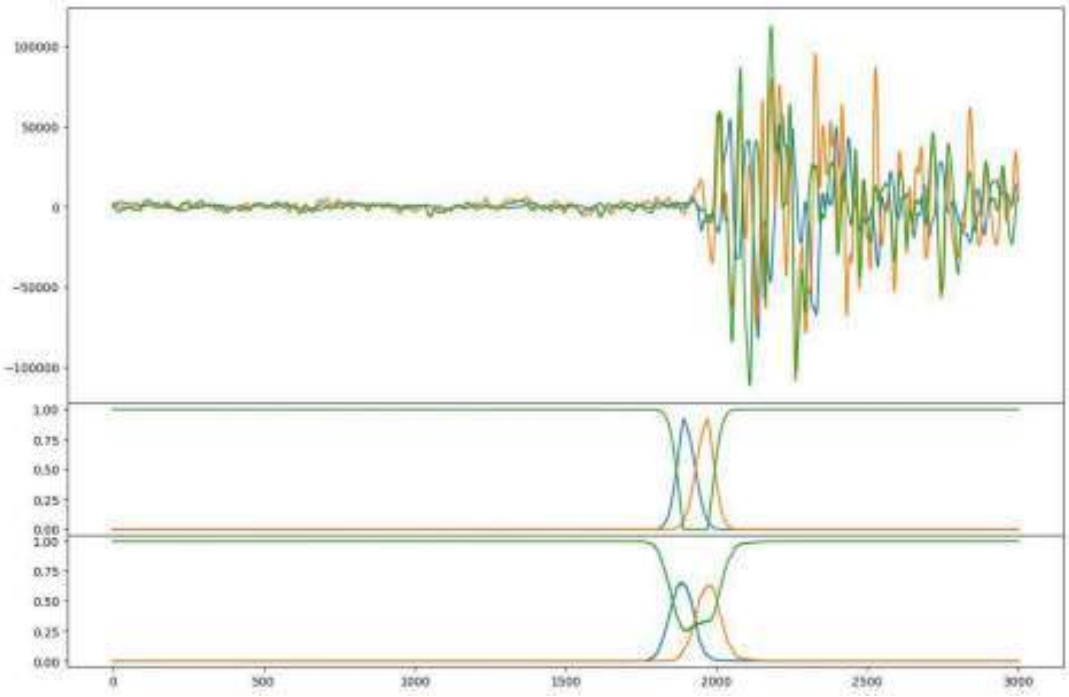


Figure 4. Data augmentation pipeline. Examples include waveform shifting, Gaussian noise injection, and synthetic mixing of two events. These augmentations help the model generalize to noisy volcanic conditions.

2.3 Evaluation

Model predictions were compared to manual picks using both qualitative and quantitative measures.

- **Qualitative:** Visual overlays of predicted vs. catalogued arrivals.
- **Quantitative:**
  - Mean Absolute Error (MAE) between predicted and true picks.
  - Precision, Recall, and F1 score following the point-based definitions of Zhong & Tan (2024).

Baseline PhaseNet was first evaluated on unseen volcanic events. Fine-tuned models were then tested on held-out sets to measure improvement in generalization and noise robustness.

3. Results

Baseline PhaseNet achieved consistent identification of P- and S-arrivals in VT earthquakes, with average MAE <x s for P picks but larger errors for S picks, especially in noisy LP events. Precision and recall degraded systematically with decreasing frequency content, echoing findings by Zhong & Tan (2024). LP events were frequently under-detected, with recall as low as x for S phases.

After fine-tuning, significant improvements were observed:

- MAE reduced to <x s for both P and S arrivals.
- F1 score for LP events improved from ~x to ~y.
    - Robustness to noise increased, with fewer spurious picks in tremor-rich records.

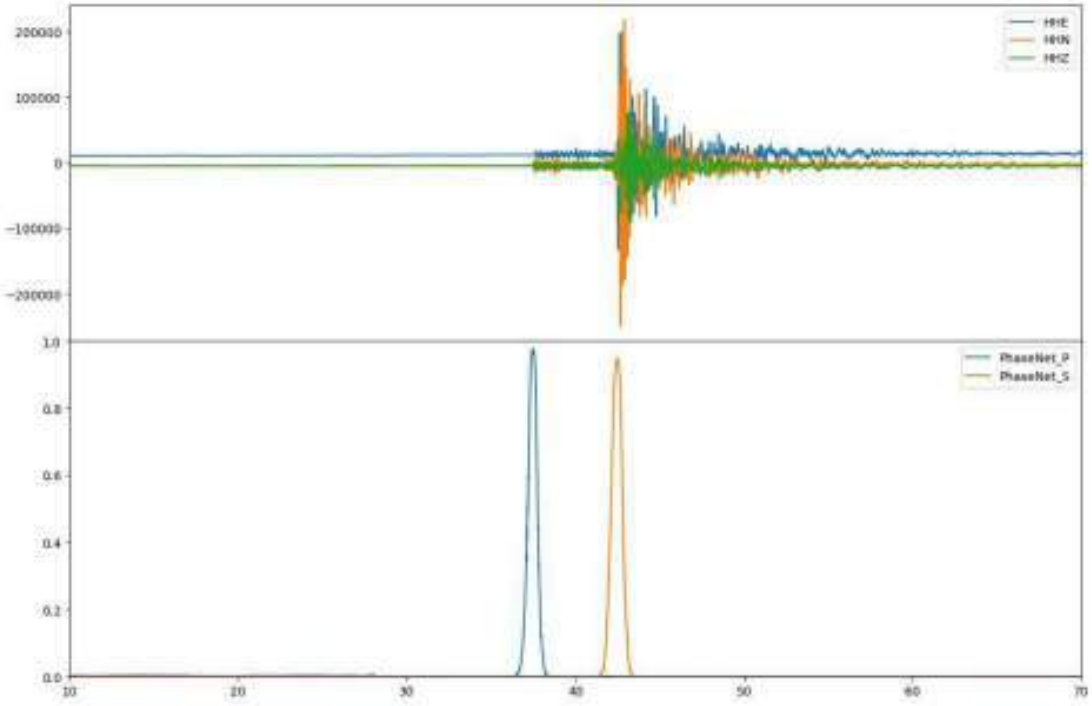


Figure 5. Example of P- and S-phase predictions by PhaseNet after fine-tuning. Predicted picks (red and blue vertical lines) align closely with catalogued arrivals (black dashed lines). Improvement over the baseline model is visible in the accurate detection of emergent S onsets.

These findings confirm the baseline performance of pretrained models, establishing a foundation for subsequent transfer learning experiments.

4. Discussion

Findings reinforce prior observations (Zhong & Tan, 2024; Lapins et al., 2021) that pretrained models degrade when applied off-the-shelf to volcanic datasets. In particular, LP earthquakes, which are diagnostic of magma and fluid movement (Chouet & Matoza, 2013; Song et al., 2023), pose significant challenges. However, transfer learning substantially improves performance, confirming that adaptation strategies are key to achieving generalizable phase pickers.

Compared with STA/LTA (Allen, 1978) and template-matching methods (Gibbons & Ringdal, 2006), deep learning not only offers superior accuracy but also eliminates the need for extensive manual parameterization. The transfer-learning approach builds on the strengths of global pretrained models while bridging regional variability. This aligns with recent directions in volcano seismology, where hybrid and fine-tuned models have shown promise (Kim et al., 2023; Armstrong et al., 2023).

Limitations remain. Data imbalance persists between VT and LP events, leading to

residual performance gaps. Moreover, while transfer learning improved results for Hawaii and Northern California, further tests on unseen volcanoes (e.g., Cascades, Japan) are necessary to validate global applicability.

Future work should explore ensemble models that combine PhaseNet, EQTransformer, and newer architectures (Mousavi et al., 2020; Zhong & Tan, 2024), as well as uncertainty quantification to inform real-time monitoring.

5. Conclusion

This study demonstrates that transfer learning enhances the ability of deep learning models to generalize seismic phase picking from tectonic to volcanic settings. By fine-tuning PhaseNet on volcanic datasets, we achieved improved accuracy and robustness, particularly for LP earthquakes that are critical for eruption forecasting. These results establish transfer learning as a practical and effective strategy for global volcano monitoring systems.

Works Cited

1. Abadi, M., Agarwal, A., Barham, P., Brevdo, E., Chen, Z., Citro, C., et al. (2015). TensorFlow: Large-scale machine learning on heterogeneous systems. Software available from tensorflow.org.
2. Acocella, V., Ripepe, M., Rivalta, E., Peltier, A., Galetto, F., & Joseph, E. (2023). Towards scientific forecasting of magmatic eruptions. Nature Reviews Earth and Environment, 5(1), 1–18.
3. Allen, R. V. (1978). Automatic earthquake recognition and timing from single traces. Bulletin of the Seismological Society of America, 68(5), 1521–1532.
4. Armstrong, A. D., Claerhout, Z., Baker, B., & Koper, K. D. (2023). A deep-learning phase picker with calibrated Bayesian-derived uncertainties for earthquakes in the Yellowstone volcanic region. Bulletin of the Seismological Society of America, 113(6), 2323–2344.
5. Aso, N., & Tsai, V. C. (2014). Cooling magma model for deep volcanic long-period earthquakes. Journal of Geophysical Research: Solid Earth, 119(11), 8442–8456. 6. Aso, N., Ohta, K., & Ide, S. (2013). Tectonic, volcanic, and semi-volcanic deep low-frequency earthquakes in western Japan. Tectonophysics, 600, 27–40. 7. Baer, M., & Kradolfer, U. (1987). An automatic phase picker for local and teleseismic events. Bulletin of the Seismological Society of America, 77(4), 1437–1445. 8. Bannister, S., Bertrand, E. A., Heimann, S., Bourguignon, S., Asher, C., Shanks, J., & Harvison, A. (2022). Imaging sub-caldera structure with local seismicity, Okataina Volcanic Centre, Taupo Volcanic Zone, using double-difference seismic tomography. Journal of Volcanology and Geothermal Research, 431, 107653.
9. Behr, W. M., & Bürgmann, R. (2021). What's down there? The structures, materials and environment of deep-seated slow slip and tremor. Philosophical Transactions of the Royal Society A, 379(2193), 20200218.
10. Bird, P. (2003). An updated digital model of plate boundaries. Geochemistry, Geophysics, Geosystems, 4(3).
11. Chai, C., Maceira, M., Santos-Villalobos, H. J., Venkatakrishnan, S. V., Schoenball, M., Zhu, W., et al. (2020). Using a deep neural network and transfer learning to bridge scales for seismic phase picking. Geophysical Research Letters, 47(16), e2020GL088651.
12. Chamberlain, C. J., Hopp, C. J., Boese, C. M., Warren-Smith, E., Chambers, D., Chu, S. X., et al. (2017). EQcorrscan: Repeating and near-repeating earthquake detection and analysis in Python. Seismological Research Letters, 89(1), 173–181.
13. Chen, H., Yang, H., Zhu, G., Xu, M., Lin, J., & You, Q. (2022). Deep outer-rise faults in the southern Mariana subduction zone indicated by a machine-learning-based high-resolution earthquake catalog. Geophysical Research Letters, 49(12), e2022GL097779.
14. Chouet, B. A., & Matoza, R. S. (2013). A multi-decadal view of seismic methods for detecting precursors of magma movement and eruption. Journal of Volcanology and Geothermal Research, 252, 108–175.
15. Garza-Girón, R., Brodsky, E. E., Spica, Z. J., Haney, M. M., & Webley, P. W. (2023). A

specific earthquake processing workflow for studying long-lived, explosive volcanic eruptions with application to the 2008 Okmok Volcano, Alaska, eruption. Journal of Geophysical Research: Solid Earth, 128(5), e2022JB025882.
16. Gibbons, S. J., & Ringdal, F. (2006). The detection of low magnitude seismic events using array-based waveform correlation. Geophysical Journal International, 165(1), 149–166.
17. Gong, J., Fan, W., & Parnell-Turner, R. (2023). Machine learning-based new earthquake catalog illuminates on-fault and off-fault seismicity patterns at the Discovery Transform Fault, East Pacific Rise. Geochemistry, Geophysics, Geosystems, 24(9), e2023GC011043.
18. Kim, A., Nakamura, Y., Yukutake, Y., Uematsu, H., & Abe, Y. (2023). Development of a high-performance seismic phase picker using deep learning in the Hakone volcanic area. Earth, Planets and Space, 75(1), 1–15.
19. Kingma, D. P., & Ba, J. (2015). Adam: A method for stochastic optimization. In Proceedings of the 3rd International Conference on Learning Representations (ICLR). 20. Kriegerowski, M., Petersen, G. M., Vasyura-Bathke, H., & Ohrnberger, M. (2019). A deep convolutional neural network for localization of clustered earthquakes based on multistation full waveforms. Seismological Research Letters, 90(2A), 510–516. 21. Lapins, S., Goitom, B., Kendall, J.-M., Werner, M. J., Cashman, K. V., & Hammond, J. O. S. (2021). A little data goes a long way: Automating seismic phase arrival picking at Nabro Volcano with transfer learning. Journal of Geophysical Research: Solid Earth, 126(7), e2021JB021910.
22. Matoza, R. S., & Roman, D. C. (2022). One hundred years of advances in volcano seismology and acoustics. Bulletin of Volcanology, 84(9), 86. https://doi.org/10.1007/s00445-022-01586-0
23. Melnik, O., Lyakhovsky, V., Shapiro, N. M., Galina, N., & Bergal-Kuvikas, O. (2020). Deep long-period volcanic earthquakes generated by degassing of volatile-rich basaltic magmas. Nature Communications, 11(1), 3918. https://doi.org/10.1038/s41467-020-17759-4
24. Mousavi, S. M., Ellsworth, W. L., Zhu, W., Chuang, L. Y., & Beroza, G. C. (2020). Earthquake Transformer: An attentive deep-learning model for simultaneous earthquake detection and phase picking. Nature Communications, 11(1), 3952. https://doi.org/10.1038/s41467-020-17591-w
25. Mousavi, S. M., Sheng, Y., Zhu, W., & Beroza, G. C. (2019). Stanford Earthquake Dataset (STEAD): A global data set of seismic signals for AI. IEEE Access, 7, 179464–179476.
26. Münchmeyer, J., Woollam, J., Rietbrock, A., Tilmann, F., Lange, D., Bornstein, T., et al. (2022). Which picker fits my data? A quantitative evaluation of deep learning-based seismic pickers. Journal of Geophysical Research: Solid Earth, 127(1), e2021JB023499. https://doi.org/10.1029/2021jb023499
27. Ross, Z. E., Meier, M.-A., Hauksson, E., & Heaton, T. H. (2018). Generalized seismic phase detection with deep learning. Bulletin of the Seismological Society of America, 108(5A),

2894–2901.
28. Soto, H., & Schurr, B. (2021). DeepPhasePick: A method for detecting and picking seismic phases from local earthquakes based on highly optimized convolutional and recurrent deep neural networks. Geophysical Journal International, 227(2), 1268–1294. https://doi.org/10.1093/gji/ggab266
29. Song, Z., Tan, Y. J., & Roman, D. C. (2023). Deep long-period earthquakes at Akutan volcano from 2005 to 2017 better track magma influxes compared to volcano-tectonic earthquakes. Geophysical Research Letters, 50(10), e2022GL101987.
30. Teney, D., Lin, Y., Oh, S. J., & Abbasnejad, E. (2022). ID and OOD performance are sometimes inversely correlated on real-world datasets. In Neural Information Processing Systems (NeurIPS).
31. Wenzel, F., Dittadi, A., Gehler, P. V., Simon-Gabriel, C.-J., Horn, M., Zietlow, D., et al. (2022). Assaying out-of-distribution generalization in transfer learning. In Neural Information Processing Systems (NeurIPS).
32. White, R. A., & McCausland, W. A. (2019). A process-based model of pre-eruption seismicity patterns and its use for eruption forecasting at dormant stratovolcanoes. Journal of Volcanology and Geothermal Research, 382, 267–297.
33. Woollam, J., Münchmeyer, J., Tilmann, F., et al. (2022). SeisBench: A toolbox for machine learning in seismology. Seismological Research Letters, 93(3), 1695–1709. https://doi.org/10.1785/0220210324
34. Zhong, Y., & Tan, Y. J. (2024). Deep-learning-based phase picking for volcano-tectonic and long-period earthquakes. Geophysical Research Letters, 51, e2024GL108438. 35. Zhu, W., & Beroza, G. C. (2019). PhaseNet: A deep-neural-network-based seismic arrival-time picking method. Geophysical Journal International, 216(1), 261–273. https://doi.org/10.1093/gji/ggy423

Acceptance of Digital Payments Among Fisherfolk in Manila NCR By Karunya Pandey

Abstract

Fisherfolk are a marginalized yet economically vital community within the Philippines' fisheries sector. Despite national growth in financial technology adoption, digital payment usage among fisherfolk remains minimal due to factors such as cultural attachment to cash, digital literacy, irregular income, and concerns over scams. Using a quantitative approach design, data were collected through a structured survey of 100 fisherfolk across Taguig, Navotas, Pasig, and Pasay. Sixteen hypotheses were tested using chi-square analyses, logistic regressions, correlation tests, t-tests, and non-parametric methods. Results indicate that gender, role in the fishing cycle, environmental encouragement, perceived fee fairness, and scam concerns significantly influence adoption, while age, education, buyer type, and transaction value do not. Cash remains the dominant mode of payment even among digital adopters, non-users are generally unwilling to shift in the near term, and overall satisfaction with digital platforms remains neutral. The findings highlight persistent structural, cultural, and perceptual barriers to fintech inclusion. Strengthening trust, improving support systems, and reducing fee-related concerns are key to enhancing digital payment adoption among fisherfolk communities.

Introduction

Fisherfolk are communities and individuals that rely on fisheries for their livelihoods. Their daily activities mainly focus on catching, processing, and selling fish or other aquatic resources (Food and Agriculture Organization, 1989). Fisherfolk are vital on a global scale because their occupation ensures access to one of the most easily obtainable sources of animal protein—fish. (Food and Agriculture Organization, 1989). This importance varies geographically, but is highest in island and peninsular locations. In these locations, the importance of fisheries is comparable to that of commonly relied-upon industries such as agriculture (Food and Agriculture Organization, 1989).

Within Southeast Asia, the Philippines is one of the nations that is more economically reliant on fishing. This can be seen when comparing the percentage of Gross Domestic Product that fishing contributes to island nations. The fishing sectors of Malaysia and Thailand respectively contribute 0.7% and 0.75% of the Gross Domestic Product, whereas the number is 1.3% in the context of the Philippines (World Bank, 2023; Infofish, 2023).

Locally, fisherfolk in the Philippines act as a backbone for small-scale economies, while also contributing highly to gross domestic product through factors such as export and employment (catching, selling, aquaculture), apart from the primary revenue generation through the sale of seafood (Philippine Statistics Authority, 2021). Fishing is treated as an act of self-sustenance by communities, evident by multiple Fishing Barangays, where the primary source of food, employment, income, and sustenance is fishing and/or fishing-related pursuits (Philippine Statistics Authority, 2021). Despite being extremely valuable to the socioeconomic landscape of the Philippines, fisherfolk are relatively impoverished. Fisherfolk are among

communities with high poverty incidence—precisely 34%, which is double the average national poverty incidence rate of 17% (Philippine Statistics Authority, 2021).

Digital payments can refer to payments that utilize technological aspects of finance, while reducing cash reliance. It can be seen in many forms globally—online banking, UPI (United Payment Interface), e-wallets, etc. These payment systems can often only be accessed through smartphones or personal computers, which leads to disparities in who can effectively and reliably utilize digital payments, and who cannot (Dubey & Gupta, 2024; Setiawati, 2025). Studies have shown that digital payment adoption is significantly higher in urban areas compared to rural areas due to better access to smartphones, internet connectivity, and financial literacy programs (Dubey & Gupta, 2024; Setiawati, 2025). In the Philippine context, urban centers such as Manila have a more developed digital infrastructure and higher exposure to fintech services, yet marginalized populations within these areas, such as fisherfolk, may still experience barriers to adoption (Dubey & Gupta, 2024; Setiawati, 2025). Understanding these urban-rural disparities is crucial for designing interventions that ensure inclusive digital payment adoption (Dubey & Gupta, 2024; Setiawati, 2025).

Digital payments in the Philippines have been steadily rising as a form of financial transactions. This can in part be accredited to high technological access of geographical demographics such as urban residents and generational cohorts such as Generation Z and Millennials (Setiawati, 2025). Due to the aforementioned factors, a sizable chunk of the Philippine population has accounts on digital payment platforms. There are multiple digital payment platforms in the Philippines. GCash, Maya, PayMaya, etc., are among some popular digital payment platforms (Bangko Sentral ng Pilipinas, 2020).

Supported by high poverty incidence rates in fisherfolk communities, the lack of adoption of digital payments has been a constant for the fisherfolk of Manila. Other factors that might influence this lack of adoption are – lines of informal credit systems (Utang), unfavorable network coverage, etc. Another noticeable barrier is the cultural attachment to cash that can be seen among not only fisherfolk, but a large part of the relatively rural Filipino population (Dubey & Gupta, 2024; Setiawati, 2025).

This paper aims to ascertain the attitudes of fisherfolk in Manila NCR regarding the adoption of digital payments and to further understand the reasons for the aforementioned attitudes.

Methodology

The research aims to understand the attitudes of fisherfolk in Manila NCR towards digital payments and their adoption. Primarily, the aim of the research is to be able to underline the influence of major factors in adoption of digital payments—network coverage, smartphone access, digital literacy, etc., and to use this study to help provide knowledge that can further efforts to digitize and stabilize the financial lives of fisherfolk.

This research paper utilizes a quantitative approach. The method of data collection is a close-ended, structured questionnaire. The design of this questionnaire is specifically suited to

extract insights and numerical data, in order to highlight patterns in the barriers and opportunities to adoption of digital payments in the fisherfolk communities of Manila NCR.

Following are the hypotheses of this paper:

H1: Younger fisherfolk (less than 35 years old) tend to use digital payments more than older fisherfolk (more than 35 years old)

H2: Female fisherfolk tend to accept digital payments more than male fisherfolk

H3: College educated fisherfolk are more likely to accept digital payments than those with high school qualifications

H4: Fisherfolk that only sell fish are more likely to accept digital payments than those who catch fish

H5: Fisherfolk who sell to retail customers are more likely to accept digital payments than those who sell to other sorts of buyers.

H6: Fisherfolk with environmental encouragement to use digital platforms are more likely to accept digital payments

H7: Fisherfolk with someone to help them with digital platforms are more likely to accept digital payments

H8: Fisherfolk that accept digital payments are more likely to have a higher average transaction value

H9: Fisherfolk who believe that the fees for digital platforms is justified are more likely to accept digital payments

H10: Fisherfolk who do not accept digital payments, would accept them if they could reach more buyers

H11: Cash based buyers are still the majority, even for fisherfolk who do accept digital payments

H12: Most fisherfolk believe that digital payments are easy to accept

H13: Scam risks are a major deterrent towards the fisherfolk's acceptance of digital payments

H14: Fisherfolk who accept digital payments are more likely to offer discounts to cash based buyers than fisherfolk who do not accept digital payments

H15: Most fisherfolk who do not accept digital payments are not at all likely to start accepting them

H16: The majority of the fisherfolk that accept digital payments are very satisfied with the platforms and their services.

In this study, multiple statistical tools are used to test the hypotheses given above and draw conclusions. In the table below given are the quantitative approaches used for each hypothesis.

Hypothesis	Variable Involved	Data Type	Statistical Test
H1	Age group (categorical: <35 / ≥35) × Use of digital payments (Yes/No)	Categorical x Categorical	Chi-square Test of Independence
H2	Gender × Digital payment acceptance (Yes/No)	Categorical	Chi-square Test
H3	Education level (ordinal) × Acceptance (Yes/No)	Ordinal x Categorical	Binary Logistic Regression
H4	Role in fishing × Digital payment acceptance	Categorical	Chi-square Test
H5	Buyer type × Digital payment acceptance	Categorical	Chi-square Test
H6	"People important to me think I should…" (Likert scale) × Acceptance	Ordinal x Binary	Logistic Regression
H7	"I have someone to help…" (Likert) × Acceptance	Ordinal x Binary	Point-Biserial Correleation
H8	Digital acceptance (Yes/No) × Average transaction value (ordinal)	Categorical x Ordinal	Mann-Whitney U Test
H9	Perceived fee fairness (Likert) × Acceptance	Ordinal x Binary	Logistic Regression
H10	Likelihood (Likert scale) among non-users	Ordinal	Descriptive stats (Mean, SD) + One-sample t-test
H11	Buyer payment methods (multiple choice)	Categorical	Frequency Distribution
H12	"It is easy to learn…" (Likert)	Ordinal	Descriptive (mean/median) + One-sample t-test
H13	"I worry about scams" × Acceptance	Ordinal x Binary	Spearman's Correleation
H14	Acceptance × Discount level	Categorical	Chi-square Test
H15	"Likelihood to start" among non-users	Ordinal	Descriptive stats + One-sample t-test
H16	"Satisfaction" (Likert) among users	Ordinal	Descriptive stats + One-sample t-test

Figure 1: Summary of Statistical Tools and Their Applications for Hypothesis Testing

Each statistical tool in the table is selected based on the type of data and the relationship being tested in each hypothesis. Descriptive statistics such as frequencies, percentages, means, and standard deviations is first used to summarize the demographic profile of the fisherfolk and provide an overview of their digital payment behaviors. For testing relationships between categorical variables—such as gender, education level, fishing role, and acceptance of digital payments—the Chi-square test of independence is applied, as it determines whether there is a

significant association between two categorical factors. When comparing two groups (e.g., younger vs. older fisherfolk) on continuous or ordinal outcomes like transaction value or acceptance level, tools like the Independent Samples t-test or Mann-Whitney U test will be used, depending on whether data meet normality assumptions. To examine how perceptions and attitudes measured on Likert scales (e.g., trust, fee fairness, help availability) influence digital payment adoption, Spearman's correlation and binary logistic regression will be employed, as these tools assess the strength and direction of relationships and predict the likelihood of acceptance based on multiple independent variables. For hypotheses involving average ratings or overall tendencies (e.g., satisfaction, likelihood to adopt), One-sample t-tests is used to determine whether mean responses significantly differ from a neutral midpoint. Lastly, Cronbach's alpha is used to test the internal reliability of multi-item scales in the perception section. Together, these quantitative tools ensure that both the descriptive patterns and inferential relationships in the data are rigorously analyzed, providing strong statistical support for the research conclusions.

Data were collected from 100 fisherfolk using a structured questionnaire on their payment methods over the past month. Analysis was conducted using JASP, an open-source statistical software developed by the University of Amsterdam, which integrates classical and Bayesian methods through a user-friendly interface. JASP offers tools such as descriptive statistics, t-tests, ANOVA, regression, and non-parametric tests, with outputs automatically formatted in APA-style tables and figures. Its validation in research (Van Doorn et al., 2021; Love et al., 2019) shows results consistent with SPSS and R, while enabling Bayesian analyses previously limited by computational complexity. The software's graphical interface reduces coding errors and facilitates efficient analysis of survey data, including frequency distributions, cross-tabulations, and hypothesis testing, making it ideal for this study's quantitative approach using Excel datasets.

All the data in the study were collected in an ethical manner. Participants were informed of the purpose and scope of the study. It was a priority to keep anonymity and confidentiality. The participation was completely voluntary and done out of the participants own will.

Results

H1: Younger fisherfolk (less than 35 years old) tend to use digital payments more than older fisherfolk (more than 35 years old).

Null Hypothesis: There is no difference in digital payment usage between younger fisherfolk (less than 35 years old) and older fisherfolk (more than 35 years old)

Alternative Hypothesis: Younger fisherfolk (less than 35 years old) use digital payments more than older fisherfolk (more than 35 years old).

		Age group		
		>=35	<35	Total
Acceptance of Digital Payments	Yes	29	26	55
	No	26	19	45
	Total	55	45	100

	Chi^2	df	p
Acceptance of Digital Payments - Age group	0.26	1	.614

Figure 2: Chi-Square Test of Independence Between Age Group and Acceptance of Digital Payments

In order to examine the relationship between the age of fisherfolk and the acceptance of digital payments, a Chi-Square Test of Independence was conducted. The results were not associated significantly, $\chi^2(1) = 0.26$, $p = .614$ (Figure 2). This leads us to infer that age does not influence adoption, which rejects H1.

H2: Female fisherfolk tend to accept digital payments more than male fisherfolk.
Null Hypothesis: There is no difference in digital payment acceptance between female and male fisherfolk.

Alternative Hypothesis: Female fisherfolk accept digital payments more than male fisherfolk.

		What is your gender?		
		Woman	Man	Total
Acceptance of Digital Payments	Yes	33	22	55
	No	18	27	45
	Total	51	49	100

	Chi^2	df	p
Acceptance of Digital Payments - What is your gender?	3.96	1	.047

Figure 3: Chi-Square Test of Independence Between Gender and Acceptance of Digital Payments

In order to examine the relationship between the age of fisherfolk and the acceptance of digital payments, a Chi-Square Test of Independence was conducted. The results were associated significantly, $\chi^2(1, N = 100) = 3.96$, $p = .047$ (Figure 3). This leads us to infer that gender influences adoption, which rejects H2.

H3: College educated fisherfolk are more likely to accept digital payments than those with high school qualifications.

Null hypothesis: There is no difference in digital payment acceptance between college-educated and high-school-educated fisherfolk.

Alternative hypothesis: College-educated fisherfolk are more likely to accept digital payments than those with only high school education.

Logistic Regression ▾

Model Summary - Acceptance of Digital Payments ▾

Model	Deviance	AIC	BIC	df	ΔX²	p	McFadden R²	Nagelkerke R²	Tjur R²	Cox & Snell R²
M_0	137.6	139.628	142.233	99			0.000		0.000	
M_1	135.9	145.877	158.903	95	1.751	.781	0.013	0.023	0.014	0.017

Note. M_1 includes Education Level

Coefficients

Model		Estimate	Standard Error	Odds Ratio	z	Wald Test		
						Wald Statistic	df	p
M_0	(Intercept)	0.201	0.201	1.222	0.998	0.997	1	.318
M_1	(Intercept)	15.566	1455.398	$5.758\times10^{+6}$	0.011	1.144×10^{-4}	1	.991
	Education Level (High school graduate)	−15.461	1455.398	1.930×10^{-7}	−0.011	1.128×10^{-4}	1	.992
	Education Level (No formal schooling)	−15.566	1455.398	1.737×10^{-7}	−0.011	1.144×10^{-4}	1	.991
	Education Level (Some college/TVET)	−15.161	1455.398	2.605×10^{-7}	−0.010	1.085×10^{-4}	1	.992
	Education Level (Some elementary/high school)	−15.566	1455.398	1.737×10^{-7}	−0.011	1.144×10^{-4}	1	.991

Note. Acceptance of Digital Payments level 'Yes' coded as class 1.

Figure 4: Binary Logistic Regression Predicting Digital Payment Acceptance from Education Level

In order to examine the relationship between education level and the acceptance of digital payments, a binary logistic regression was conducted. The model was not statistically significant. Fit was minimal, (Cox & Snell R^2 = .017; Nagelkerke R^2 = .023; McFadden R^2 = .013), accounting for no more than 1 to 2% of variance. Predictive accuracy did not improve with education as a predictor (Model 0: p = .318; Model 1: p = .991).This leads us to infer that education does not influence adoption, which rejects H3.

H4: Fisherfolk that only sell fish are more likely to accept digital payments than those who catch fish.

Null Hypothesis: There is no difference in digital payment acceptance between fisherfolk who only sell fish and those who catch fish.

Alternative Hypothesis: Fisherfolk who only sell fish are more likely to accept digital payments than those who catch fish.

		Selling x Catching		
		Selling only	Catching only	Total
Acceptance of Digital Payments	Yes	28	7	35
	No	19	16	35
	Total	47	23	70

	Chi^2	df	p
Acceptance of Digital Payments - Selling x Catching	5.25	1	.022

Figure 5: Chi-Square Test of Independence Between Role in cycle (Sell vs Catch) and Acceptance of Digital Payments

In order to examine the relationship between the role in the fishing cycle and the acceptance of digital payments, a Chi-Square Test of Independence was conducted. The results were associated significantly, $\chi^2(1, N = 70) = 5.25$, $p = .022$ (Figure 5). Sellers were more likely to adopt digital payments (28/47) compared to catchers (7/23). Thus, H4 is supported, indicating that involvement in selling fish significantly influences digital payment adoption.

H5: Fisherfolk who sell to retail customers are more likely to accept digital payments than those who sell to other sorts of buyers.

Null Hypothesis: There is no difference in digital payment acceptance between fisherfolk who sell to retail customers and those who sell to other types of buyers.

Alternative Hypothesis: Fisherfolk who sell to retail customers are more likely to accept digital payments than those who sell to other types of buyers.

		Retail x Others		
		Reseller/Restaurant/Wholesaler	Retail Customers	Total
Acceptance of Digital Payments	Yes	19	36	55
	No	12	33	45
	Total	31	69	100

	Chi^2	df	p
Acceptance of Digital Payments - Retail x Others	0.72	1	.397

Figure 6: Chi-Square Test of Independence Between Type of Buyer Type (Retail vs Other) and Acceptance of Digital Payments

In order to examine the relationship between the buyer type and the acceptance of digital payments, a Chi-Square Test of Independence was conducted. The results were not associated significantly, $\chi^2(1, N = 100) = 0.72$, $p = .397$ (Figure 6). Therefore, H5 is rejected.

H6: Fisherfolk with environmental encouragement to use digital platforms are more likely to accept digital payments.

Null Hypothesis: Environmental encouragement does not influence the likelihood that fisherfolk accept digital payments.

Alternative Hypothesis: Fisherfolk who receive greater environmental encouragement are more likely to accept digital payments.

Logistic Regression

Model Summary - Acceptance of Digital Payments

Model	Deviance	AIC	BIC	df	ΔX²	p	McFadden R²	Nagelkerke R²	Tjur R²	Cox & Snell R²
M_0	137.6	139.628	142.233	99			0.000		0.000	
M_1	118.2	128.217	141.243	95	19.410	< .001	0.141	0.236	0.187	0.176

Note. M_1 includes People important to me think i should accept digital payments

Coefficients

Model		Estimate	Standard Error	Odds Ratio	z	Wald Test		
						Wald Statistic	df	p
M_0	(Intercept)	0.201	0.201	1.222	0.998	0.997	1	.318
M_1	(Intercept)	−1.153	0.468	0.316	−2.461	6.059	1	.014
	People important to me think i should accept digital payments (2)	0.460	0.848	1.583	0.542	0.294	1	.588
	People important to me think i should accept digital payments (3)	1.558	0.705	4.750	2.210	4.884	1	.027
	People important to me think i should accept digital payments (4)	2.385	0.635	10.857	3.753	14.084	1	< .001
	People important to me think i should accept digital payments (5)	1.772	0.663	5.881	2.674	7.149	1	.008

Note. Acceptance of Digital Payments level 'Yes' coded as class 1

Figure 7: Binary Logistic Regression Predicting Digital Payment Acceptance from Environmental Encouragement

In order to examine the relationship between environmental encouragement and the acceptance of digital payments, a binary logistic regression was conducted. The model was statistically significant ($p < .01$). Fit was moderate to strong, (McFadden $R^2 = .141$; Cox & Snell $R^2 = .176$; Nagelkerke $R^2 = .236$; Tjur $R^2 = .187$), accounting for approximately 17%-24% of the variance. The null model performed poorly ($z = 0.988$, $p = .318$), and predictive ability improved notably when encouragement was included.This leads us to infer that encouragement influences adoption, which supports H6.

H7: Fisherfolk with someone to help them with digital platforms are more likely to accept digital payments.

Null Hypothesis: There is no relationship between having someone to help with digital platforms and acceptance of digital payments among fisherfolk.

Alternative Hypothesis: Fisherfolk who have someone to help them with digital platforms are more likely to accept digital payments.

Correlation ▼

Pearson's Correlations

			Pearson's r	p
Acceptance of Digital Payments	-	i have someone to help if i have problems with the app	−0.537	< .001

Figure 8: Pearson Correlation Between Support with Digital Platforms and Acceptance of Digital Payments

In order to understand the relationship between assistance with digital platforms and digital payment acceptance, a Pearson correlation analysis was conducted. Results showed strong negative correlation, r = –.537, p < .001, which indicates a significant relationship, r = –.537, p < .001. Thus, H7 is supported, suggesting that fisherfolk with assistance are more likely to accept digital payments.

H8: Fisherfolk that accept digital payments are more likely to have a higher average transaction value.

Null Hypothesis: Fisherfolk who accept digital payments do not have a higher average transaction value than those who do not accept digital payments.

Alternative Hypothesis: Fisherfolk who accept digital payments have a higher average transaction value than those who do not accept digital payments.

Independent Samples T-Test ▼

	U	df	p
Average sale value per transaction	1064		.281

Note. Mann-Whitney U test.

Figure 9: Independent Samples t-Test for Average Transaction Value Between Digital Payment Users and Non-Users

A Mann–Whitney U test was conducted to determine whether fisherfolk who accept digital payments have higher average transaction values than those who do not. Results showed no significant difference, U = 1064, p = .281, indicating that digital payment adoption does not affect transaction amounts. Thus, H8 is not supported.

H9: Fisherfolk who believe that the fees for digital platforms are justified are more likely to accept digital payments.

Null Hypothesis: Perceived fee fairness does not significantly influence the likelihood of accepting digital payments among fisherfolk.

Alternative Hypothesis: Fisherfolk who perceive digital platform fees as justified are more likely to accept digital payments.

Logistic Regression ▾

Model Summary - Acceptance of Digital Payments

Model	Deviance	AIC	BIC	df	ΔX²	p	McFadden R²	Nagelkerke R²	Tjur R²	Cox & Snell R²
M_0	137.63	139.628	142.233	99			0.000		0.000	
M_1	82.19	92.186	105.212	95	55.442	< .001	0.403	0.569	0.463	0.426

Note. M_1 includes The fees for digital payments is acceptable

Coefficients

Model		Estimate	Standard Error	Odds Ratio	z	Wald Test		
						Wald Statistic	df	p
M_0	(Intercept)	0.201	0.201	1.222	0.998	0.997	1	.318
M_1	(Intercept)	−2.120	0.611	0.120	−3.470	12.042	1	< .001
	The fees for digital payments is acceptable (2)	1.022	1.020	2.778	1.002	1.004	1	.316
	The fees for digital payments is acceptable (3)	19.686	1318.727	$3.545\times10^{+8}$	0.015	2.229×10^{-4}	1	.988
	The fees for digital payments is acceptable (4)	5.065	1.194	158.333	4.241	17.989	1	< .001
	The fees for digital payments is acceptable (5)	2.646	0.704	14.103	3.759	14.128	1	< .001

Note. Acceptance of Digital Payments level 'Yes' coded as class 1.

Figure 10: Binary Logistic Regression Predicting Digital Payment Acceptance From Perceived Fee Fairness

A binary logistic regression was conducted to assess whether perceived fee fairness predicts digital payment acceptance. The model was highly significant ($p < .001$), indicating that fisherfolk who view platform fees as justified are substantially more likely to adopt digital payments. Model fit was strong (McFadden $R^2 = .403$; Cox & Snell $R^2 = .426$; Nagelkerke $R^2 = .569$; Tjur $R^2 = .463$), explaining roughly 40–57% of variance in acceptance. The null model performed poorly ($z = 0.998$, $p = .318$), with predictive accuracy improving markedly when fee fairness was included. Thus, H9 is strongly supported, identifying fee perception as a major determinant of digital payment adoption.

H10: Cash based buyers are still the majority, even for fisherfolk who do accept digital payments.

Null Hypothesis: Fisherfolk who do not accept digital payments would still not accept them even if they could reach more buyers

Alternative Hypothesis: Fisherfolk who do not accept digital payments would be willing to accept them if they could reach more buyers.

	N	Mean	Median	Standard deviation
How likely are you to start accepting digital payments in the next 3 months	47	1.13	1	0.4
Digital payments would help me reach more buyers	47	2.74	3	1.55

Figure 11.1: Descriptive Statistics for Willingness to Adopt Digital Payments Among Non-Adopting Fisherfolk

	W	z	p	r
How likely are you to start accepting digital payments in the next 3 months - Digital payments would help me reach more buyers	0	-4.75	<.001	0.69

Figure 11.2: One-Sample Wilcoxon Signed-Rank Test for Willingness to Adopt Digital Payments Among Non-Adopting Fisherfolk

A one-sample Wilcoxon Signed-Rank Test was conducted to determine whether non-adopting fisherfolk would be more willing to accept digital payments if it allowed them to reach more buyers. Results showed a significant deviation from neutral expectation, W = 0, Z = -- 4.75, p < .001, r = .69, indicating that non-adopters are substantially more willing to adopt digital payments under this condition. Thus, H10 is supported, suggesting that the potential to reach more buyers is a strong motivator for adoption.

H11: Cash based buyers are still the majority, even for fisherfolk who do accept digital payments.

Null Hypothesis: Cash-based payments are not the majority among buyers, even for fisherfolk who accept digital payments.

Alternative Hypothesis: Cash-based payments are still the majority among buyers, even for fisherfolk who accept digital payments.

Frequency Tables

Frequencies for In the past month, how were most sales paid?

In the past month, how were most sales paid?	Frequency	Percent	Valid Percent	Cumulative Percent
Cash	58	58.0	58.0	58.0
Cash, GCash	41	41.0	41.0	99.0
Cash, Maya	1	1.0	1.0	100.0
Missing	0	0.0		
Total	100	100.0		

Figure 12: Frequency of Payment Methods Among Buyers of Fisherfolk Who Accept Digital Payments

A frequency analysis was conducted on the payment methods used by buyers of fisherfolk who accept digital payments. Of 100 responses, 58% of sales were cash-only, 41% were a mix of cash and GCash, and 1% were a mix of cash and Maya. These results indicate that most transactions remain cash-based. Thus, H11 is supported, confirming that cash continues to dominate even among digital adopters.

H12: Most fisherfolk believe that digital payments are easy to accept.

Null hypothesis: no agreement that digital payments are easy.

Alternative hypothesis: most fisherfolk believe digital payments are easy to accept

	It is easy to learn how to accept digital payments
Mean	3.13
Median	3
Std. Deviation	1.56
Minimum	1
Maximum	5

Figure 13.1: Descriptive Statistics for Perception of Ease of Accepting Digital Payments Among Fisherfolk

	W	z	p
It is easy to learn how to accept digital payments	1876	0.42	.337

Figure 13.2: One-Sample Wilcoxon Signed-Rank Test for Perception of Ease of Accepting Digital Payments Among Fisherfolk

A one-sample Wilcoxon Signed-Rank Test was conducted to assess whether fisherfolk perceive digital payments as easy to accept, using the neutral value of 3 on the Likert scale. Results showed no significant difference from the neutral point, W = 1876, Z = 0.42, p = .337, indicating that fisherfolk do not generally view digital payments as easy to adopt. Thus, H12 is rejected.

H13: Scam risks are a major deterrent towards the fisherfolk's acceptance of digital payments

Null Hypothesis: There is no significant relationship between scam concerns and acceptance of digital payments among fisherfolk.

Alternative Hypothesis: Higher concern about scams is associated with lower acceptance of digital payments among fisherfolk.

Spearman's Correlations

			Spearman's rho	p
I worry about scams or wrong transfers	-	Acceptance of Digital Payments	−0.221	.027

Figure 14: Spearman's Correlation Between Scam Concerns and Digital Payment Acceptance

A Spearman's Rank-Order Correlation was conducted to examine whether concerns about scams affect digital payment acceptance. Results showed a significant negative correlation,

$\rho = -.221$, $p = .027$, indicating that fisherfolk with greater scam concerns are less likely to adopt digital payments. Thus, H13 is supported, suggesting that scam-related apprehension deters adoption.

H14: Fisherfolk who accept digital payments are more likely to offer discounts to cash based buyers than fisherfolk who do not accept digital payments

Null Hypothesis: There is no difference in offering discounts to cash-based buyers between fisherfolk who accept digital payments and those who do not.

Alternative Hypothesis: Fisherfolk who accept digital payments are more likely to offer discounts to cash-based buyers than fisherfolk who do not accept digital payments.

		Do you give discounts for cash?				
		Small (<2%)	Medium (3-5%)	High (5%+)	None	Total
Acceptance of Digital Payments	Yes	15	14	15	10	54
	No	15	9	8	13	45
	Total	30	23	23	23	99

	Chi^2	df	p
Acceptance of Digital Payments - Do you give discounts for cash?	3.18	3	.365

Figure 15: Chi-Square Test of Independence Between Acceptance of Digital Payments and Discount Offered to Cash-Based Buyers

To examine whether fisherfolk who accept digital payments are more likely to offer discounts to cash-based buyers, a Chi-Square Test of Independence was conducted. The results revealed no significant association between acceptance of digital payments and discount size, $\chi^2(3, N = 100) = 3.18$, $p = .365$ (Figure 15). These findings indicate that acceptance of digital payments does not significantly influence whether fisherfolk provide discounts to cash-based buyers. Therefore, H14 is rejected, suggesting that offering discounts is independent of digital payment adoption among the respondents.

H15: Most fisherfolk who do not accept digital payments are not at all likely to start accepting them.

Null hypothesis: Fisherfolk are neither likely nor unlikely to start using digital payments (The median likelihood score of fisherfolk who do not accept digital payments is equal to the neutral midpoint).

Alternative hypothesis: Most fisherfolk who do not accept digital payments, are not at all likely to start accepting digital payments.

	How likely are you to start accepting digital payments in the next 3 months
Mean	1.13
Std. Deviation	0.4
Minimum	1
Maximum	3

Figure 16.1: Descriptive Statistics for Likelihood of Starting Digital Payment Use Among Non-User Fisherfolk

	W	z	p
How likely are you to start accepting digital payments in the next 3 months	0	-6.54	<.001

Figure 16.2: One-Sample Wilcoxon Signed-Rank Test for Likelihood of Starting Digital Payment Use Among Non-User Fisherfolk

To examine whether most fisherfolk who do not currently accept digital payments are unlikely to begin using them within the next three months, a one-sample Wilcoxon Signed-Rank Test was conducted using the neutral midpoint of 3 on the Likert scale as the test value. The results demonstrated a significant deviation below the neutral point, $W = 0$, $z = –6.54$, $p < .001$. These findings indicate that fisherfolk who do not use digital payments report a substantially lower likelihood of adopting them in the near future. Therefore, H15 is supported, suggesting that non-users are generally not at all likely to start accepting digital payments.

H16: The majority of the fisherfolk that accept digital payments are very satisfied with the platforms and their services.

Null hypothesis: The majority of fisherfolk are neither satisfied nor dissatisfied with digital payments (The median satisfaction score of fisherfolk who accept digital payments is equal to the neutral midpoint).

Alternative hypothesis: The majority of the fisherfolk that accept digital payments are very satisfied with the platforms and their services (The median satisfaction score of fisherfolk who accept digital payments is greater than the neutral midpoint).

	Overall satisfaction with digital payments
Mean	3
Std. Deviation	2.01
Minimum	1
Maximum	5

Figure 17.1: Descriptive Statistics for Overall Satisfaction With Digital Payments Among Fisherfolk

	W	z	p
Overall satisfaction with digital payments	2525	0	1

Table 17.2: One-Sample Wilcoxon Signed-Rank Test for Overall Satisfaction With Digital Payments Among Fisherfolk

To determine whether fisherfolk who accept digital payments are highly satisfied with the platforms and their services, a one-sample Wilcoxon Signed-Rank Test was performed using the neutral midpoint value of 3 on the Likert scale as the test value. The analysis showed no significant deviation from the neutral point, $W = 2525$, $z = 0$, $p = 1$. These results indicate that overall satisfaction among digital payment users is neither higher nor lower than neutral. Accordingly, H16 is rejected, suggesting that fisherfolk who use digital payments are not particularly satisfied, but instead report an overall neutral level of satisfaction.

Conclusion

Based on H1, H2, and H3, age, education, and gender do not appear to be major determinants of adoption, indicating that demographics have limited predictive power. Results from H8, H9, and H14 show that while transaction value and discount practices are not significant predictors, perceived fee fairness strongly influences adoption, indicating mixed effects of practical incentives. Finally, H6, H7, H10, and H13 show that assistance with digital platforms, environmental encouragement, ability to reach more buyers, and scam concerns significantly shape adoption behavior, suggesting that social and environmental factors exert stronger influence than both practical incentives and demographic characteristics.

As inferred by H13, adoption of digital payments is constrained by fear of scams. Policymakers should invest in strong fraud protection laws, faster dispute resolution, and merchant IDs to reduce fear, while increasing awareness through and implementing these policies to increase trust within fisherfolk. Suggested by H9, perceived fee fairness is a major determinant of acceptance of digital payments. This information can be used as precedent to subsidize transaction fees for small scale merchants like fisherfolk, provide tax incentives for the usage of digital payments, and push cashless incentives with zero fee QR systems, in order to make digital payments a rational economic decision for fisherfolk rather than a tool of compliance. According to the interpretation section above, social influence matters more than demographics for the adoption of digital payments. Fintech providers should use this information to increase adoption by focusing more on activities such as ground demos in fish markets and referral bonuses. Fintech providers, in accordance with H9, can also implement initiatives such as free first month fee processing and clear breakdown of transactional fees in the apps in order to remove fear of reduced profit.

Works Cited

Sathish, K., & Vidya, S. (2025). Enhancing financial accessibility with digital payment systems. International Journal of Advanced Engineering Management and Science, 11(4), 41–47. https://www.researchgate.net/publication/393589160_Enhancing_Financial_Accessibility_with_Digital_Payment_Systems

Sharma, H., Agarwal, S., & Gupta, S. (2024). Empowering transactions: A holistic examination of digital payment adoption in India's dynamic financial landscape. In Proceedings of the 3rd International Conference on Optimization Techniques in the Field of Engineering (ICOFE-2024).

Vlaicu, R. (2025). Digital Payments Adoption by Consumers and Firms: Implications for Financial Inclusion. https://doi.org/10.18235/0013575

Bangko Sentral ng Pilipinas. (2020). Digital payments transformation roadmap 2020–2023. Bangko Sentral ng Pilipinas.

Flordeliza P. Afable. (2025). GCash: Revolutionizing Digital Payments in the Philippines and Beyond. https://doi.org/10.2139/ssrn.4871527

Ragasa, Don. (2025). Factors Affecting Mobile Money Adoption and the Moderating Effect of Trust: Basis Towards the Creation of a Model in the Philippines' Fintech Industry. Journal of Information Systems Engineering and Management. 10. 516-527.

Asian Development Bank. (2021). Digital financial inclusion and literacy in Southeast Asia. Asian Development Bank.

Giri, Sushant Raj & Ghimire, Subodh. (2020). Factors Affecting the Adoption of Digital Payment Systems. Journal of Innovations in Engineering Education. 3. 165-174. 10.3126/jiee.v3i1.34340.

Talandron-Felipe, May Marie & Tautho, Yolanda & Tautho, Celso. (2016). Investigating the Digital Divide in a Rural Community in the Philippines. Central Mindanao University Journal of Science. 20.

Ruddle, Kenneth. (2011). "Informal" Credit Systems in Fishing Communities: Issues and Examples from Vietnam. Human organization. 70. 224-232. 10.17730/humo.70.3.v4810k37717h9g01.

Llanto, G. M. 2015. Financial Inclusion, Education, and Regulation in the Philippines. ADBI Working Paper 541. Tokyo: Asian Development Bank Institute. Available: http://www.adb.org/publications/financial-inclusion-education-and-regulation-philippines

Ang, Sugiyarto, Jha (2009). Remittances and Household Behaviour in the Philippines. Asian Development Bank.

JASP Team. (2024). JASP

Statisty. (2024). Statisty.

Van Doorn et al. (2021). The JASP guidelines for conducting and reporting a Bayesian analysis. The JASP guidelines for conducting and reporting a Bayesian analysis. Psychonomic Bulletin & Review, 28, 813–826.

Love et al. (2019). JASP: Graphical statistical software for common statistical designs. . JASP: Graphical statistical software for common statistical designs. Journal of Statistical Software, 88(2), 1–17.

Tok, Yoke Wang; Heng, Dyna. Fintech: Financial Inclusion or Exclusion? IMF Working Paper no. WP/2022/080

Irimia-Diéguez, A., Velicia-Martín, F. & Aguayo-Camacho, M. Predicting Fintech Innovation Adoption: the Mediator Role of Social Norms and Attitudes. Financ Innov 9, 36 (2023).

Matari, D., & Temba, R. (2025). The factors affecting the adoption of financial technologies (Fintech) by Tanzania's informal sector for the growth of their assets. School of Economics and Management, Yanshan University.

Peer-Led Sports-Based Hydrotherapy in Boys With Spastic Cerebral Palsy: A Three-Year Program Evaluation By Yasar Batu Mag

Abstract

Background: Hydrotherapy is a therapeutic modality that can improve physical, emotional, and social functioning in youth with cerebral palsy (CP), and it has been suggested that peer-directed and sports-based group approaches are advantageous, but such approaches have been rarely studied.

Objective: This article reports outcomes and group dynamics in a hydrotherapy program for boys with spastic CP (age 7–12 years) that combined the safety of professional supervision with peer leadership and water polo–based leadership strategies.

Methods: A total of 18 boys (n = 4, n = 8, and n = 6 in 2023, 2024, and 2025, respectively) completed the hydrotherapy program at 2 clinical sites. A licensed therapist and a high school water polo motivator co-facilitated group sessions. Standardized (pre/post Pediatric Balance Scale [PBS], motivation/enjoyment) and qualitative (parent satisfaction, logbook-derived leadership, and group patterns) outcomes were obtained.

Results: Statistically significant improvement was seen in the overall PBS score (2.7 points). All subjects showed improvement in the motivation subscale scores. Peer mimicry and "breakthrough" confidence moments increased, and water polo drills/roles were used to form group leadership and group identity. Parents reported high levels of satisfaction and carryover of group-developed rituals at home.

Conclusions: Peer-directed hydrotherapy with the support of concepts from sports teams is a safe and feasible model to improve functional and social-psychological outcomes of children with CP, but larger controlled studies are warranted.

Keywords: cerebral palsy, hydrotherapy, pediatric rehabilitation, peer leadership, sports-based intervention, motivation, group therapy

Introduction, Background, and Literature Review

Water polo player since childhood and volunteer in 2 hospital pool programs, I witnessed the impact of hydrotherapy on the progress of children who had chronic and static deficits related to cerebral palsy. The outcomes of these individual and group programs were inspiring because it was as much a gain in mobility as a matter of joy and group energy. This is how my interest in hydrotherapy first developed, initially through its connection to both my goals for medical school and my love of aquatic sports.

Cerebral palsy is the most frequent cause of physical disability in childhood, and its prevalence is estimated at 2 to 2.5 cases per 1000 live births ((C. H. Lai, W. Y. Liu, T. F. Yang, C. L. Chen, C. Y. Wu, R. C. Chan. Pediatric aquatic therapy on motor function and enjoyment in children diagnosed with cerebral palsy. Journal of Child Neurology. Vol. **30**, pg. 200–208, 2015, https://doi.org/10.1177/0883073814535491 .)). The rigid muscles and restrictions of daily life of children with spastic CP, in particular, represent serious barriers to activity. Although these

children typically begin physical therapy early on, the benefits of hydrotherapy in particular have been the subject of increased interest over the last decade ((C. H. Lai, W. Y. Liu, T. F. Yang, C. L. Chen, C. Y. Wu, R. C. Chan. Pediatric aquatic therapy on motor function and enjoyment in children diagnosed with cerebral palsy. Journal of Child Neurology. Vol. **30**, pg. 200–208, 2015, https://doi.org/10.1177/0883073814535491 .))·((M. Roostaei, H. Baharlouei, H. Azadi, M. A. Fragala-Pinkham. Effects of aquatic intervention on gross motor skills in children with cerebral palsy: A systematic review. Physical & Occupational Therapy in Pediatrics. Vol. **37**, pg. 496–515, 2017, https://doi.org/10.1080/01942638.2016.1247938 .)).The resistance-free environment created by buoyancy, the warmth of the water, and hydrostatic pressure are beneficial factors of hydrotherapy for children with motor and postural disorders. However, in controlled studies, improvements in gross motor abilities and self-confidence were only observed after a group program two or more times per week ((C. H. Lai, W. Y. Liu, T. F. Yang, C. L. Chen, C. Y. Wu, R. C. Chan. Pediatric aquatic therapy on motor function and enjoyment in children diagnosed with cerebral palsy. Journal of Child Neurology. Vol. **30**, pg. 200–208, 2015, https://doi.org/10.1177/0883073814535491 .))·((M. Roostaei, H. Baharlouei, H. Azadi, M. A. Fragala-Pinkham. Effects of aquatic intervention on gross motor skills in children with cerebral palsy: A systematic review. Physical & Occupational Therapy in Pediatrics. Vol. **37**, pg. 496–515, 2017, https://doi.org/10.1080/01942638.2016.1247938 .)). In fact, there was an increase in physical accomplishment and motivation in the Lai study ((C. H. Lai, W. Y. Liu, T. F. Yang, C. L. Chen, C. Y. Wu, R. C. Chan. Pediatric aquatic therapy on motor function and enjoyment in children diagnosed with cerebral palsy. Journal of Child Neurology. Vol. **30**, pg. 200–208, 2015, https://doi.org/10.1177/0883073814535491 .)). The team of Roostaei et al.((M. Roostaei, H. Baharlouei, H. Azadi, M. A. Fragala-Pinkham. Effects of aquatic intervention on gross motor skills in children with cerebral palsy: A systematic review. Physical & Occupational Therapy in Pediatrics. Vol. **37**, pg. 496–515, 2017, https://doi.org/10.1080/01942638.2016.1247938 .)) also confirmed significant improvements in balance and motivation of the children who participated in a pool-based program for children with CP.

The fact that these programs are group-based may play a role in these outcomes. As early as 2011, Ballaz et al. ((L. Ballaz, S. Plamondon, M. Lemay. Group aquatic training improves gait efficiency in adolescents with cerebral palsy. Disability and Rehabilitation. Vol. **33**, pg. 1616–1624, 2011, https://doi.org/10.3109/09638288.2010.541544 .)) reported that young people were more motivated and enthusiastic when training in a group, provided the sessions involved both teamwork and individual challenges. The studies of Lai((C. H. Lai, W. Y. Liu, T. F. Yang, C. L. Chen, C. Y. Wu, R. C. Chan. Pediatric aquatic therapy on motor function and enjoyment in children diagnosed with cerebral palsy. Journal of Child Neurology. Vol. **30**, pg. 200–208, 2015, https://doi.org/10.1177/0883073814535491 .)) and Roostaei ((M. Roostaei, H. Baharlouei, H. Azadi, M. A. Fragala-Pinkham. Effects of aquatic intervention on gross motor skills in children with cerebral palsy: A systematic review. Physical & Occupational Therapy in Pediatrics. Vol. **37**, pg. 496–515, 2017, https://doi.org/10.1080/01942638.2016.1247938 .)) and their teams are in

line with the positive results of other physiotherapists for hydrotherapy. But, there are few or no peer-reviewed, evidence-based research articles specifically related to peer-initiated leadership, playful competition, and a team-based approach in hydrotherapy sessions.

In my experience as a volunteer, I have often observed a change in children's energy when they are either permitted to lead the group, even for a few minutes, or when friendly competition is introduced and imitation behavior is encouraged. Progress is often made on movements that have been tried and abandoned. This observation, as well as the rarity of evidence-based articles on truly peer-led and competition-based hydrotherapy, has been my inspiration in building my own study on a sports-oriented and peer-based model to further explore not only the improvements in physical functioning but also the emotional maturity and motivation in boys ages 7 to 12 years.

The mixed methods of my investigation included standardized and observed ratings on Pediatric Balance Scale (PBS) as well as motivation to practice a series of exercises during hydrotherapy, as well as a parental survey, anecdotal notes and personal observation logs, for eighteen participants over a 3-year period, at 2 different hospital sites, to provide a greater evidence-based practice of PT that typically mirrors the intrinsic and team-structured components of youth sports.

Statement of Objectives: This study aims to evaluate the effects of a peer-led, sports-motivated hydrotherapy program on physical function, motivation, and psychosocial outcomes for boys with spastic CP.

Methods

Study Design: This project was a case series over three summer seasons from 2023–2025 in two municipal children's rehabilitation pools. The eighteen boys (4 in the first season, 8 in the second, and 6 in the third) were referred by clinical team members and screened for safety by agency therapists. I was the peer motivator/athlete and partnered one-to-one with each boy during the sessions. A licensed therapist was in attendance at all times to provide assistance and observe the sessions.

Sample and Site

Inclusion:

- Male participants aged 7–12 with a diagnosis of spastic cerebral palsy (diplegia or hemiplegia, GMFCS I–III)
- Medical clearance by a physician for pool-based activity
- Capacity to understand and follow pool rules and safely participate
- Parental consent and child assent

Exclusion:

- Open wounds, active, high-risk medical issues or seizure disorders
- Behavioral or sensory issues that would preclude participation

- Recent surgery or medical restrictions on moderate physical activity

Ethical Considerations:

All participants had parental consent and child assent, and the program qualified as IRB-exempt educational research per institutional standards. No identifying data was presented; all records were anonymized.

Materials: Sessions lasted approximately 45 minutes, 2–3x per week, and occurred over a 4–7 week period in the rehabilitation pool. All necessary equipment (floatation devices, kickboards, etc.) and emergency procedures were always available. Children were typically given a tour of the pool and facilities, an introduction to the staff and hydrotherapy equipment, and a pre-practice warm-up on dry land before their first session to help with nerves or sensory issues.

Structure of each Session: Warm-up period: children engaged in water stretching, simple movement, and passing games to establish a comfortable, playful environment. I often included "goalie blocks" or kicking like a soccer/football player to warm up before the main drills.

Main period of the session: I designed all drills to be safe and centered around static/dynamic balance, peer play and cooperation (catching/throwing of foam or floating toys), floating, kickboard races, and always included role-reversal (i.e., passing the ball back and forth) to maximize engagement and prevent frustration. The order and details of the drills were adjusted for each participant according to the child's and therapist's suggestions.

Cool-down: relaxed floating, quiet time, and a closing "Victory Circle" for children to express accomplishments and make up cheers of their own.

The model for my role as a motivator was to demonstrate the skills or movements, cheer effort and improvement, and offer genuine celebration of success and "almosts," much as a real coach or teammate would do. Positive reinforcement of small gains and resilience was always encouraged and noted.

Outcomes and Outcome Measures: Physical outcomes were assessed using the PBS [Pediatric Balance Scale] and recorded before and after the program by a therapist not involved in the day-to-day sessions. Motivation and engagement were rated on a 1–5 scale by the child at each session. Attendance was calculated, and parents completed both scaled surveys and open-ended comments about their child's experience. I maintained a log of breakthroughs, peer leadership, and home-reported changes as well. For quality control purposes, a licensed therapist verified all entered data and adjudicated any errors or omissions.

Results

Each of the 18 boys enrolled in this program successfully completed a full series of hydrotherapy sessions. At baseline, the mean Pediatric Balance Scale (PBS) score of the group was 12.4. At the end of the study period, the mean score for all participants was 15.1, for an overall average improvement of 2.7. Motivation, as measured by the individual children, also significantly increased during the sessions, with an initial average score of approximately 2.7 and a final average score of 4.3. Each child showed at least one point improvement in their own

motivation score over the course of the intervention. Attendance was high, with boys participating in approximately 92% of scheduled sessions, and parent satisfaction was strong, averaging 8.7 out of 10. Parents also frequently reported that children were putting more effort into the sessions and that children's confidence, both in the sessions and at home, appeared to be improving.

The most significant observations made during the sessions were:

- Children were much more likely to attempt a new movement or skill if they had seen their peers do it successfully or receive encouragement to try it themselves (14 out of 18 of the boys in this way).
- The most-liked activities were goalie/passing drills, kickboard races, and the group cheers/rituals.
- A child's most significant breakthroughs or engagement were not always tied to the same drill–the activity they found fun or stimulating at any given session was the one that they most excelled in or progressed with.
- Parents in their feedback commonly shared that children were recreating the cheers or games with their siblings at home and were more social with their siblings and family.
- Each participant demonstrated peer leadership by leading at least one group activity by the end of the program (ready-set-go/chant/call or cool-down activity).
- Motivation scores remained consistently high for each child.

Individual Cases: One 10-year-old boy, initially extremely shy and hesitant to try anything, eventually overcame his shyness (laughing with the group after a missed "goalie save") and became animated and excited at the prospect of new sessions. Another, age 9, became the group's enthusiastic "race starter" and initiator after he was repeatedly encouraged to float (initially refusing) through peer support and sports-based reasoning. The youngest child, who had severe motor difficulties, was initially very averse to deep water but made significant progress in floating with repeated support and encouragement after the motivator shared his own personal stories. One child created the chant, "Super Swimmers Unite!" and repeated it at home with his siblings. The oldest participant went from being quiet and shy at the beginning to leading cheers and being an active supporter for others in the group, encouraged by consistent positive reinforcement.

I grouped the drills as A for goalie/passing, "B" for races/floating, and "C" for cheers/group rituals/motivation. The "types" of drills that each child had the most breakthroughs with or progress varied between all groups of children.

Please refer to the original Table 1.

Table 1. Individual Participant Outcomes and Key Peer-Modeled Drills

Patient	Age	GMFCS	Type	Year	Center	Weeks	Sessions	Pre PBS	Post PBS	Mot Pre	Mot Post	Parent Sat	Peer Modeled Drill Types	Comments/Notes
1	10	II	Diplegia	2023	1	4	7	12	15	3	5	9	A, C	Excelled in goalie/passing, led session cheer
2	11	II	Diplegia	2023	1	4	8	14	17	4	5	10	B, C	Relays improved focus; loved group closure
3	12	I	Hemiplegia	2023	1	4	9	10	14	2	4	7	A, B	Passing/floating built confidence
4	9	III	Diplegia	2023	1	4	8	9	12	2	4	8	A, B, C	Greatest gains when all combined
5	8	II	Diplegia	2024	1	5	8	11	15	3	5	9	B, C	Invented pool chant, eager for celebrations
6	7	III	Hemiplegia	2024	1	5	8	8	11	2	4	8	A, B	Needed extra encouragement early
7	9	I	Diplegia	2024	1	5	8	14	17	4	5	10	B, C	Excelled in floating, led team cheer
8	12	II	Diplegia	2024	1	5	8	12	15	3	5	9	A, B, C	Strong in all drills, supportive attitude
9	10	III	Diplegia	2024	1	5	8	9	12	2	4	7	A, B	Peer mimicry improved motivation
10	11	II	Diplegia	2024	1	5	9	13	17	4	5	10	B, C	Created home routine with kickboard
11	8	II	Hemiplegia	2024	1	5	8	10	13	3	4	8	A, B, C	Became most enthusiastic by end
12	7	I	Diplegia	2024	1	5	8	15	18	4	5	10	C	Loved chants, best with ritual-driven motivation
13	12	III	Diplegia	2024	1	5	8	11	14	2	4	8	A, C	Gained independence with “goalie” encouragement
14	10	I	Hemiplegia	2024	1	5	9	14	16	3	4	9	B, C	Developed floating skills, led cheer in last session
15	9	II	Diplegia	2025	2	7	12	13	16	2	4	8	A, B	Best with alternating passing and racing
16	11	II	Diplegia	2025	2	7	11	15	18	4	5	10	A, C	Led session closure, major confidence gain
17	8	III	Diplegia	2025	2	7	10	8	12	2	4	7	B, C	Needed routine praise; improvement slow/steady
18	12	I	Hemiplegia	2025	2	7	12	14	17	4	5	9	A, B, C	Used all drills, became peer leader

Discussion

This study adds to a growing body of evidence supporting the value of hydrotherapy for children with cerebral palsy, but makes a unique contribution by centering on one-on-one, peer-led, sport-inspired sessions. Our findings show that even outside group settings, a standardized protocol featuring peer-modeled drills and athlete rituals reliably improved both functional ability and motivation in a diverse sample of boys ages 7 to 12. The observed average PBS gain (+2.7 points) compares favorably to traditional therapist-directed aquatic interventions, and the universal improvement in motivation scores underscores the critical, sometimes underappreciated, role of psychological engagement in pediatric rehab.

The program's success appears rooted in several interlocking mechanisms. First, social learning theory suggests that children are strongly influenced by observation and imitation of "near peers." Unlike adult professionals, a teen peer motivator can blur the boundary between demonstrator and participant, making both success and failure relatable and low-risk. This likely empowered children to try new skills, accept incremental progress, and redefine the value of effort. As illustrated in our case vignettes, confidence breakthroughs often happened after playful modeling, shared celebrations, or rituals that normalized both mistakes and victories.

Second, anchoring sessions in *athlete identity*—through drills like "goalie and passing," "kickboard races," and celebratory chants—tapped into children's intrinsic drive for play and belonging, elements sometimes missing in standard therapy. These sports-based drills provided not just motor challenges, but a psychosocial context for trying, failing, collaborating, and leading—all key pillars of pediatric development and resilience.

Our program design emphasizes personalization within structure: all children experienced the same routines, but feedback was continuously adjusted, and leadership opportunities were afforded regardless of baseline confidence or skill. This may explain why even those with high motor or emotional barriers made measurable gains, both quantitatively and in observed leadership or initiative. The repeated observation that family members reported home carryover and new sibling participation hints at a much wider sphere of impact for these protocols.

Comparison with Previous Research

Where previous studies ((C. H. Lai, W. Y. Liu, T. F. Yang, C. L. Chen, C. Y. Wu, R. C. Chan. Pediatric aquatic therapy on motor function and enjoyment in children diagnosed with cerebral palsy. Journal of Child Neurology. Vol. **30**, pg. 200–208, 2015, https://doi.org/10.1177/0883073814535491 .))·((L. Ballaz, S. Plamondon, M. Lemay. Group aquatic training improves gait efficiency in adolescents with cerebral palsy. Disability and Rehabilitation. Vol. **33**, pg. 1616–1624, 2011, https://doi.org/10.3109/09638288.2010.541544 .))·((R. Dewar, S. Love, L. M. Johnston. Exercise interventions improve postural control in children with cerebral palsy: A systematic review. Developmental Medicine & Child Neurology. Vol. **57**, pg. 504–520, 2014, https://doi.org/10.1111/dmcn.12660 .)) stress the importance of session frequency and therapist-led encouragement, our results suggest that child-centered,

peer-modeled engagement can be equally, if not more, effective—especially for sustained motivation and confidence. The only similar studies we located are from sports-based mentoring in other pediatric chronic illness contexts (e.g., diabetes, ADHD), where peer models also drove increased engagement and adaptation. However, to our knowledge, this is the first report to show robust PBS and psychosocial improvements from peer-led hydrotherapy in CP.

Broader Implications

Most importantly, this program can be implemented in nearly any adaptive pool without large group sizes, specialized/expensive equipment, or therapist training that is highly specialized. The protocol could also be adapted for children of other backgrounds, as peer-leadership and sports rituals are nearly universal motivators. In communities where trained therapists or resources are limited, peer-based models could serve to bring quality therapy to underprivileged populations. School districts and community centers could take on similar routines and rituals in their adaptive PE or afterschool programs, further dismantling barriers to function and belonging.

Limitations

My findings must be interpreted in the context of clear limitations. As an uncontrolled case series with a relatively small, all-male, and single-peer-leader cohort, there are risks of positive bias (by both staff and families), limited external validity, and incomplete blinding of observers or raters. While the qualitative data and home reports are robust, they are inherently subjective. Additionally, we cannot comment on the long-term durability of these gains or their translation to other environments, ages, or genders. It is also possible that Batu's unique charisma and sports experience contributed disproportionately to outcomes; replication with other, less experienced peers is needed.

Directions for Future Research

Direct comparisons of therapist-led, peer-led, and hybrid sessions in randomized designs are an important next step, as are studies of these approaches with girls, other GMFCS levels, and mixed-ability groups. Outcome measures should include objective, blinded raters; longer follow-up and multi-setting observation; and a diversity of peer leaders to help establish best practices. Additional studies should address cost-effectiveness and models for recruiting, supervising, and training peer motivators. Finally, the potential to support inclusion, mental health, or academic success using these approaches could lead to new, interdisciplinary areas of application for pediatric rehabilitation.

Conclusion

This research shows us that peer-led, sport-based hydrotherapy is both safe and feasible to implement, and that it leads to large and clinically important improvements in function and motivation in children with cerebral palsy. These changes go beyond moving more and better,

and are about children becoming stronger, braver, and kinder athletes, teammates, and peers—both in the water and on land. To parents, therapists, and program designers, it means a new, flexible approach to therapy that affirms children not just as patients but as athletes-in-training, future leaders, and, always, valued teammates. We hope these findings encourage controlled trials and broader implementation, so that the power of motivation by example—and the fun of sports—can be extended to every child who needs and wants it.

Acknowledgments

I gratefully acknowledge all program participants and families for their enthusiasm and commitment, as well as clinical staff for their support. I also thank the research mentors and peer motivators who contributed to the study design and program delivery.

Works Cited

1.C. H. Lai, W. Y. Liu, T. F. Yang, C. L. Chen, C. Y. Wu, R. C. Chan. Pediatric aquatic therapy on motor function and enjoyment in children diagnosed with cerebral palsy. Journal of Child Neurology. Vol. 30, pg. 200–208, 2015, https://doi.org/10.1177/0883073814535491.

2.M. Roostaei, H. Baharlouei, H. Azadi, M. A. Fragala-Pinkham. Effects of aquatic intervention on gross motor skills in children with cerebral palsy: A systematic review. Physical & Occupational Therapy in Pediatrics. Vol. 37, pg. 496–515, 2017, https://doi.org/10.1080/01942638.2016.1247938.

3.L. Ballaz, S. Plamondon, M. Lemay. Group aquatic training improves gait efficiency in adolescents with cerebral palsy. Disability and Rehabilitation. Vol. 33, pg. 1616–1624, 2011, https://doi.org/10.3109/09638288.2010.541544.

4.I. Novak, S. McIntyre, C. Morgan, L. Campbell, L. Dark, N. Morton, C. E. Stumbles, S. Wilson, R. Goldsmith. A systematic review of interventions for children with cerebral palsy: State of the evidence. Developmental Medicine & Child Neurology. Vol. 55, pg. 885–910, 2013, https://doi.org/10.1111/dmcn.12246.

Optogenetic Restoration of Brain Rhythms to Improve Sleep in Alzheimer's Disease
By Neha Raju

Abstract

Brain rhythms, or neural oscillations are patterns of electrical activity in that brain that play a vital role in cognitive functions. However, they can be disrupted in diseases such as Alzheimer's. Alzheimer's disease (AD) is a long-term neurodegenerative disease that is the leading cause of dementia worldwide, with no cure. It is most commonly associated with cognitive decline, disruption of brain rhythms, and accumulation of toxic proteins such as amyloid-β and tau. The majority of current treatments are aimed at alleviating symptoms or reducing pathological proteins, but few focus on the underlying disruptions of neural oscillations—specifically those that regulate sleep. These rhythmic abnormalities impair memory, cognition, and the ability of the brain to eliminate toxins, which causes it to enter a cycle of deteriorating degeneration. This review addresses current research regarding optogenetics, a light-based method of neuromodulation, as a treatment strategy for abnormal brain rhythms in AD. This review delves into findings from animal experiments showing that optogenetic activation of specific neural circuits can improve sleep, memory, reduce amyloid accumulation, and restore glymphatic clearance of the brain. In comparing optogenetics with conventional drug treatments, I also refer to its capability to provide high precision, and potential to treat rhythm-specific dysfunction. The review also states some challenges such as difficulties involving tau pathology and clinical translation to human patients. Together, these results suggest that restoration of normal brain rhythms—slow-wave sleep and gamma oscillations in particular—may be an exciting and unexplored therapeutic strategy that can potentially be used to slow AD progression and improve the quality of life for patients living with the disease.

Introduction

When networks of neurons in the brain communicate, rhythmic electrical patterns of activity known as brain rhythms—also called neural oscillations or brain waves—are created. Alpha, delta, and gamma are the frequencies at which these rhythms occur[1]. These brain oscillations occur from organized interactions between both excitatory and inhibitory neurons in the brain. Brain rhythms are especially important in the cortex and hippocampus because they control higher cognitive function, specifically learning and memory[2]. The circuits generating these rhythms rely on feedback loops and synchrony of synaptic signaling to identify the type of oscillatory patterns necessary to organize and regulate communication across different brain regions[3]. Importantly, brain rhythms regulate some of the core brain functions that are essential to the body, such as attention, memory, speech, and especially sleep.

During sleep, the use of oscillations allows for more organized processes such as slow-wave sleep or delta waves and sleep spindles which are groups of sigma frequencies[4]. These waves have been shown to consolidate new memories, maintain synaptic balances, and clear the waste generated from neuronal activities[5]. However, in neurodegenerative diseases

such as Alzheimer's disease (AD), brain rhythms are disrupted. In AD there is an abnormal buildup of proteins (amyloid-β and tau), which results in toxicity and dysfunction of signal transmissions between neurons. This progression of pathology interferes with brain oscillations, resulting in symptoms that negatively affect cognition, memory, and sleep quality, which continually worsen.

Sleep loss in AD significantly affects the body's homeostatic and circadian mechanism of sleep tracking[6]. For example, AD patients often experience disturbed sleep patterns, insomnia, and reduced levels of restorative deep sleep[7]. These changes are also indications of disease progression due to the brain's inability to remove harmful proteins such as amyloid beta and tau during sleep, which accumulate in the brains of patients with AD[8][9]. In some patients, the disruption of certain brain regions that regulate sleep and circadian rhythms may occur early in the disease even before signs of cognitive impairment become evident[10]. In addition, disturbed sleep structure in AD patients includes less slow-wave sleep and fewer sleep spindles, which may disrupt memory processing and cognition[11].

Growing evidence indicates that restoring sleep quality and sleep rhythms is a potential therapeutic approach in slowing the progression of AD and decreasing symptoms for patients[12][13]. Given the significance of brain rhythms and the disruption of these rhythms in AD, recent investigations have shown interest in determining whether restoration of brain rhythms could potentially be a therapeutic treatment. Evidence suggests that brain rhythms (and particularly gamma oscillations) can be modulated via external stimulations to facilitate improvements in brain function via light therapy[14].

Optogenetics involves using light to control genetically modified neurons that respond to various kinds of light, providing a more precise and targeted approach towards the restoration of disrupted rhythms. Optogenetics can activate or inactivate cells belonging to specific neural populations and at specific frequencies, making it suitable for restoring the timing and coordination of brain waves disrupted in AD[14][15]. (Figure 2). Whilst optogenetics is still an emerging tool used to help restore brain rhythmicity, it is based on the understanding that these rhythms are disrupted in AD, and that controlling neural activity can also influence sleep and cognition. However, by treating dementia and degeneration caused by AD as dysfunctions of neural rhythm, it is thought to be possible to modulate neural population oscillations. By using optogenetics to target specific neural circuits that are responsible for generating brain waves, it may be possible to restore them[16][17]. In this review, I will explore how disrupted brain rhythms during sleep contribute to the symptoms and progression of Alzheimer's disease, and how it may be possible to restore these rhythms through the utilization of optogenetics. It will be made clear that altering brain rhythms is a very promising new approach in slowing the progression of AD and improving the quality of life for patients suffering from it.

Disrupted Brain Rhythms and Sleep in Alzheimer's Disease

Alzheimer's disease (AD) is commonly known to cause progressive memory loss and cognitive decline, but mounting evidence indicates that one of the most noticeable and early

symptoms of AD is the disturbance of brain rhythms, particularly those that take place while you're sleeping. These rhythms–slow-wave sleep (SWS) and gamma oscillations in particular–play a vital role in neural synchronization, memory consolidation, and the cleansing of toxic proteins from the brain such as amyloid-β and tau. The abnormalities in these rhythms strongly correlate with Alzheimer's symptoms and are believed to further AD progression (Figure 1). Studies have shown that when individuals have sound sleep, especially SWS, the brain cleanses the toxic proteins known as amyloid-β and tau[9]. These proteins are reported to build up in the brains of AD patients. During daytime or wakefulness and elevated brain activity, more amyloid and tau are present due to increased production. However during sleep, amyloid and tau levels are reduced due to clearance. Consequently, if someone experiences poor sleep, it can impair the brain's ability to get rid of these abnormal proteins. This leads to a vicious cycle in which poor sleep leads to increased protein deposition, which further disrupts sleep and aggravates AD symptoms (Figure 1).

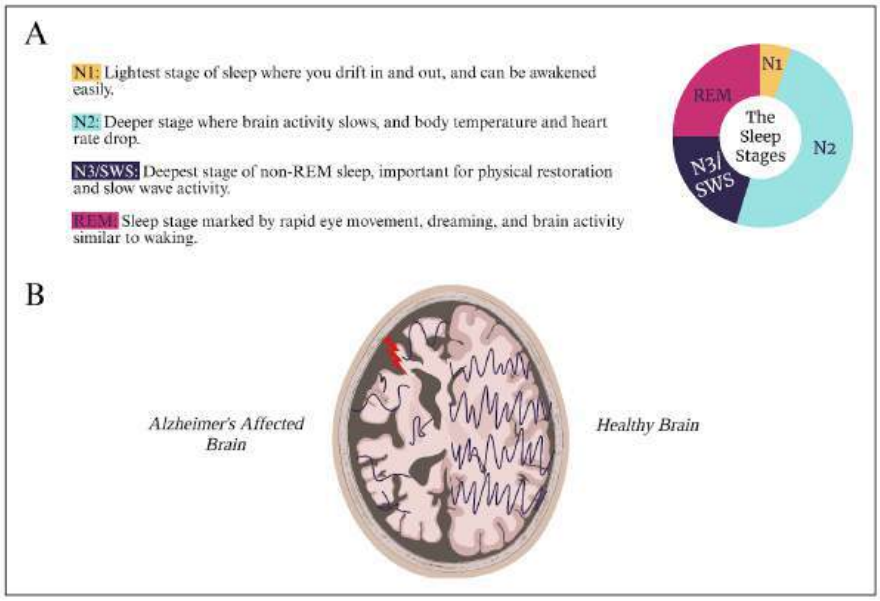


Figure 1. Sleep wave patterns in health and diseased brain. A. Description of the sleep stages. B. Right side shows healthy slow wave sleep (SWS). Left side shows Alzheimer's diseased brain with loss of volume and disrupted slow wave sleep. The red lightning bolt represents disrupted activity/neurodegeneration.
Made with Biorender.

In an early study by Ju et al. (2017), scientists selectively interfered with SWS in a study involving 17 healthy adults aged 35-65 years. In the study acoustic stimulation was used to disrupt slow-wave activity (without waking the participants), whilst a polysomnography was used to monitor the participants' sleep stages (including when they entered SWS). The next morning, cerebrospinal fluid (CSF) was collected to assay the amyloid-β content. Although there was no change in the overall sleep duration, the attenuation of slow-wave activity led to a 6-16%

increase in CSF amyloid-β_{40}. This change strongly correlates with the extent of loss of SWS. The fewer slow-waves were accompanied by more amyloid accumulation, providing direct evidence that deep sleep plays a role in amyloid clearance from the brain. This study was one of the first to show that sleep quality, rather than amount, might influence Alzheimer's risk[18].

Aligning with this finding, Varga et al. (2016) used lumbar punctures and overnight EEG to study cognitively normal older adults (age 66.9 ± 8.3 years), which supported this finding. They found that reduced or fragmented SWS was associated with higher concentrations of amyloid-β_{40} in CSF, even in asymptomatic individuals (Figure 1). This would suggest that sleep disorder is not just a result of AD – it may be subtle and early, occurring before memory impairment itself, and therefore potentially acting as an early biomarker and therapeutic target[19]. Similarly, Himali et al. (2024) prospectively followed up with 346 healthy, older individuals (ranging 60-87 years, 69 average) over a 17-year period in the Framingham Heart Study, and found that a 27% increased risk of new-onset dementia was associated with every 1% annual decrease in SWS[20]. While dementia does not necessarily imply AD, it is still a class of disorders that refer to deficits in cognitive function that are very similarly seen in AD patients. These long-term results support the notion that a key contributing factor to neurodegeneration is the progressive loss of deep sleep.

Other studies have not only measured for the presence of amyloid, but clearance as well. Xie et al. (2013) demonstrated that during SWS the space between neurons increases and that there is an increased flow of cerebrospinal fluid through the glymphatic system, or the brain's waste-clearing system. Their study showed that sleep deprivation or disruption caused compromised glymphatic clearance of amyloid and tau, positioning poor sleep as a contributing cause of toxic protein accumulation[9][21]. Further, more recent fMRI by Fultz et al. (2019) showed that slow-waves in brain activity during SWS corresponded directly with waves of pulsatile CSF moving through the brain, providing a real-time visualization of this clearance process in action[22].

Taken together, these findings support the idea that SWS is neuroprotective because it facilitates the clearance of toxic proteins from the brain. In Alzheimer's disease, SWS is disrupted by pathological changes in the brain, which creates a vicious cycle by promoting further accumulation of amyloid-beta and accelerating neurodegeneration. This feedback loop is why improving sleep has become an important focus for researchers attempting to assist in Alzheimer's research and treatment. With this, they have begun to look for new tools that can efficiently target and repair disrupted rhythms, among the most compelling of which is optogenetics.

Light-Based Neuromodulation: Optogenetics as a Therapeutic Strategy for AD

With the new discovery that brain rhythm disruption is one of the core contributors in AD pathology, naturally the question is how to restore these rhythms in a precise and effective way. Optogenetics is a novel neuroscience technology that allows the modulation of an individual neuron with high precision. The method was first developed in the early 2000s and utilizes light

to control genetically altered neurons' activity. It works by infecting the cells with genetically encoded light-sensitive proteins called opsins, which can be turned on or off using certain wavelengths of light. This allows scientists to finely control when and where neurons fire, in most instances to the millisecond[14]. Through the excitation or inactivation of specific populations of cells, researchers are able to activate or inactivate neurons at specific frequencies. Given its great accuracy, optogenetics has now become a useful tool for studying and understanding brain circuits that are responsible for behaviour, memory, and disease, which proves useful in possibly recovering the natural rhythms lost as a consequence of AD (Figure 2).

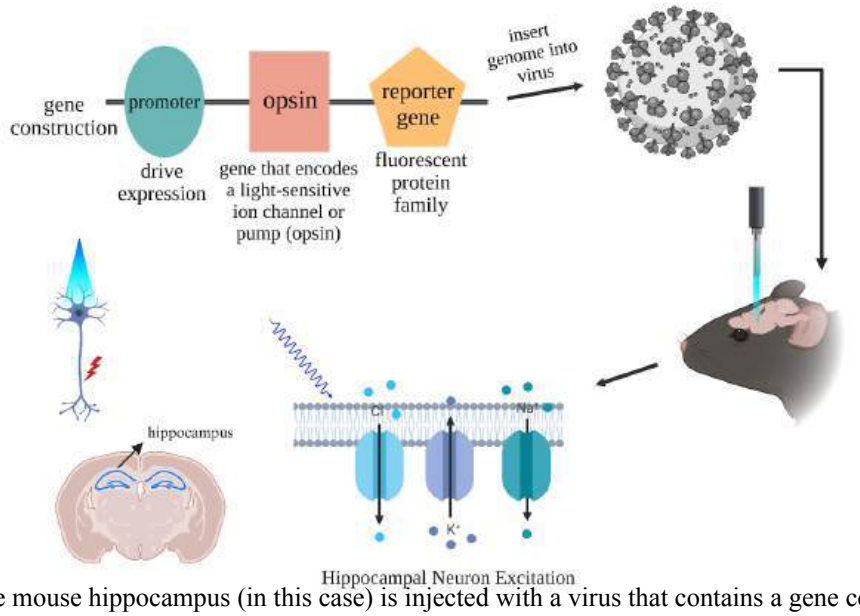


Figure 2. The mouse hippocampus (in this case) is injected with a virus that contains a gene construct which includes a reporter, opsin, and promoter. Opsin is activated by light transmitted through an optical fibre, which results in ion flow and precise excitation of neurons. Made with Biorender.

Recently Lee et al. (2023) investigated the contribution of astrocytes (a type of support cell in the central nervous system) to AD caused disruptions of slow-wave brain rhythms that are important for memory consolidation during non-REM sleep. Using optogenetics and multiphoton microscopy in amyloid precursor protein/presenilin 1 (APP/PS1) mice, it was found that astrocytes involved in slow-wave networks exhibited weaker astrocytic calcium signaling relative to healthy controls, particularly in the magnitude of calcium transients. By using optogenetics to activate astrocytes at the natural frequency of their slow waves, they were able to restore slow-wave power which induced a great reduction in amyloid plaque deposition. Astrocyte stimulation also reversed pathological neuronal calcium increase, a sign of neural dysfunction, and most importantly, improved memory performance on behavioral tasks[23]. Together, these results suggest an early underappreciated role for astrocytes in the maintenance of brain rhythms during health, and that selective stimulation of astrocytes via optogenetics may

represent a novel therapeutic approach to treat sleep disruption and cognitive impairments associated with AD.

Cui et al. (2020) carried out an investigation into the effect of glutamatergic (excitatory) neuronal activation on amyloid-β induced dysfunction using C57BL/6 mice. AAV5-CaMKII–ChR2 was injected into the dentate gyrus (DG) of a mouse that had received prior Aβ1-42 injections. Optogenetic stimulation was carried out hours post-injection into the DG, and the stimulation was carried across daily sessions for several days. The results were significant improvement in both working memory and short-term memory as assessed by behavioural tests. At the cellular level, results showed increase in synaptic markers (NeuN and synapsin), increased IL-10 expression, and decreased GFAP, showing that the activated neurons at the DG regulated neuroinflammation but, in the targeted region only. In this case, the effects did not extend to distant regions and indicate that optogenetic benefits are specific to locations and need further investigation[24].

In another optogenetic study on a targeted region, Etter et al. (2019) chose to stimulate the medial septal area of J20-APP mice during the memory retrieval task. They were able to restore the hippocampal gamma oscillations, which had been significantly disrupted in the Alzheimer's mice, by stimulating the parvalbumin-positive cells in that area with 40 Hz optogenetic stimulation. The restored rhythm led to significant spatial memory improvement, as measured by performance in an appetitive version of the Barnes maze task. The hippocampus, where memories are formed and retrieved, appears to depend on well-tuned gamma rhythms to operate. This study illustrates that gamma-based stimulation not only reduces pathology – but also improves memory circuits directly and rescues cognitive impairment, even in the presence of already-established amyloid plaques[25].

Whilst many optogenetic studies in AD target amyloid-β, fewer examine its effects on tau pathology. In one study, channelrhodopsin-2 (ChR2) was used to activate excitatory hippocampus neurons for 30 minutes each day over a few days using the rTg4510 mouse model of tauopathy. They found that the stimulated hemisphere showed significantly higher levels of tau and greater propagation of tau pathology. These findings imply that tau accumulation may be exacerbated by increased neuronal activity, particularly in excitatory circuits, most likely through an increase in activity-dependent tau release and transmission. The study also reported elevated levels of synaptic hyperactivity markers and increased tau seeding activity, directly involving optogenetic overactivation in processes that enhance tau aggregation and propagation[26]. This does not mean that optogenetics does not work. Instead, it testifies to the importance of precision in determining which neurons to target, how frequently to stimulate, and at what point in the disease. So far, most optogenetic experiments on tau exhibit neutral or negative effects, and there is a clear lack of studies targeting tau reduction versus amyloid reduction. Still, this preliminary data shows that optogenetics can be refined– for example, by targeting inhibitory neurons, modulation of astrocytes, or pairing stimulation with tau-clearing mechanisms. Such changes may lead to more positive outcomes.

It is well known that hyperexcitability enhances tau transmission: when a neuron with tau becomes excited, the protein is transmitted more rapidly into connected neurons. AD is often described as a disorder of hyperexcitability where excessive neuronal activity causes more rapid tau spread and worsening pathology[27][28]. This information may suggest that dampening excitability (preferably early in the disease) could potentially slow the progression of AD and preserve cognitive function. This raises the question of whether optogenetics can be used not to stimulate excitatory neurons, which have been shown to enhance tau propagation, but rather activate inhibitory neurons that would suppress the hyperactive circuits, and counteract the burden of excitatory drive. This targeted approach contrasts with broad stimulation methods such as deep brain stimulation or transcranial magnetic stimulation which would stimulate the entire region with lack of cell-type specificity. Also, optogenetics does not need to be a "one-size-fits-all" intervention, for example; stimulation could be performed in the brain regions responsible for sleep-wake-rhythm to recover entire network synchrony, while in the hippocampus or a tau-vulnerable region of the brain, it could be used to suppress overactivity. Brain area and engagement-specific modulation has the potential to capture both pathological tau dynamics and disrupted brain rhythms, which may offer a dual therapeutic outcome.

As a whole, these studies suggest that optogenetics–like all other rhythmic brain stimulations–may be a very useful new treatment for AD. Instead of trying to stop symptoms or slow down pathology with developing drugs, optogenetics allows researchers to skip the drug approach and go straight to working with the brain. For example, by restoring a critical rhythm in the brain (e.g., 40 Hz gamma), it is possible that amyloid burden will decrease, microglia will be reactivated, sleep cycles will be repaired, and cognition will improve. The effects on tau pathology are less established. There are some instances of optogenetic stimulation–especially of excitatory neurons–demonstrating the opposite effect, ultimately exacerbating tau accumulation[28]. However, just as with all neuromodulation therapy, optogenetics requires a direct improvement in methodology. This doesn't exclude using optogenetics as a treatment but emphasises the use of optogenetics down to a greater degree of precision in employing the right cell types at the right frequencies and at the right stage of disease. Upon continual research and development, optogenetics has the potential to become a very targeted and unique method that can treat amyloid and tau-related disruption, and lead to more effective treatments for AD.

A Comparison of Optogenetics to Other Therapies

A majority of Alzheimer’s drugs available today — with the exception of cholinesterase inhibitors and memantine, only offer temporary symptom relief and do not address the disrupted brain rhythms on which the disease progression is based upon. All drugs work indiscriminately throughout the brain and the body, and have a tendency to induce side effects such as insomnia, dizziness, and gastrointestinal issues[29]. For example, donepezil was found to disrupt slow-wave sleep, which is critical for memory and toxic clearance[30]. Above all, the current treatments lack the precision to target individual neural circuits or restore disrupted oscillation patterns– like gamma and slow-wave activity– that are disturbed in Alzheimer's disease. In contrast,

optogenetics offers high-precision control of neural activity, and research has been shown to accurately restore disturbed brain rhythms at a millisecond timescale[14]. This kind of specificity makes optogenetics a more promising and effective strategy for treating the root cause of cognitive impairments in Alzheimer's.

Newer treatments have switched strategies, and instead are trying to target the abnormal proteins associated with Alzheimer's: amyloid-β and tau. Drugs like aducanumab and lecanemab aim to remove amyloid plaques, and whilst they have succeeded at reducing plaque levels, the cognitive gains themselves have been moderate, and side effects like ARIA (amyloid-related imaging abnormalities) remain a large concern[31][32] (Figure 3).

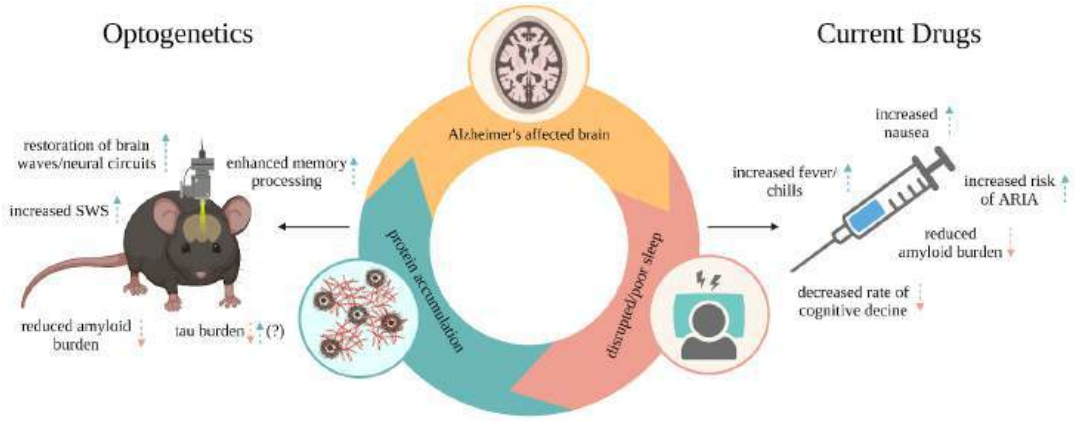


Figure 3. Comparison of optogenetics and current drug treatments for Alzheimer's disease. Middle shows the cycle of AD, sleep disruption, and protein accumulation. Either side shows a potential treatment. Left side shows benefits of optogenetics. Right side shows state of current drugs. Green arrow represents an increase, red arrow represents a decrease. Made with Biorender.

These drugs do not necessarily improve sleep quality, which is directly linked to memory and waste removal. Tau-targeting drugs–such as anti-tau antibodies– have been even more difficult, with most failing to show even substantial effects in clinical trials. None have moved past late-stage testing or received FDA approval. This highlights tau as an extremely difficult target to treat[33]. This issue extends to optogenetics as well: studies have shown that when excitatory neurons are overactivated, tau pathology can worsen. Rather than disproving optogenetics, however, this reveals how little is understood about tau and why more targeted work needs to be conducted. If drugs and current optogenetic treatment cannot clear tau, it reflects the challenge in the protein, not in the treatment method. This could justify future optogenetic strategies targeting glial cell modulation inhibitory circuits, or combining stimulation with tau-clearing agents. (Figure 3).

One of the most promising and overlooked uses of optogenetics is its potential to restore natural sleep rhythms, which are all but impossible to restore with current drugs. Disrupted sleep is one of the very earliest symptoms of AD and is a large contributor to worsening memory, cognition, and protein buildup. Whilst sleep aids like sedatives or melatonin help patients fall

asleep, they do not restore the structure of sleep– especially not the deep slow-wave stages that clear toxins from the brain[34]. There are no FDA approved drugs on the market that are capable of directly recovering this stage of sleep once it is lost. Optogenetics may uniquely target the circuits that generate these rhythms, and studies provide evidence to support its ability to improve sleep quality, memory, and even brain cleansing in animal (mouse) models. Although human applications are still in development, related non-invasive techniques, like 40 Hz sensory stimulation using visual and auditory cues, have already advanced to clinical trials.

In a six-month randomized pilot trial of patients with mild to moderate AD, daily one-hour gamma entrainment via audio-visual stimulation significantly reduced nocturnal activity, which represents improved sleep quality, and stabilized daily living capacity relative to sham controls[35]. These results closely replicate preclinical mouse research where 40 Hz entrainment restored circadian rhythm, increased glymphatic clearance, reduced amyloid burden, and enhanced cognition. Although mechanisms are still not understood in humans, translational consistency between animal models and sensory-based gamma stimulation in humans is a testament to its potential. Entrainment of light-based treatments on normal brain rhythms may offer a practical, scalable method for alleviating sleep disruption and halting functional deterioration in early AD, bridging results of optogenetic approaches in rodents to potential applications in people.

Conclusion

Alzheimer's disease continues to be one of the most disabling and complex neurodegenerative conditions, with a majority of therapies only providing, at best, temporary symptom relief. Mounting evidence now positions disrupted brain rhythms—particularly during sleep—as a key element in AD pathology[17][18][19][21]. Disruption not only compromises memory and cognition but also derails the brain's capacity to clear toxic proteins like amyloid-β and tau that accumulate in disease[11]. Although these disordered rhythms cannot be directly addressed by conventional pharmaceutical methods, optogenetics has become a targeted and innovative treatment. Through cell-specific excitation or inactivation on the neural networks generating brain rhythms, optogenetic therapies have been found to restore gamma and slow-wave activity, reduce protein aggregation, and improve sleep and cognition in mouse models[23][25]. Whilst optogenetics is still in its infancy in human therapeutic translation, studies using non-invasive gamma entrainment have already demonstrated promise to improve both sleep and function in AD patients[35]. Now the task is to maximize the technique—deciding which populations of neurons to activate, at what frequencies, and at what disease stages—to increase maximum efficiency. With further research, optogenetics could become a revolutionary approach to treating AD, providing symptom relief, rhythm restoration, and an even more individualized/targeted treatment plan.

Works Cited

1.Jee, Sungju. “Brain Oscillations and Their Implications for Neurorehabilitation.” Brain & Neurorehabilitation 14, no. 1 (January 1, 2021). https://doi.org/10.12786/bn.2021.14.e7.

2.Barbas, Helen. et al. “Pathway Mechanism for Excitatory and Inhibitory Control in Working Memory.” Journal of Neurophysiology 120, no. 5 (September 26, 2018): 2659–78. https://doi.org/10.1152/jn.00936.2017.

3.Andrade-Talavera, Yuniesky, Fisahn, André, and Rodríguez-Moreno, Antonio. “Timing to Be Precise? An Overview of Spike Timing-dependent Plasticity, Brain Rhythmicity, and Glial Cells Interplay Within Neuronal Circuits.” Molecular Psychiatry 28, no. 6 (March 29, 2023): 2177–88. https://doi.org/10.1038/s41380-023-02027-w.

4.Weiner, Oren M., and Dang-Vu, Thien Thanh. “Spindle Oscillations in Sleep Disorders: A Systematic Review.” Neural Plasticity, vol. 2016, 2016, p. 7328725. PubMed Central, https://doi.org/10.1155/2016/7328725.

5.Dijk, Derk-Jan. “Regulation and Functional Correlates of Slow Wave Sleep,” April 15, 2009. https://pmc.ncbi.nlm.nih.gov/articles/PMC2824213/.

6.“Circadian Rhythms | National Institute of General Medical Sciences,” n.d. https://www.nigms.nih.gov/education/fact-sheets/Pages/circadian-rhythms.

7.Hennawy, Mirna, et al. “Sleep and Attention in Alzheimer’s Disease.” The Yale Journal of Biology and Medicine, vol. 92, no. 1, Mar. 2019, pp. 53–61. PubMed Central, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6430169/.

8.Bhandari, Tamara. “Decreased Deep Sleep Linked to Early Signs of Alzheimer’s Disease | WashU Medicine.” WashU Medicine, January 21, 2019. https://medicine.washu.edu/news/decreased-deep-sleep-linked-to-early-signs-of-alzheimers-disease/.

9.Xie, Lulu. et al. “Sleep Drives Metabolite Clearance From the Adult Brain.” Science 342, no. 6156 (October 17, 2013): 373–77. https://doi.org/10.1126/science.1241224.

10.Musiek, Erik S., Xiong, David D, and Holtzman, David M. “Sleep, Circadian Rhythms, and the Pathogenesis of Alzheimer Disease.” Experimental & Molecular Medicine, vol. 47, no. 3, Mar. 2015, p. e148. PubMed Central, https://doi.org/10.1038/emm.2014.121.

11.Hanert, Annika. et al. “Reduced Overnight Memory Consolidation and Associated Alterations in Sleep Spindles and Slow Oscillations in Early Alzheimer’s Disease.” Neurobiology of Disease, vol. 190, Jan. 2024, p. 106378. ScienceDirect, https://doi.org/10.1016/j.nbd.2023.106378.

12.Trafton, Anne. MIT News | Massachusetts Institute of Technology. “Brain Wave Stimulation May Improve Alzheimer’s Symptoms,” March 14, 2019. https://news.mit.edu/2019/brain-wave-stimulation-improve-alzheimers-0314.

13.Traikapi, Artemis and Konstantinou, Nikos. “Gamma Oscillations in Alzheimer’s Disease and Their Potential Therapeutic Role.” Frontiers in Systems Neuroscience 15 (December 13, 2021). https://doi.org/10.3389/fnsys.2021.782399.

14.Yizhar, Ofer. et al. “Optogenetics in Neural Systems.” Neuron, vol. 71, no. 1, Jul. 2011, pp. 9–34. ScienceDirect, https://doi.org/10.1016/j.neuron.2011.06.004.
15.Zhao, Qiuchen. et al. “Optogenetic Targeting of Cortical Astrocytes Selectively Improves NREM Sleep in an Alzheimer’s Disease Mouse Model.” Scientific Reports 14, no. 1 (October 4, 2024). https://doi.org/10.1038/s41598-024-73082-8.
16.Etter, Guillaume. et al. “Optogenetic Gamma Stimulation Rescues Memory Impairments in an Alzheimer’s Disease Mouse Model.” Nature Communications 10, no. 1 (November 22, 2019). https://doi.org/10.1038/s41467-019-13260-9.
17.Zhao, Qiuchen. et al. “Sleep Restoration by Optogenetic Targeting of GABAergic Neurons Reprograms Microglia and Ameliorates Pathological Phenotypes in an Alzheimer’s Disease Model.” Molecular Neurodegeneration 18, no. 1 (December 1, 2023). https://doi.org/10.1186/s13024-023-00682-9.
18.Ju, Yo-El. et al. “Slow Wave Sleep Disruption Increases Cerebrospinal Fluid Amyloid-β Levels.” Brain 140, no. 8 (May 30, 2017): 2104–11. https://doi.org/10.1093/brain/awx148.
19.Varga, Andrew. et al. “Reduced Slow-Wave Sleep Is Associated With High Cerebrospinal Fluid Aβ42 Levels in Cognitively Normal Elderly.” SLEEP 39, no. 11 (October 31, 2016): 2041–48. https://doi.org/10.5665/sleep.6240.
20.Himali, Jayandra J. et al. “Association Between Slow-Wave Sleep Loss and Incident Dementia.” JAMA Neurology 80, no. 12 (October 30, 2023): 1326. https://doi.org/10.1001/jamaneurol.2023.3889.
21.Nedergaard, Maiken and Goldman, Steven. “Glymphatic Failure as a Final Common Pathway to Dementia.” Science 370, no. 6512 (October 2, 2020): 50–56. https://doi.org/10.1126/science.abb8739.
22.Fultz, Nina. et al. “Coupled Electrophysiological, Hemodynamic, and Cerebrospinal Fluid Oscillations in Human Sleep.” Science 366, no. 6465 (October 31, 2019): 628–31. https://doi.org/10.1126/science.aax5440.
23.2Lee, Yee Fun. et al. “Optogenetic Targeting of Astrocytes Restores Slow Brain Rhythm Function and Slows Alzheimer’s Disease Pathology.” Scientific Reports 13, no. 1 (August 11, 2023). https://doi.org/10.1038/s41598-023-40402-3.
24.Cui, Xiaorui. et al. “Neuroprotective Effect of Optogenetics Varies With Distance From Channelrhodopsin-2 Expression in an Amyloid-β-Injected Mouse Model of Alzheimer’s Disease.” Frontiers in Neuroscience 14 (October 9, 2020). https://doi.org/10.3389/fnins.2020.583628.
25.Etter, Guillaume. et al. “Optogenetic Gamma Stimulation Rescues Memory Impairments in an Alzheimer’s Disease Mouse Model.” Nature Communications 10, no. 1 (November 22, 2019). https://doi.org/10.1038/s41467-019-13260-9.
26.Wu, Jessica W. et al. “Neuronal Activity Enhances Tau Propagation and Tau Pathology in Vivo.” Nature Neuroscience 19, no. 8 (June 20, 2016): 1085–92. https://doi.org/10.1038/nn.4328.

27.Targa Dias Anastacio, Helena. et al. “Neuronal Hyperexcitability in Alzheimer’s Disease: What Are the Drivers behind This Aberrant Phenotype?” Translational Psychiatry, vol. 12, no. 1, Jun. 2022, pp. 1–14. www.nature.com, https://doi.org/10.1038/s41398-022-02024-7.
28.Nishida, Itaru. et al. “Chronic Neuronal Hyperexcitation Exacerbates Tau Propagation in a Mouse Model of Tauopathy.” International Journal of Molecular Sciences, vol. 25, no. 16, Aug. 2024, p. 9004. PubMed Central, https://doi.org/10.3390/ijms25169004.
29.Portlock, Gabbie E. et al. “Therapeutic Dilemmas: Cognitive Enhancers and Risk of Falling in Older Adults—a Clinical Review.” European Geriatric Medicine 14, no. 4 (July 7, 2023): 721–32. https://doi.org/10.1007/s41999-023-00821-x.
30.Hsieh, Cheng-Fang. et al. “The Association of Changes of Sleep Architecture Related to Donepezil: A Systematic Review and Meta-Analysis.” Journal of the Formosan Medical Association, vol. 121, no. 8, Aug. 2022, pp. 1466–77. ScienceDirect, https://doi.org/10.1016/j.jfma.2021.10.013.
31.Bugos, Claire. “Leqembi: An Antibody Treatment for Early Alzheimer'S Disease.” Verywell Health, January 18, 2023. https://www.verywellhealth.com/leqembi-fda-approval-7095676.
32.Tampi, Rajesh R, Forester, Brent P, and Agronin, Marc. “Aducanumab: Evidence From Clinical Trial Data and Controversies.” Drugs in Context 10 (September 30, 2021): 1–9. https://doi.org/10.7573/dic.2021-7-3.
33.Geerts, Hugo. et al. “Analysis of Clinical Failure of Anti-tau and Anti-synuclein Antibodies in Neurodegeneration Using a Quantitative Systems Pharmacology Model.” Scientific Reports 13, no. 1 (September 1, 2023). https://doi.org/10.1038/s41598-023-41382-0.
34.Jung, Ji-Young. et al. “Effects of Single Treatment of Anti-Dementia Drugs on Sleep-Wake Patterns in Rats.” Korean Journal of Physiology and Pharmacology 16, no. 4 (January 1, 2012): 231. https://doi.org/10.4196/kjpp.2012.16.4.231.
35.Cimenser, Aylin. et al. “Sensory-Evoked 40-Hz Gamma Oscillation Improves Sleep and Daily Living Activities in Alzheimer’s Disease Patients.” Frontiers in Systems Neuroscience 15 (September 24, 2021). https://doi.org/10.3389/fnsys.2021.746859.

Property Defense and Lethal Force: A Natural Rights Approach By Anjin Lim

Abstract

This essay examines what injury property owners should be permitted to inflict when defending their possessions against theft. Drawing on Locke's natural rights theory, the analysis argues that property represents an extension of human dignity deserving robust protection, including lethal force when necessary. The essay demonstrates how strict proportionality requirements create perverse incentives that enable crime while leaving victims defenseless. Through examination of the exclusion principle, the aggregation problem in serial property crimes, and practical limitations defenders face, the work challenges current legal frameworks that restrict defensive force. The essay contends that democratic societies should determine appropriate force levels based on local crime conditions and deterrent needs rather than universal standards. Communities with high crime rates or limited police response should authorize greater defensive force than peaceful areas with rapid law enforcement. The conclusion maintains that property owners should be permitted to inflict whatever injury proves necessary to stop theft when less forceful means are ineffective, which honors the principle that law-abiding citizens should not surrender their possessions to criminals.

Introduction

When a thief breaks into your home at 2 AM, grabs your laptop, and runs toward the door, how much violence can you use to stop them? Can you tackle them? Hit them with a baseball bat? What if they're stealing your car with your life savings hidden in the trunk does that change the equation? These scenarios, far from hypothetical, represent daily realities that force property owners into split-second decisions with potentially life-altering consequences. In April 2018, a homeowner in London fatally stabbed an alleged burglar and was arrested on suspicion of murder before being released without charge, sparking national debate about victims being treated as perpetrators (Robin 15). Such incidents reveal the profound uncertainty surrounding what British law calls reasonable force in property defense, a standard that recognizes homeowners cannot be expected to calculate precise force levels during threatening situations, yet still requires their actions to stay within legal limits **(**Householders 1).

This question forces us to confront a fundamental tension in modern society: the collision between individual property rights and the collective interest in preventing private violence. Private property gives individuals extensive rights over their belongings, including use and control, with legal protection through the courts (Introduction to Property Law, p.19). Yet this legal protection contains a critical gap: while courts will eventually punish thieves, property owners must decide in real-time what level of force they can justifiably use before the law arrives. Legal scholars recognize that common law provides no clear answers to these seemingly simple questions about using force to recover property, and the scope of recaption rights remains unclear (Robin 2). As one legal analysis notes, this uncertainty reflects how modern property theory changes obscure the deeper ideological shifts happening when society tries to balance

individual rights against collective stability **(**Gregory 1549).

This uncertainty isn't merely academic; it reflects deeper philosophical disagreements about the nature of property, the acceptable limits of private violence, and who has the authority to determine those limits. The answer to what injury one person may inflict to defend property depends not on abstract legal principles, but on how we understand the relationship between individual ownership rights and collective social stability.

I. Property is an extension of the self and deserves strong protection.

John Locke's theory of natural rights provides the foundational philosophical justification for using substantial force to defend private property. Writing in the tumultuous context of 17th-century England, Locke witnessed firsthand the arbitrary seizure of property by monarchs and the Church. His experiences during the English Civil War and the Glorious Revolution shaped his conviction that property rights must exist independently of political authority. This historical context matters because Locke was not merely theorizing in abstract terms. He saw how the absence of secure property rights led to social chaos and individual suffering. Locke argued that property rights derive not from the grace of monarchs or the Church, but from natural law and individual labor. As Ruiz-Gallardón explains, for Locke property comes from natural human rights for sustenance and comfort of life and for the advantage of the owner (Ruiz-Gallardón 178). This conception transforms property from a mere privilege granted by authority into an extension of personal identity and self-ownership. When understood this way, attacks on property become attacks on the person. The thief who steals your tools steals your capacity to work. The burglar who invades your home violates your sanctuary and security. These violations touch the core of human existence in ways that transcend mere material loss.

This philosophical foundation gains additional support from modern human rights theory, which recognizes property rights as fundamental to human dignity itself. As Francis Cheneval argues, the body itself represents the first property of human beings, and respecting property relates directly to respecting bodily integrity and human freedom (Hernando 11). This understanding elevates property defense beyond mere material protection to safeguarding human autonomy and dignity. The connection runs deeper than simple analogy. Our bodies require shelter, food, and clothing to survive. We need tools to work and create. We need secure spaces to rest and recover. Property provides these necessities. Without property rights, human beings become dependent on the arbitrary goodwill of others for their most basic needs. This dependency undermines human dignity at its foundation. Moreover, owning property forms part of personal autonomy and ethical integrity while creating responsibility and dignity, which establish property rights as essential to human personhood rather than mere legal constructs (Hernando 13).

The relationship between property and personhood extends beyond physical necessities. Property allows individuals to express their values, maintain their traditions, and build their futures. A family home holds memories and provides stability across generations. Professional

tools enable craftsmen to practice their trades and support their families. Personal belongings carry emotional significance that monetary value cannot capture. These dimensions of property ownership reveal why violations of property rights inflict psychological and social harm beyond economic loss.

However, critics drawing from social contract theory raise concerns about this expansive view. As Whitman observes, traditional social contract theory justifies state coercion by arguing that individuals possess natural self-defense rights which they surrender to the state through social contracts (Whitman 903). These critics worry that strong property defense rights could lead to vigilante justice and social breakdown. They argue that civilized society requires individuals to rely on collective enforcement mechanisms rather than personal violence. While this criticism has some merit in emphasizing collective enforcement, it fails to account for the immediacy of property threats and the state's inability to provide real-time protection when needed most. Police cannot materialize instantly when thieves break down doors at night. Courts cannot restore stolen property that thieves have already destroyed or sold. The social contract assumes state protection that often exists only in theory. Property owners facing immediate threats must act without waiting for authorities who may arrive too late to help.

Given this foundation, property owners should be permitted to inflict whatever injury is necessary to protect their fundamental human dignity and autonomy. This includes severe physical harm when facing threats to property essential to their personhood and livelihood. Locke's framework establishes a reciprocity principle where property owners can legitimately match or exceed the force level aggressors bring to the encounter. Locke believed that through exercising knowledge and will, people acquire ownership of themselves and the external world around them through effort (Ruiz-Gallardón 166). Those who respect others' property rights gain corresponding protections for their own. Criminals who violate this social compact forfeit their claim to proportional treatment. They cannot demand gentle handling while engaged in violent theft. This creates a moral foundation where property owners can legitimately use substantial force when their autonomy and dignity face violation through property crimes. The aggressor chooses the terms of the encounter by initiating violence against property. The defender merely responds to that choice with necessary force to preserve what is rightfully theirs. Locke's natural rights theory thus justifies significant injury to aggressors in property defense. This positions such force as fundamentally about protecting individual autonomy rather than mere material accumulation. The person who defends property defends their very capacity to exist as a free and dignified human being in society.

II. Owners should be allowed to use any force necessary to stop theft.

The practical answer to what injury one person should be permitted to inflict in property defense is clear: property owners should be allowed to use lethal force when necessary to stop theft, regardless of the property's monetary value or the thief's personal circumstances. This position may seem extreme to those accustomed to modern legal frameworks that carefully calibrate force to threat levels. Yet these frameworks rest on false assumptions about criminal

behavior and victim capabilities. Thieves choose to violate property rights. They select their targets and timing. They control the initial terms of confrontation. Property owners react to situations criminals create. This fundamental asymmetry means defenders cannot afford to hesitate or calculate proportional responses while crimes unfold. Contemporary legal theories often impose artificial limitations, but as Steinhoff argues, theories that try to prevent lethal self-defense against property threats or minor assault by appealing to life's supreme value have counterintuitive implications and cannot be sustained (Steinhoff 265).

The fundamental nature of property rights requires recognizing the right to exclude as central to ownership itself. Property ownership means nothing without the ability to exclude others from accessing and using one's possessions. This exclusion right forms the core of what ownership means in any coherent system of property. A person who cannot exclude others from their property does not truly own it in any meaningful sense. They merely possess it temporarily until someone stronger or more aggressive takes it away. When criminals violate this fundamental right through theft, property owners must have effective means to restore their exclusive control. This includes inflicting severe physical harm or death if necessary. The alternative leaves property rights as mere suggestions that criminals can ignore whenever they calculate that the benefits outweigh the risks. Modern encryption technology demonstrates this principle clearly: as noted in recent legal scholarship, encryption ensures confidential and secure communications among individuals by creating digital barriers that exclude unauthorized access (McClure 466). Just as encryption creates absolute digital exclusion through technological means, physical property rights require owners to maintain absolute exclusion through whatever injury proves necessary to inflict on aggressors. The digital realm accepts absolute exclusion as necessary for security. The physical realm should recognize the same necessity. Property owners need tools as effective as encryption to protect their possessions from those who would take them.

Any injury short of what is required to stop the theft should be permitted. This principle follows from the nature of criminal choice and victim vulnerability. Criminals select when and how to strike. They choose victims who appear weak or distracted. They exploit surprise and superior numbers. Property owners must respond instantly without time for careful deliberation. Strict proportionality rules create perverse incentives that actually enable more crime. These rules tell criminals exactly how far they can go without facing serious consequences. They create safe zones for theft where criminals know their victims cannot effectively resist. Consider Steinhoff's apple thief scenario: if a frail elderly farmer can only stop a threatening bully by using lethal force, proportionality rules would require her to surrender her property. This leaves innocent people morally defenseless against inventive bullies who can exploit legal protections (Steinhoff 267). Property owners should be permitted to inflict whatever injury is necessary to stop the theft, including death. The criminal who initiates theft assumes the risk that defense might prove fatal. Society should not protect aggressors from consequences they bring upon themselves through criminal choices.

The aggregation problem demonstrates why society should permit substantial injury

against even minor thefts. Small thefts add up to massive social harm when multiplied across thousands of victims. A thief who steals ten dollars from a thousand people causes ten thousand dollars in losses plus the psychological trauma of victimization. Yet proportionality rules would protect this serial thief from serious harm because each individual theft seems minor. Steinhoff's sequential kidnapping hypothetical shows how prohibiting lethal force against individual property crimes enables systematic victimization. Strict proportionality would leave thousands of people defenseless against a culpable attacker because each individual theft might not justify lethal force under traditional analysis (Steinhoff 273). This creates an absurd situation where criminals can inflict unlimited aggregate harm while facing minimal individual consequences. Society cannot function when legal rules systematically favor criminals over victims. However, as Steinhoff observes, the proportionality of self-defense depends not only on the aggressor's rights but also on precautionary rules shaped by society's balance of interests (Steinhoff 264). Society's interest in deterring crime justifies permitting property owners to inflict any injury necessary, including death, even against thieves who pose no immediate threat to life. The social contract requires protecting those who follow rules from those who break them. This protection must be effective rather than theoretical.

Critics might argue that allowing substantial injury in property defense creates risks of excessive violence. They worry about vigilante justice and cycles of retaliation. They fear that property owners might use defensive rights as cover for aggressive violence. However, such concerns misunderstand both the deterrent effect of strong property protection and the practical limitations that property owners face. Most people avoid violence whenever possible. They use force only when cornered and threatened. Strong defensive rights deter crime by raising its costs. Criminals seek easy targets and avoid confrontations that might prove fatal. When property owners can defend themselves effectively, criminals move to other activities or locations. This reduces overall violence by preventing crimes before they start. As the encryption export debate illustrates, the widespread availability and use of robust, non-recoverable encryption will ultimately devastate our ability to fight crime and prevent terrorism unless proper protective measures exist (McClure 473). Similarly, restricting the injuries property owners can inflict ultimately devastates their ability to protect their fundamental rights against criminal aggression. Property owners need defensive options as robust as the threats they face. Anything less leaves them vulnerable to predation by those willing to exploit legal restrictions on defensive force.

III. Each society should set force limits based on its own needs.

The injury one person should be permitted to inflict in defense of property should be determined by democratic societies based on their crime levels and deterrent needs, not abstract philosophical principles. Different communities face different threats. A farming community where police response takes hours cannot apply the same defensive force standards as a downtown district with officers on every corner. Mountain communities isolated by weather for months need different rules than suburbs with constant patrol coverage. These practical realities matter more than theoretical frameworks developed in academic settings. As Steinhoff

demonstrates, proportionality requirements are ultimately shaped by the balance of interests in society and aimed at protecting innocent people and other social interests (Steinhoff 264). High-crime societies should permit greater defensive force than peaceful ones, and rural areas with limited police response should allow more self-help than urban centers with rapid law enforcement. Communities experiencing property crime waves need stronger deterrents than those with minimal theft. Societies recovering from conflict or natural disasters require different defensive permissions than stable prosperous regions. These variations reflect legitimate differences in social needs rather than arbitrary preferences.

This democratic approach aligns with emerging recognition of community-based property rights that derive their authority from local communities rather than state mandates. Communities understand their own security challenges better than distant legislators or judges. They know which neighborhoods face chronic theft problems. They recognize when drug epidemics drive property crime spikes. They see how economic downturns affect local crime patterns. As legal scholars observe, community-based property rights by definition come from and are enforced by communities, with their distinguishing feature being that they derive authority from the community where they operate, not from the state where they are located (Community-Based Property Rights 1). Just as indigenous communities determine their own resource management systems, local societies should establish appropriate levels of defensive force based on their specific crime conditions. Property defense rights must reflect community standards rather than imposed uniform rules. Urban residents might accept waiting for police while rural residents cannot. Wealthy areas might prefer insurance claims while poor communities need immediate defense. These preferences deserve respect rather than override by universal mandates.

This democratic approach aligns with Rojek's insight that property rights create individual autonomy while requiring social accountability. Rojek notes how Locke's framework made private experience a legitimate value of social worth that commanded a price (Rojek 553). Property defense rights must serve both individual protection and collective deterrence. Societies should explicitly authorize substantial force, including lethal force, when it serves these dual purposes effectively. Communities can evaluate their own crime statistics and determine appropriate responses. They can adjust defensive permissions as conditions change. Rising crime might justify expanded defensive rights while falling crime could support restrictions. This flexibility allows societies to balance competing interests based on actual conditions rather than theoretical ideals.

Based on philosophical foundations and practical considerations, property owners should generally be permitted to inflict severe injury, including death, when: (1) it is necessary to stop theft in progress, (2) less forceful means are unavailable or ineffective, and (3) the property owner reasonably believes the theft cannot be prevented otherwise. These criteria provide structure while allowing situational judgment. Property owners must assess threats quickly without perfect information. They cannot know whether thieves carry weapons or accomplices wait nearby. They cannot predict whether criminals will escalate violence if challenged. As

Ruiz-Gallardón observes, Locke's empiricism embraced contingency, immediacy and ephemerality as natural consequences of human experience (Ruiz-Gallardón 167). Property owners facing theft must make split-second decisions and should be given broad latitude to err on the side of protecting their possessions. Legal systems should recognize these decision pressures through generous defensive permissions rather than demanding perfect judgment under extreme stress.

Critics drawing from human rights law might argue that allowing substantial defensive force violates international standards requiring that force be used only as a last resort with non-violent or less violent means preferred (Heyns 5). However, these international law enforcement standards fundamentally misapply police protocols to private defensive situations. Unlike state agents with backup and training, property owners face immediate threats with limited options. Police officers have radios, partners, and procedures. Property owners have only their immediate capabilities and whatever tools they can reach. When the state cannot guarantee protection, it cannot deny citizens effective means of self-protection. International standards developed for professional law enforcement cannot govern civilian emergency responses.

The answer is clear: individuals should be permitted to inflict whatever injury is necessary to defend their property, up to and including lethal force, when such force is the only effective means available. This serves individual autonomy, provides criminal deterrence, and honors the fundamental principle that law-abiding citizens should not be required to surrender their possessions to criminals. Democratic societies can adjust these permissions based on local conditions, but the presumption should favor property owners over aggressors.

Conclusion

The question of what injury one person may inflict to defend property ultimately reveals the fundamental tension between individual rights and collective order that defines modern society. While legal systems struggle with concepts like "reasonable force," the philosophical foundations are clear: property represents an extension of human dignity and autonomy that deserves robust protection. Locke's natural rights theory, combined with practical deterrence needs, supports allowing property owners to use whatever force proves necessary to stop theft, including lethal force when no alternatives exist.

However, the specific boundaries of acceptable force should reflect democratic community standards rather than abstract universal principles. High-crime areas may reasonably permit greater defensive measures than peaceful communities, and rural locations with limited police response may justify more self-help than urban centers. What remains constant is the principle that law-abiding citizens should not be required to surrender their possessions to criminals. Property defense ultimately protects not just material goods, but the individual autonomy and human dignity that property ownership represents in a free society.

Works Cited

Alexander, Gregory. "The Concept of Property in Private and Constitutional Law: The Ideology of the Scientific Turn in Legal Analysis." Cornell Law Faculty Publications, 1 Dec. 1982. Accessed 26 August 2025.

"Community-Based Property Rights: A Concept Note." A Center for International Environmental Law, 2002. Accessed 30 September 2025.

Hernando De Soto, and Francis Cheneval. Realizing Property Rights. Zürich, Rüffer & Rub, 2006. Accessed 25 August 2025.

Heyns, Christof. "Autonomous Weapons Systems and Human Rights Law." United Nations Office of Disarmament Affairs. Accessed 30 September 2025.

Hickey, Robin. "Defending Property: Self-Help, the Use of Force, and the Concept of a Property Right." Queen's University Belfast, vol. 10, 2019. Accessed 27 July 2025.

"Householders and the Use of Force against Intruders." The Crown Prosecution Service, 2018. Accessed 24 August 2025.

"Introduction to Property Law in TIMOR-LESTE." Timor-Leste Legal Education Project (Stanford Law School). Accessed 30 July 2025.

McClure, David. "First Amendment Freedoms and the Encryption Export Battle: Deciphering the Importance of Bernstein v. United States Department of Justice, 176 F.3d 1132 (9th Cir. 1999)." Nebraska Law Review, vol. 79, no. 2, 2000. Accessed 30 Augst 2025.

Rojek, Chris. "John Locke, Private Property and the Birth of Achieved Celebrity." SAGE, 2022. Accessed 24 Augst 2025.

Ruiz-Gallardón, Isabel, and García De La Rasilla. "Knowledge and Property in John Locke." Global Jurist 2021, vol. 21(1): 165–180, 24 Sept. 2020. Accessed 27 August 2025.

Steinhoff, Uwe. "Proportionality in Self-Defense." The Journal of Ethics, vol. 21, no. 3, Sept. 2017. Accessed 27 July 2025.

Whitman, James Q. "Between Self-Defense and Vengence/between Social Contract and Monopoly of Violence." Tulsa Law Review, vol. 39, 2004. Accessed 29 July 2025.

Fashion Influencers and Sustainable Consumption: Assessing the Effectiveness of Sustainability Campaigns on Korean Generation Z By Kelly Choi

Abstract

The fast-fashion industry has become one of the most environmentally destructive sectors, generating extensive waste, pollution, and greenhouse gas emissions. Despite increasing awareness of these issues, consumers continue to prioritize affordability and convenience, revealing that unsustainable consumption patterns persist even amid rising environmental consciousness. While previous research has explored the environmental and psychological dimensions of fast fashion, limited attention has been given to the influence of digital fashion influencers in encouraging sustainable behavior among Generation Z consumers. This study examines the impact of influencer-led sustainability campaigns on the fast-fashion consumption patterns of Korean Gen Z consumers. A quantitative survey of 234 participants aged 16–24 measured shopping frequency, perceived influencer credibility, self-reported behavioral change, and social media engagement with fashion content framed around sustainability. Descriptive statistics were used to analyze correlations between exposure to sustainability campaigns and fast-fashion purchasing frequency. Findings reveal that although most participants were aware of the environmental harms of fast fashion, the majority continued to purchase such products frequently, even after exposure to influencer-led sustainability campaigns. Nearly 80% of respondents reported familiarity with sustainability-related content, yet more than three-quarters continued buying fast fashion at least once a month. While half of the respondents found sustainability-focused influencer content more persuasive than conventional fashion posts, only about one-third reported adopting more sustainable purchasing behaviors. This awareness–action gap suggests that greater knowledge does not necessarily lead to meaningful behavioral change, as consumers continue to weigh affordability, trend pressure, and social validation in their decisions. To encourage more sustainable consumption, this study recommends several policy interventions: integrating sustainability education into school curricula, offering tax incentives for sustainable purchases, implementing Extended Producer Responsibility (EPR) frameworks in the fashion industry, and establishing government-certified “green influencer” programs to strengthen the credibility of sustainability campaigns. Collectively, these measures could promote more responsible consumer behavior and support a more sustainable fashion ecosystem in South Korea.

1. Introduction

1.1. The Impact of Fast Fashion

The fashion industry is one of the most environmentally damaging sectors worldwide, generating vast amounts of waste, pollution, and greenhouse gas emissions. Fast fashion, driven by rapid production cycles and low-cost trend replication, amplifies these harms by promoting excessive consumption and disposal. Its reliance on synthetic materials such as polyester

contributes to microplastic pollution and significant carbon emissions. These practices directly contradict the principles of sustainable fashion, which emphasize minimizing environmental damage, reducing toxic chemical use, and advancing circular production systems (Adamkiewicz et al., 2022; Gurova, 2024).

The linear "take–make–dispose" model of fast fashion drives resource depletion and waste (Olivar Aponte et al., 2024). For instance, the European Union reports that textile consumption averages 19 kilograms per person annually, of which 12 kilograms are discarded, and producing a single T-shirt requires roughly 2,700 liters of water (European Union, 2025). Only about 1% of used textiles are recycled into new garments, while up to 9% are destroyed before sale.

Despite growing awareness of sustainability, consumer behavior in South Korea continues to prioritize affordability and convenience over environmental responsibility. The country's $14 billion fast-fashion market is still expanding (Precision Analysis Hub, 2025). Research by Yoon et al. (2020) indicates that many Korean consumers externalize responsibility for environmental harm attributing it primarily to corporations while overlooking their own participation in overconsumption. There is a gap between what people know and the way they actually behave, and it shows why it is important to look at how culture and social media influence ideas about responsibility. In South Korea where people are very connected online, influencers have a big influence on how students view sustainable fashion. They often present sustainability as something that is both the "right thing to do" and a stylish choice, which can make it hard to tell the difference between real advocacy and just looking trendy.

1.2. Korea's Growing Market with Young, Trend-Focused Consumers

South Korea's fashion market is characterized by its strong digital connectivity and trend-driven consumer base. According to Precision Analysis Hub (2025), the market was valued at approximately $14 billion in 2024 and is projected to reach $17 billion by 2033. This anticipated growth is driven by increasing demand and the expanding use of AI-assisted retail. The report highlights intense competition between global and local brands and notes the rapid rise of e-commerce as a dominant retail channel. Although sustainability is gaining greater recognition among both consumers and policymakers, speed and affordability continue to dominate purchasing decisions.

Kyung (2023) provides insight into the values shaping young Korean consumers' decisions to purchase sustainable fashion. Through in-depth interviews, she identified four key motivational orientations: financial, self-concept, social, and environmental consciousness. The study revealed that sustainability alone is rarely sufficient to influence consumer behavior—young Koreans also weigh factors such as cost, social status, and aesthetic appeal. Moreover, product attributes like material quality and durability are tied to personal outcomes such as feeling responsible or looking fashionable. Understanding these motivations is essential for social media influencers, whose sustainability campaigns can strategically appeal to these

values to shape perceptions and encourage more responsible fashion choices among Generation Z consumers.

1.3. Social Media Influence on Fast Fashion

Over the past decade, social media platforms such as TikTok and Instagram have profoundly reshaped fashion consumption patterns. Generation Z influencers, in particular, have emerged as the new gatekeepers of taste, determining which styles are considered fashionable (El-Shihy & Awaad, 2025). Through "haul" videos and aspirational content, they promote rapid consumption cycles that reinforce fast fashion's immediacy and disposability (Munaro, 2024; Liu, 2022). At the same time, influencer culture is evolving: El-Shihy and Awaad (2025) found that social media can also motivate Gen Z to engage with sustainable fashion, while Vikaite-Vaitone et al. (2024) showed that consumers are more likely to adopt eco-conscious behaviors when guided by credible and authentic influencers. This suggests that although the culture of disposability remains strong, influencer-led sustainability campaigns may hold growing potential to inspire behavioral change among young consumers.

Research in recent times shows that the design of social media platforms adds to the mixed outcomes. For instance, Cotter (2019) shows that Instagram's algorithms give priority to visually engaging content that is fast paced, so this could be a factor that amplifies trend-driven fast fashion purchasing. Also, McNeill and Venter (2019) add to this that young consumers are getting more responsive to sustainability messaging when it is framed as socially meaningful or identity affirming. Influencer credibility and their engagement can make these conditions stronger. Together, the findings bring out the point that platform infrastructures and influencer dynamics work at the same time to make rapid consumption and emerging forms of fashion engagement.

1.4. Psychological and Cultural Barriers to Fast-Fashion Consumption

Yoon et al. (2020) studied why consumers in Korea and Spain avoid fast fashion and found clear cultural differences. In Korea, feelings of deindividuation, losing one's unique identity in mass trends and foreignness, and seeing brands as too distant, were linked to anti-consumption attitudes. In Spain, however, people avoided fast fashion mainly because of poor product quality and irresponsible brand behavior, though attractive styles could still draw them back. These findings show that cultural context shapes how consumers respond to fashion messages, suggesting that influencer campaigns may work differently across countries.

This also relates to what Green (2025) calls the accountability gap: many consumers blame fast-fashion brands for environmental harm but keep buying their products for reasons of price and style. Yoon et al. (2020) argue that recognizing how fast fashion conflicts with personal and social values can motivate behavioral change. Therefore, sustainability campaigns should not only present facts about pollution or waste but also connect to identity and self-image, especially in Korea, where these factors strongly influence consumer decisions. Korea is a country where fashion consumption is closely linked to social comparison and identity

expression in a highly networked society. It means that trends can spread quickly and people get pressured to match their appearance with group norms (Workman and Lee, 2010).

Huang et al. (2025) add another perspective by studying how people view fast-fashion consumers in South Korea. They found that frequent buyers are often judged as impulsive and short-term thinkers, while those who shop less are viewed more positively. These social perceptions highlight that psychological and cultural factors are key to understanding, and potentially reducing, fast-fashion consumption.

1.5. The Awareness-Action Gap

Other research demonstrates that there is often a misconception that awareness naturally leads to action, whereas, in practice, this is rarely the case. As noted earlier in this review, fast-fashion sales in South Korea continue to show strong growth (Precision Analysis Hub, 2025), even as public awareness of the industry's environmental impact rises (e.g., Yoon et al., 2020). This persistent gap between awareness and action has been attributed to several interrelated factors. For instance, young consumers may acknowledge the environmental damage caused by fast fashion yet continue purchasing it for reasons of price, trend appeal, and convenience. Huang et al. (2025) highlight the influence of instant gratification in driving these choices, while other studies point to the compounding effects of perceived brand credibility, limited circularity in the fashion system, and peer influence as barriers to behavioral change (Munaro et al., 2024; EU, 2025).

Yoon et al. (2020) further reveal that in Korea, identity-based beliefs, such as deindividuation and perceptions of foreignness, can foster anti-consumption attitudes that resist the overconsumption encouraged by fast fashion. However, transforming these attitudes into consistent behavioral change remains a major challenge. Lee (2023) emphasizes that factors such as self-concept and social value strongly shape whether individuals choose sustainable products, while Huang et al. (2025) associate fast-fashion consumption with low perceived self-control. This, in turn, can generate social pressure and, paradoxically, lead to resistance or backlash when sustainability discourse becomes moralizing or shame-driven.

While previous literature has examined environmental sustainability and its relationship with fast fashion in the contemporary period (Olivar Aponte et al., 2024; EU, 2025; Precision Analysis Hub, 2025), there remains limited evidence exploring how sustainability campaigns on social media influence this relationship, particularly within the South Korean context. Korean consumers tend to value financial, self-concept, social, and environmental aspects of fashion simultaneously (Lee, 2023), which makes a full shift toward anti-consumerism difficult. At the same time, their emphasis on identity-related beliefs can motivate greater awareness of consumption patterns and foster selective engagement with sustainability messages (Yoon et al., 2020).

Social media influencers can play a significant role in this process by enhancing the credibility and emotional appeal of environmentally focused messages shared through their campaigns (Munaro et al., 2024; Villaite-Vaitone, 2024; El-Shihy & Awaad, 2025). However, to

the best of the authors' knowledge, a direct causal relationship between influencer-led sustainability communication and measurable behavioral change has not yet been established. Moreover, as Huang et al. (2025) note, the long-term environmental consequences of fast fashion are often overlooked, and many consumers continue to struggle to translate awareness into consistent action - a reflection of the persistent awareness–action gap.

To address this gap, the present study focuses on the consumption patterns of South Korean Generation Z consumers and examines how influencer-led sustainability campaigns on social media shape, or fail to shape, behavioral change within the fast-fashion industry.

1.6. Influencers and Sustainable Consumption

Building on the discussion above, which highlighted the growing importance of social media campaigns in shaping sustainability perceptions, this section examines how influencers specifically contribute to sustainable consumption behaviors. Existing research has explored how social media influencers shape consumers' purchasing decisions related to sustainability. For example, Munaro et al. (2024) conducted a meta-analysis of 52 studies and found that influencers indeed have the power to affect consumer behavior, particularly when their messaging is supported by credibility and perceived expertise. The authors emphasize that the effectiveness of influencer communication increases when it demonstrates a clear "green orientation" and delivers a compelling message appeal.

Vilkaite-Vaitone (2024) expands on this understanding by testing the mechanisms that determine the strength of influencer impact. Her findings indicate that an influencer's social standing, authenticity, and emotional engagement within their network are critical in shaping the success of sustainability-related campaigns. These studies collectively suggest that credibility and trustworthiness are central to the persuasive power of influencer marketing in the sustainability context.

Several additional studies put these ideas to the test through platform-specific analyses. El-Shihy and Awaad (2025), for instance, compared brand-generated content (BGC) and user-generated content (UGC) on TikTok and Instagram targeting Gen Z consumers interested in sustainable fashion. They report that BGC exerts a stronger influence because it tends to appear more professional, consistent, and emotionally resonant. This indicates that influencers, and sustainability advocates more broadly, must communicate with both aesthetic quality and emotional authenticity to effectively engage their audiences.

Similarly, Yildirim (2021) investigated the impact of "green women influencers," finding them especially effective in promoting sustainable consumption due to their micro-celebrity status and the perceived personal closeness they cultivate with followers. Their individualized voice, often framed around relatable experiences and values, enhances both credibility and emotional connection, positioning them as powerful agents in the promotion of sustainable fashion.

1.7. Research Focus

Building on the preceding discussion of influencer credibility and its potential to shape sustainable consumption, this study investigates how influencer-led sustainability campaigns on social media affect Generation Z consumers' fast-fashion purchasing behaviors in South Korea. Existing scholarship has extensively documented the environmental degradation and labor exploitation associated with fast fashion (El-Shihy & Awaad, 2025; Rodriguez, 2024; Gunawan, Matahariza, & Putri, 2023), yet there remains limited exploration of how digital culture and influencer engagement translate environmental awareness into behavioral change.

Recent studies examining the intersection between digital influencer culture and psychosocial drivers of fast fashion (Wojdyla & Chi, 2024) suggest that consumer perceptions are deeply embedded in sociocultural norms shaped by social media ecosystems. This influence appears particularly pronounced among Gen Z consumers in East Asia, where digital platforms play a central role in identity construction and peer validation (Sun, Wang, Kao, & Lee, 2022). However, despite the ubiquity of influencer campaigns promoting sustainable lifestyles, their actual effectiveness in reducing fast-fashion consumption remains largely untested.

This study aims to address this gap by empirically analyzing the perceived impact of social media influencers on the purchasing habits of South Korean Gen Z consumers. Specifically, it asks:

- How do influencer-led sustainability campaigns impact Gen Z consumers' fast-fashion purchasing behavior in South Korea?

By focusing on this question, the study contributes to a growing body of research that seeks to understand how digital communication, cultural identity, and sustainability awareness intersect in shaping consumption patterns. The findings are expected to provide insights not only into consumer psychology but also into how digital platforms can be leveraged to promote more sustainable fashion systems.

2. Methodology

2.1. Background

This research examines the relationship between Generation Z consumers' fast-fashion purchasing behaviors and their exposure to social media influencer-led sustainability campaigns. The study employs a quantitative survey design to analyze how young consumers in South Korea perceive the fashion industry and influencer culture, and how these perceptions relate to their sustainable consumption awareness and behaviors.

A survey method was chosen to identify behavioral patterns across a relatively large sample of Gen Z consumers. The data collection took place over a ten-day period (30 September–9 October 2025). The independent variable in this study was exposure to influencer-led sustainability campaigns, while the dependent variable was fast-fashion consumption behavior among Gen Z participants.

The survey was administered through Google Forms and included multiple-choice, scaled, and short-answer questions. It was conducted with the assistance of the Cambridge Centre for International Research (CCIR) and was administered by Dr. Meital Peleg Mizrachi.

2.2. Research Design

This study utilized a cross-sectional survey design, collecting data from 234 South Korean Gen Z participants aged 16–24 years. The survey consisted of 22 closed-ended questions and was originally developed in English, then translated into Korean to ensure accessibility and cultural clarity. The questionnaire was informed by prior research on sustainability and consumer behavior; specifically, questions related to fast fashion shopping habits and sustainability related consumption were adapted from El-Shihy & Awaad, 2025, while questions addressing social media use, exposure to influencer content, and the role of online networks were based on Yoon et al. (2020).

The survey was divided into four sections: (1) demographic information, (2) shopping habits, (3) perceptions of influencer credibility, and (4) attitudes toward sustainability. Most questions used a five-point agreement or frequency scale, allowing respondents to express varying levels of perception or behavior.

To reach participants effectively, the finalized questionnaire was distributed online through Instagram stories, KakaoTalk groups, and other youth-oriented digital platforms. A combination of convenience and snowball sampling techniques was employed, allowing participants to share the survey within their social networks and thereby expand the sample size within the limited time frame. The first two questions of the survey confirmed eligibility by screening for nationality and age criteria.

2.3. Data Analysis

The collected data were coded and entered into a spreadsheet for descriptive statistical analysis. Percentages and mean values were calculated to identify patterns in participants' shopping frequency, agreement with sustainability-related statements, and perceptions of influencer credibility. Comparative analysis was conducted across demographic groups (e.g., gender and purchasing frequency) to explore how these variables may influence sustainable decision-making. The analysis aimed to identify correlations between exposure to influencer-led sustainability campaigns and the frequency of fast-fashion purchases among South Korean Gen Z consumers.

2.4 Ethical Considerations

Prior to completing the survey, all participants were presented with an online informed consent statement clearly outlining the study's purpose, procedures, and voluntary nature of participation. Respondents were assured that their answers would remain anonymous and would be used solely for academic research purposes. No personally identifiable information was collected, and all data were stored securely to maintain confidentiality and participant privacy.

2.5. Limitations

While this study collected measurable data from a relatively large sample of participants, the use of non-probability sampling methods limits the generalizability of the findings. Additionally, the reliance on self-reported responses introduces the potential for social desirability bias, as some participants may have provided answers that align with socially approved behaviors rather than accurately reflecting their actual purchasing habits. These limitations should be considered when interpreting the results, and future research may benefit from incorporating mixed methods or longitudinal designs to deepen understanding of influencer impacts on sustainable consumption.

3. Results

This chapter examines three interrelated dimensions of Generation Z consumers and fast fashion: environmental awareness, influencer impact, and purchasing behavior. These dimensions, taken together, offer a broad understanding of the psychological and social factors shaping sustainable and unsustainable consumption patterns.

Before discussing these dimensions, it is important to provide an overview of the survey sample. The study included 234 participants aged 16–24, of whom approximately 64% identified as female, 31% as male, and 5% as non-binary or preferred not to say. The largest age group represented was 16-20 years old (78%), followed by 21-24 years old (22%), indicating strong engagement from younger Gen Z consumers. The majority of respondents reported residing in urban areas (61%), while 22% were from suburban or rural regions. On average, participants reported purchasing 2.8 fast-fashion items per month, with 87% indicating that they follow at least one fashion influencer on social media.

The results are organized into three subsections. The first subsection analyzes participants' awareness of fast fashion environmental impacts, including pollution, textile waste, and overproduction. The second examines purchasing frequency and behavioral patterns to assess how awareness translates into action. The third explores how credibility, reliability, and trust in digital influencers shape consumer attitudes toward sustainability oriented content. Finally, the third examines purchasing frequency and behavioral change, identifying whether exposure to sustainability campaigns leads to measurable shifts in consumption habits. Taken together, these findings reveal a persistent imbalance between environmental awareness and actual behavior, pointing to the need for stronger educational and motivational interventions to promote meaningful change.

3.1. Awareness of Fast Fashion's Environmental Impacts

Approximately 43% of participants reported that they regularly purchase fast-fashion products, while an additional 35% indicated buying on a monthly basis. In contrast, only 22% reported purchasing fast fashion just a few times per year or less. This distribution, illustrated in Figure 1, suggests that fast fashion remains deeply embedded in the everyday consumption patterns of South Korean Gen Z consumers.

Even among those who claimed to buy less frequently, several respondents described fashion shopping as a habitual or routine activity rather than a need-based one, emphasizing that purchasing clothes has become part of social participation and self-expression rather than a response to necessity. On average, participants reported buying 2.8 fast-fashion items per month, highlighting how normalized rapid consumption cycles have become among young consumers.

These findings demonstrate that convenience, affordability, and alignment with social media trends continue to outweigh sustainability concerns when making purchasing decisions. The results reflect the well-documented consumer behavior paradox, in which high environmental awareness does not translate into responsible consumption. Recognizing this awareness–action gap is essential, as it underscores the need to examine how influencer culture and self-perception may help explain why knowledge of environmental issues alone fails to drive meaningful behavioral change.

Section 1- Fast Fashion Shopping Habits

The graph depicts the frequency with which the 234 survey participants purchase fast-fashion items, categorized as weekly, monthly, biannually, annually, and rare or never. The majority of respondents shop on a weekly basis (43%), followed by those who shop monthly (35%), indicating that frequent purchasing is prevalent within the sample. Conversely, a limited minority acquires rapid fast fashion items biannually or annually (15%), while 7% reported purchasing such items rarely or never. On average, participants reported purchasing 2.8 fast fashion items per month, underscoring the extent to which rapid consumption is normalized. Overall, the figure underscores a prevalent trend of frequent browsing, indicating that purchasing fast fashion is a habitual practice for many individuals rather than an infrequent occurrence.

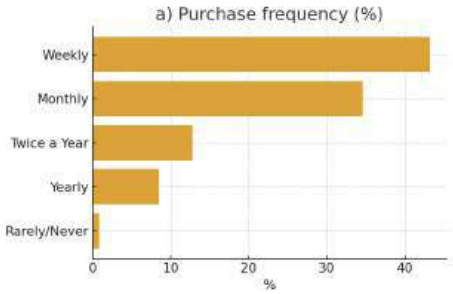


Fig 1: Purchase frequency (%)

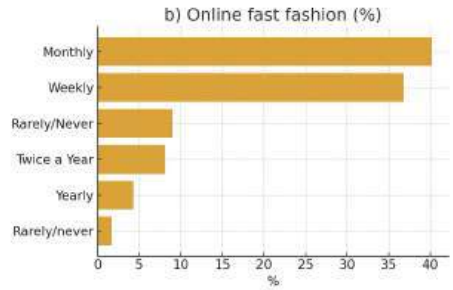


Fig 2: Online fast fashion purchase frequency (%)

3.2. Influence of Social Media and Digital Platforms on Consumption Behavior

The results show that online platforms play a central role in shaping the consumption patterns of Korean Gen Z consumers. Approximately 40% of respondents reported purchasing fast fashion monthly through e-commerce websites, while 37% indicated making purchases weekly via online platforms. An additional 9% reported buying clothing exclusively online rather than in physical stores. This growing reliance on digital retail channels is illustrated in Figure 3, which demonstrates the high accessibility and frequency of online fashion consumption among participants.

Continuous exposure to social media advertisements, influencer content, and algorithmically tailored marketing reinforces impulsive purchasing behaviors. Respondents noted that features such as “quick buy” options, one-click checkouts, and personalized recommendations made them more likely to purchase immediately after encountering online fashion content. These results suggest that sustainability messages on social media are competing directly with algorithmic incentives designed to promote instant gratification and repeat consumption.

This duality positions digital retail environments as both a challenge and an opportunity: while online shopping fuels unsustainable purchasing habits, it also provides a potentially powerful platform for sustainability education and influencer-led campaigns. Leveraging the same mechanisms that drive impulsive buying, such as engagement algorithms and influencer credibility, could help redirect consumer attention toward more responsible and mindful purchasing choices.



Fig 3: Monthly spend on fast fashion (%)



Fig 4: Monthly spend on fast fashion distribution (%)

3.3. Impact of Influencer Credibility on Sustainable Consumption

Building on the relationship between digital exposure and purchasing behavior, the data also reveal that Gen Z consumers maintain a consistent financial commitment to fast fashion despite increasing awareness of sustainability concerns. Approximately 34% of respondents reported spending ₩150,000–₩300,000 per month on fast-fashion items, while 31% spent between ₩50,000–₩150,000. A smaller group of 35% reported spending above ₩300,000 monthly. These patterns, presented in Figure 2, indicate a stable mid-range expenditure that supports frequent purchasing cycles and emphasizes affordability and accessibility over sustainability as the dominant motivators.

For many respondents, fashion functions as a central component of lifestyle and identity rather than an occasional indulgence. This financial consistency suggests that fast fashion satisfies both practical and expressive needs, providing consumers with a sense of participation in cultural trends while remaining economically feasible. The persistence of such spending behavior underscores the strength of social and psychological incentives, including peer influence and online visibility, that often outweigh environmental considerations.

At the same time, the survey found evidence of partial but short-lived shifts toward sustainable practices. Over 30% of participants indicated that exposure to sustainability initiatives or influencer campaigns prompted them to reconsider or modify their purchasing behavior, at least temporarily. In the survey, "sustainability initiatives" is referring specifically to influencer-led awareness campaigns, brand-launched eco-friendly products lines, and platform-based features that show recycled or low-impact items. This definition was made to make sure the participants evaluated a consistent set of sustainability signs and not their own varied interpretations of what they thought "sustainability might mean. However, these modifications were often emotionally driven, influenced by celebrity endorsements, aesthetic appeal, or peer validation, rather than grounded in lasting ethical or environmental commitment.

These findings suggest that while influencer-led campaigns can raise awareness and momentarily shift attitudes, sustained behavioral change depends on linking sustainability with relatable and aspirational lifestyles that maintain emotional resonance over time. In other words, credibility alone is not enough, successful campaigns must connect values, identity, and everyday experience to foster durable change among Gen Z consumers.

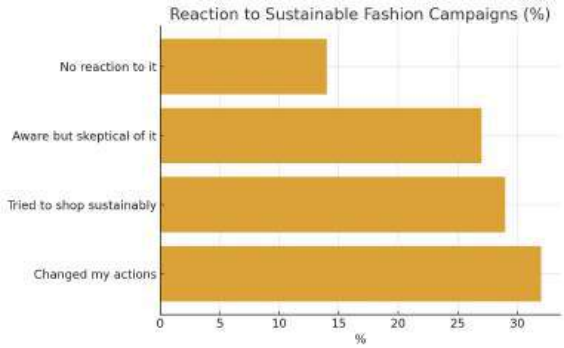


Fig 5: Reaction to sustainable fashion campaigns (%)

3.4. Influence of Social Media and Digital Influencers

Figure 4 illustrates the leading platforms through which South Korean Gen Z consumers engage with fashion-related content. Instagram (37%) and TikTok (31%) emerged as the dominant sources of fashion information, far surpassing the influence of traditional media such as television, online news outlets, or print magazines (32% combined). These platforms blur the lines between entertainment, community, and commerce, making influencer marketing an integral driver of purchasing behavior. Given the speed at which trends circulate, sustainability messaging must adopt visual, trend-driven, and emotionally engaging formats to compete with the continuous novelty cycles of fast fashion.

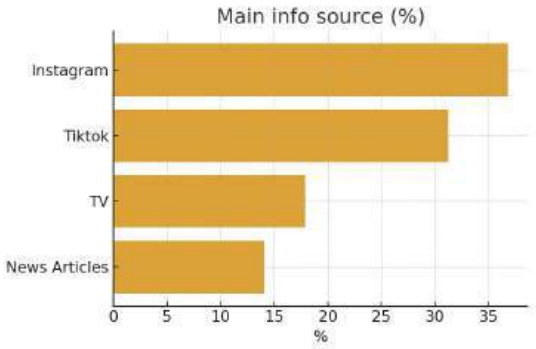


Fig 6: Main information source (%)

Participants reported most frequently encountering sponsored advertisements (35%), followed by instructional or fashion-advice content (31%), lifestyle posts (25%), and haul videos (10%). This distribution demonstrates that influencer marketing is heavily commercialized, prioritizing brand collaborations and monetized content over authentic or educational engagement. While informative content, such as styling tutorials or sustainability recommendations, can foster trust and credibility, excessive exposure to sponsored material tends to diminish perceived authenticity, ultimately weakening its capacity to drive behavioral change.

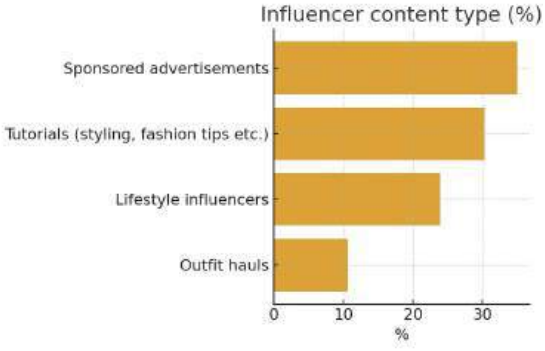


Fig 7: Influencer content type (%)

When asked about their level of trust in influencers, responses varied considerably: 44% of participants expressed a neutral stance, 26% reported strong trust, and 23% indicated moderate trust, with only 11% reporting low or no trust. Although the majority perceive

influencers favorably, few demonstrate unwavering confidence in their recommendations. This moderate level of faith suggests that persuasive sustainability communication depends on authenticity, transparency, and relatability. Even the most carefully designed sustainability campaigns struggle to achieve behavioral impact without genuine emotional resonance and credible identification between influencer and audience.

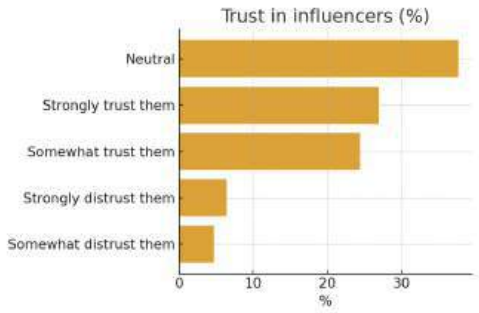


Fig 8: Trust in influencers (%)

Together, these findings highlight that digital influence is both powerful and fragile - capable of shaping perception yet limited by skepticism. They reinforce the need for sustainability communication strategies that move beyond awareness to cultivate trust-based engagement and long-term value alignment among young consumers.

3.5. Campaign Effectiveness and the Awareness–Action Gap

Figure 9 summarizes participants' perceptions of the persuasiveness of sustainability campaigns compared to conventional fashion content. Nearly 49% of respondents found sustainability-focused campaigns substantially more persuasive, while an additional 32% regarded them as somewhat more persuasive. These findings suggest that sustainability messaging successfully elicits emotional and cognitive engagement among Generation Z consumers. Participants reported that they appreciated the aesthetic and moral dimensions of such campaigns, viewing them as "inspiring," "positive," and "important." However, the effect remains largely attitudinal rather than behavioral. Although many respondents endorse sustainable messages, their purchasing patterns continue to favor fast fashion, underscoring that persuasive communication alone rarely alters established consumption routines.

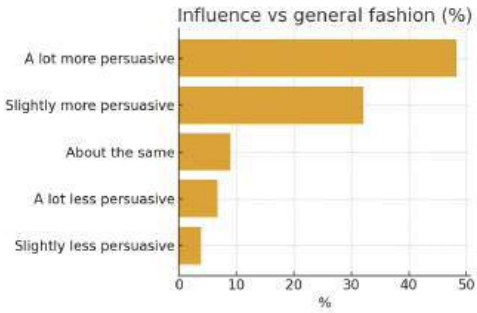


Fig 9: Influence vs. general fashion (%)

When asked about the degree to which exposure to sustainability campaigns influenced actual purchasing behavior, 37% of respondents reported that they "rarely" changed their purchasing decisions, 33% did so "frequently," 25% "sometimes," and only 6% "never." These responses demonstrate that while awareness can inspire incremental or situational behavior changes, it seldom leads to a sustained shift toward conscious consumption. In qualitative comments ([insert quote or brief summary, if available]), several participants noted that although they "try to shop more mindfully," factors such as affordability, convenience, and social media trend pressure often override environmental concerns.

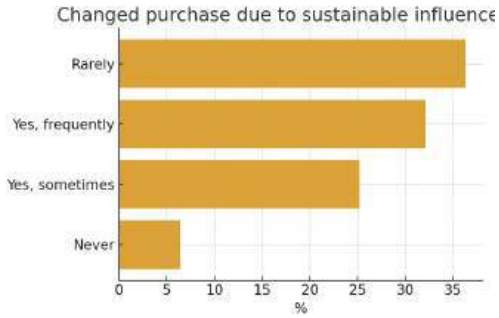


Fig 10: Changed purchase due to sustainable influence (%)

Collectively, these results encapsulate the core awareness–action gap: Generation Z consumers admire sustainability ideals but struggle to integrate them consistently into daily purchasing decisions. This discrepancy reveals that the emotional appeal of sustainability campaigns must be complemented by systemic and structural interventions, including education, incentive mechanisms, and credible influencer partnerships, to translate attitudes into durable behavior change.

4. Discussion

4.1 Overview of Findings:

For South Korean Gen Z consumers, the findings of this study reveal that influencer campaigns emphasizing sustainability have a visible yet limited impact on reducing fast-fashion consumption. While sustainability awareness is widespread, actual purchasing behavior continues to reflect a pattern of high-frequency consumption. More than three-quarters of participants reported purchasing fast-fashion items at least once per month, and 43% did so weekly. Meanwhile, approximately 80% of respondents were at least "somewhat familiar" with sustainability messaging.

This duality underscores a recurring tension between awareness and behavioral change: influencer-led sustainability campaigns appear to be effective at shaping attitudes and increasing visibility, but less so at altering entrenched consumption patterns. Despite being environmentally conscious, Gen Z consumers operate within a social and economic environment that reinforces

affordability, peer validation, and the constant renewal of digital trends. These cultural and structural factors, particularly the velocity of online consumption and the normalization of disposability, make it difficult for awareness alone to translate into consistent action.

4.2 Effectiveness of Influencer-led campaigns

The results demonstrate that influencer campaigns are powerful tools for shaping perception but less successful at fostering enduring behavioral transformation. Nearly 49% of participants described sustainability campaigns as "much more persuasive" than general fashion content, while 32% found them "somewhat more persuasive." These findings confirm that sustainability-themed content resonates emotionally with Gen Z audiences, especially when delivered through high-engagement platforms such as Instagram and TikTok. The visual and interactive nature of these platforms enhances message accessibility and emotional appeal—qualities often absent from traditional advertising.

Nevertheless, the gap between persuasion and behavior remains substantial. Only about one-third of participants reported frequently or occasionally modifying their spending habits after engaging with influencer content, whereas 37% "rarely" did so. This aligns with the attitude–behavior gap identified by Vilkaite-Vaitone et al. (2024), which highlights the disjunction between valuing sustainability and translating that value into concrete behavioral change. The findings also support El-Shihy and Awaad's (2025) argument that influencer credibility, message authenticity, and relational trust are essential for converting awareness into commitment.

However, in South Korea's commercialized influencer economy, sustainability messaging competes against sponsored and profit-driven content that often undermines perceived sincerity. This context weakens the credibility of influencers and limits the reach of environmental advocacy. As a result, most sustainability influencers function primarily as awareness-raising agents rather than catalysts of measurable behavioral change. Their impact lies in broadening public discourse and normalizing sustainable values, even if such influence remains attitudinal rather than behavioral.

4.3 The Persistence of the Awareness-Action Gap

The most striking finding of this research is that the awareness–action gap remains persistent and largely unresolved. Although the majority of respondents reported a solid understanding of sustainability concepts, more than 75% continued to purchase fast-fashion items regularly (Figure 1). This inconsistency highlights the psychological and cultural complexity of consumer decision-making. As Yoon, Lee, and Choo (2020) argue, many Korean consumers acknowledge the importance of sustainability but tend to transfer responsibility to corporations and institutions, framing sustainability as a collective or systemic obligation rather than a personal behavioral norm. The current findings reinforce this tendency, suggesting that sustainability is frequently understood as an external moral ideal rather than an internalized lifestyle practice.

The results show that exposure to sustainability campaigns does not reliably bring about reduced consumption. Over 30% of respondents reported that influencer-led sustainability initiatives made them think again about their purchases, but the changes were only usually for a short time. Also, participants continued to use stable monthly spending of between 150,000 won and 300,000 won on fast-fashion items. This pattern gives the sign that sustainability messaging can momentarily impact attitudes but not change long-term behavior.

This research also suggests that the persuasive power of influencers may conflict with the inherent contradictions of contemporary fashion consumption. Sustainability influencers frequently promote eco-friendly lifestyles through highly aestheticized, aspirational imagery - minimalist homes, curated wardrobes, and luxury "green" products. Survey responses gave support to this idea. Many of the participants talked about being influenced by the aesthetic appeal of posts, celebrity endorsements, and lifestyle-oriented content, but this influence most often resulted in new purchases and not less consumption happening (Figures 4-6). As Munaro (2024) cautions, such portrayals can inadvertently replicate the consumerist logic of fast fashion by valorizing acquisition over reduction. In this sense, influencer campaigns may reinforce consumer desire under the guise of ethical consumption, encouraging audiences to substitute "eco-friendly" purchases for conventional ones rather than to fundamentally reduce consumption.

4.4 Sociocultural Context: Gen Z and Digital Consumption in Korea

The cultural and digital landscape of South Korea plays a decisive role in shaping these outcomes. Korean Gen Z consumers inhabit one of the most digitally saturated societies in the world, where fashion trends evolve almost instantaneously through online platforms. According to the survey, Instagram (37%) and TikTok (31%) were the leading sources of fashion information, highlighting the centrality of social media as a cultural conduit between brands, influencers, and audiences (Figure 4).

The data brings out the clear way that the digital ecosystem makes energy for rapid consumption. Approximately, 40% of the respondents purchased fast fashion monthly, and 37% of them did it weekly. This means that online exposure and accessibility seem to support frequent purchasing cycles. Also, many participants said that algorithmic features, such as "quick buy" buttons, one-click checkouts, and personalized recommendations made it more likely that they would be buying when they look at the fashion content. The findings give the point that Korea's platform-driven environment both hosts fashion culture and also actively gives incentives for overconsumption by giving benefits like convenience and algorithmic nuedging as well as visual stimulation that is constant.

Influencers both shape and mirror consumer values, operating within algorithmic environments that reward immediacy, novelty, and visual appeal. The fast-paced, image-driven logic of these platforms amplifies the constant turnover of trends and reinforces the idea that social validation—through likes, shares, and outfit posts, is a key marker of self-worth. Participants frequent weekly or monthly purchases even though they know about sustainability

shows that peer visibility and aesthetic appeal had more weight than worries about the environment. Consequently, influencer-led sustainability campaigns often coexist uneasily with the very culture of overconsumption they seek to challenge.

In South Korea, fashion also carries significant social and symbolic capital. It serves not only as a form of self-expression but also as a marker of professionalism, confidence, and belonging within a highly image-conscious society. As a result, sustainability frequently becomes a symbolic performance of identity, a signifier of moral awareness or aesthetic refinement, rather than a consistent behavioral commitment. This interpretation is supported by the survey findings that say short-lived and emotionally driven movements in purchasing after sustainability campaigns, and not a real long-lasting change in the behavior. This dynamic is consistent with Lee (2023), who found that young Korean consumers often perceive sustainable fashion as aspirational branding rather than an everyday practice of ethical restraint.

4.5 Authenticity, Credibility, and Consumer Trust

Authenticity emerged as a defining factor in the perceived success of influencer-led campaigns. Survey respondents showed that 26% of participants had strong trust in influencers, 23% moderate trust, and 44% stayed neutral. This gives the hint that influencers are generally viewed positively, but trust is not universal or unconditional (Figure 6). Participants expressed greater trust toward influencers who communicated transparently about their personal challenges with sustainability and who proposed realistic, affordable, and accessible alternatives.

To the contrary, participants made a negative response to excessive sponsored content. Sponsored advertisements were the most frequently encountered content type at 35%. Also, many of the respondents made a connection with heavy commercialization and lower authenticity and weaker persuasive impact. This links to the survey's bigger finding about sustainability only having a temporary influence on attitudes. The effectiveness of the messaging gets left when audiences perceive influencers as over promotional or not linked to the real reality of consumption for most people in normal life.

These results give support to research from before that focuses on authenticity and emotional relatability as the big drivers when it comes to sustainable engagement (El-Shihy & Awaad, 2025). In the context of this study here, authenticity was the bridge making the connection for awareness and action. It was the thing that decided if influencer-led messages got interpreted as meaningful guidance or just the extra layer of commercialized fashion content.

5. Policy Recommendations

Drawing on the findings of this study, several policy recommendations can be proposed to help narrow the awareness, action gap and foster more sustainable consumption patterns among South Korean Gen Z consumers. Recommendations can be made from the survey results, which showed high environmental awareness but continued fast-fashion purchasing, strong price sensitivity, and moderate trust due to influencer authenticity.

5.1 Integrate sustainability education into mainstream curricula

This study found that Gen Z environmental awareness is reasonably high, but it does not often translate into consistent changes in behavior (Figures 1 & 7). It is shown by the fact that over 75% of the respondents kept buying the fast fashion items regularly even though they had knowledge about the environmental impact it has. It shows that there is a need for better and more sustained learning that goes deeper than just having surface level awareness.

The Korean government should expand and systematize sustainability education, particularly by linking it to topics such as consumer responsibility, environmental impact, and ethical production. At present, sustainability initiatives in Korea remain concentrated in academic or specialist research settings. Incorporating sustainability modules into high school and university curricula would help normalize public discussion of fashion's environmental consequences. Moreover, collaboration between government agencies and credible influencers could make such education more engaging. Co-produced short-form videos or public service announcements on platforms like TikTok and YouTube could significantly enhance youth engagement. As the data showed in this research survey, these platforms are a key source to get information about fashion, with Instagram hitting 37% and TikTok 31%. This recommendation is supported by the fact that similar initiatives in Sweden and Finland, where sustainability education is embedded in national curricula, have been associated with higher environmental literacy among young people (OECD, 2024).

5.2 Introduce economic incentives for sustainable purchasing

The survey findings pointed out that affordability and convenience were dominating issues when it came to fast-fashion consumption. This was clear with a big proportion of the survey takers spending between 150,000 won to 300,000 won each month on fast fashion. The exposure to sustainability campaigns only had a temporary impact on most of the participants, which shows that economic barriers continue to be a big obstacle to getting long-term change.

With the evidence that affordability remains one of the strongest motivators for fast-fashion consumption, economic instruments are critical for shifting behavior. Policymakers could introduce tax reductions or voucher schemes for consumers purchasing certified sustainable products, thereby reducing the cost differential between sustainable and unsustainable options. These incentives could be amplified through fashion influencers, who could disseminate information about such programs across digital networks. Comparable schemes in Japan and France have shown potential in increasing participation in sustainable consumption and recycling programs (OECD, 2023).

5.3 Strengthen environmental regulation of the fashion industry

The study showed that consumers frequently put responsibility for sustainability towards the brands and institutions instead of thinking it is their responsibility, which is the similar point that Yoon et al. (2020) found. It was further emphasized by just the short-term change in behavior that the survey showed as it implies that consumer solutions are not the most effective.

Regulatory interventions are also essential. Korea could adopt measures similar to the European Union's Extended Producer Responsibility (EPR) framework (EU, 2025), which places direct responsibility on brands for managing post-consumer textile waste and unsold inventory. Such policies would encourage companies to design longer-lasting, repairable, and recyclable garments, thereby reducing textile waste and improving material efficiency throughout the supply chain.

5.4 Institutionalize collaboration with "green influencers"

The survey found that influencer trust was just moderate and not absolute. This comes from the figures of 44% neutral, 26% showing strong trust, and 23% moderate trust (Figure 6). In addition, respondents had greater trust in the influencers showing authenticity and transparency. This matches the findings that credibility is a critical factor if behavior is going to be influenced by influencers' messaging.

As such, policy actors should recognize influencers as key partners in driving public awareness and behavioral change. A certification system for verified "green influencers" could enhance credibility and transparency in sustainability communication. This system might mirror the UK's "Green Claims Code" (UK CMA, 2023), which ensures that environmental claims made in advertising are accurate and verifiable. By providing formal recognition and accountability, such certification could both empower content creators and strengthen public trust in sustainability messaging.

Works Cited

Adamkiewicz, J., Kochańska, E., Adamkiewicz, I., & Łukasik, R. M. "Greenwashing and the Sustainable Fashion Industry." Journal of Cleaner Production, (2022), 356-390, Accessed October 15, 2025. https://doi.org/10.1016/j.jclepro.2022.131827

Bailey, K., Basu, A., & Sharma, S. (2022). "The Environmental Impacts of Fast Fashion on Water Quality: A Systematic Review." Water, 14, no. 7 (2022), 1073-1084. Accessed October 15, 2025. https://doi.org/10.3390/w14071073

Cotter, K. "Playing the Visibility Game: How Digital Influencers and Algorithms Negotiate Influence on Instagram." New Media & Society, 21, no. 4 (2019), 895-913. Accessed October 15, 2025. https://doi.org/10.1177/1461444818815684

Yildirim, S. "Do Green Women Influencers Spur Sustainable Fashion Consumption?" Emerald EFCC, 2, no. 4 (2023), 198–215. Accessed October 15, 2025. https://www.emerald.com/efcc/article/2/4/198/87137

El-Shihy, D., & Awaad, S. "Leveraging social media for sustainable fashion: How brand and user-generated content influence Gen Z's purchase intentions." Future Business Journal, 11, no. 1 (2025), 113-126. Accessed October 15, 2025. https://doi.org/10.1186/s43093-025-00529-3

European Parliament. "Fast fashion: EU Laws for Sustainable Textile Consumption." European Parliament. Last modified 2025. Accessed October 15, 2025. https://www.europarl.europa.eu/topics/en/article/20201208STO93327/fast-fashion-eu-laws-for-sustainable-textile-consumption

Green, A. The hidden cost of fast fashion: Bridging the gap between consumer values and behavior. 2025. Cascale.

Gunawan, Y., Matahariza, A., & Putri, W. K. "The Dark Side of Fast Fashion: Examining the Exploitation of Garment Workers in Bangladesh." Journal Hukum dan Peradilan, 12 no. 3 (2023), 441–468.

Huang, Y., Zhang, K., Deng, X., & Zhang, Q. "Fast Fashion Consumption Signals Low Self-control." Journal of Consumer Research, (2025). Accessed October 15, 2025. https://doi.org/10.1093/jcr/ucaf032

Lee, Y. K. "Exploring the Value of Sustainable Fashion Products among Young Korean Consumers." International Journal of Fashion Design, Technology and Education, 16 (2023). 152-163. Accessed October 15, 2025. https://doi.org/10.1080/17543266.2022.2136251

Li, Z., Zhou, Y., Zhao, M., Guan, D., & Yang, Z. (2024). The Carbon Footprint of Fast Fashion Consumption and Mitigation Strategies: A Case Study of Jeans." Science of the Total Environment, 924, 2024. Accessed October 15, 2025. https://doi.org/10.1016/j.scitotenv.2024.171508

Liu, M. (2022). "Determining the Role of Influencers' Marketing Initiatives on Fast Fashion Industry Sustainability: The Mediating Role of Purchase Intention." Frontiers in Psychology, 13 (2022), 940649. https://doi.org/10.3389/fpsyg.2022.940649

Maiti, R. “The Environmental Impact of Fast Fashion, Explained.” Earth.org & Global Commons, 20 (2025) https://earth.org/environmental-impact-of-fast-fashion/

McNeill, L., & Venter, B. “Identity, Self-Concept and Young Women’s Engagement with Collaborative, Sustainable Fashion Consumption Models.” International Journal of Consumer Studies, 43, no. 4 (2019), 368–378. https://doi.org/10.1111/ijcs.12516

Munaro, A. C. “The Impact of Influencers on Sustainable Consumption: A Systematic Literature Review.” Journal of Cleaner Production, 437 (2024), 140932. https://doi.org/10.1016/j.jclepro.2023.140932

Olivar Aponte, J. “Fast Fashion Consumption and Its Environmental Impact.” Fashion, Style & Popular Culture, 11, no. 2 (2024), 165–183. https://doi.org/10.1080/15487733.2024.2381871

Precision Analysis Hub. “South Korea Fast Fashion Market Size, Trends in Emerging Market Players 2033.” LinkedIn, 2025. https://www.linkedin.com/

Sun, Y., Wang, R., Cao, D., & Lee, R. “Who Are Social Media Influencers for Luxury Fashion Consumption of the Chinese Gen Z? Categorisation and Empirical Examination.” Journal of Fashion Marketing and Management: An International Journal, 26, no. 4 (2022), 603–621. https://doi.org/10.1108/JFMM-10-2021-0259

Vilkaite-Vaitone, N., et al. “From Likes to Sustainability: How Social Media Influencers Drive Sustainable Consumption.” Sustainability, 16, no. 2 (2024), 955.https://doi.org/10.3390/su16020955

Wojdyla, W., & Chi, T. “Decoding the Fashion Quotient: An Empirical Study of Key Factors Influencing US Generation Z’s Purchase Intention Toward Fast Fashion.” Sustainability, 16, no. 12 (2024), 5116. https://doi.org/10.3390/su16125116

Workman, E. J., & Lee, S. “Materialism, Fashion Consumers and Gender: A Cross-Cultural Study.” International Journal of Consumer Studies, 35, no. 1 (2010), 50–57. https://doi.org/10.1111/j.1470-6431.2010.00935.x

Yoon, N., Lee, K. H., & Choo, J. H. “Fast Fashion Avoidance Beliefs and Anti-Consumption Behaviors: The Cases of Korea and Spain.” Sustainability, 12, no. 17 (2020), 6907. https://doi.org/10.3390/su12176907

Exploratory Analysis of Shallow Convolutional Networks for Motor Imagery Classification in Brain-Computer Interfaces By Nam Nguyen

Abstract

Deep learning models have emerged as popular tools for Motor Imagery (MI) tasks in Brain-Computer Interfaces (BCI), with many capable of achieving high performance in a variety of datasets. However, their internal processes are often treated as "black boxes", hindering insight into how they work. This lack of transparency in these models creates challenges for validating model behavior, understanding MI-related neural mechanisms, and improving system reliability for clinical adoption. In this paper, we aim to address this issue by conducting an exploratory analysis on a Shallow Convolutional Neural Network (Shallow CNN) model designed for EEG-based MI classification. We utilize data from the BCI Competition IV 2b dataset, which we then process and use to train the model. Grid-search hyperparameter tuning was employed to find the best-performing model, which serves as the candidate for subsequent analysis. We conduct six exploratory analyses designed to probe different aspects of the network's processes in order to gain an understanding of its function. We explore how the model processes EEG signals, what it learns in its internal representations, as well as suggest potential improvements based on our findings.

Keywords neural networks, exploratory analysis, EEG, motor imagery, BCI

I. Introduction

Deep learning has produced remarkable performance gains in MI tasks (Al-Saegh et al., 2020). Convolutional Neural Networks (CNNs) and their derivative hybrid-CNNs (h-CNNs) in particular have been shown to outperform other architectures in processing electroencephalography (EEG) data, and have demonstrated strong capability in extracting meaningful spatio-spectral representations (Al-Saegh et al., 2020). However, the success of these models is often unexplainable, and understanding how the model arrives at its decision remains challenging. This lack of transparency limits our ability to:

1) Validate if the model is learning neurophysiologically plausible features
2) Diagnose failure modes and improve system reliability
3) Advance neuroscientific understanding of MI mechanisms

In this study, we focus on understanding the internal computation of neural networks. Particularly, we train the Shallow CNN (by Wang et al.) on an EEG-based MI classification task, and conduct an exploratory study using a set of six analyses.

II. Literature Review

Deep learning is a powerful approach to addressing challenges in BCI applications through its ability to extract features from neural signals and to capture rich, complex spatiotemporal patterns. (Zhang et al., 2019; Gu et al., 2020; Abibullaev et al., 2023). This field has experienced rapid growth, with architectures like CNNs and recurrent neural networks (RNNs), as well as hybrid architectures showing potential for improving performance in classification tasks (Zhang et al., 2019; Ha et al., 2019; Lionakis et al., 2023).

CNNs have become the most popular deep learning architecture for motor imagery classification, with many studies demonstrating their effectiveness in capturing spatiotemporal patterns from raw EEG signals (Rashid et al., 2020; Abibullaev et al., 2020; Du et al., 2022; Liang et al., 2024). CNN-based approaches have consistently achieved classification accuracies ranging from 80% to 95% across different datasets, with notable examples including achieving 92.75% accuracy using wavelet transform time-frequency images (Rashid et al., 2020; Xu et al., 2019) and multilevel feature fusion models achieving competitive performance (Amin et al., 2019). The success of CNNs comes from their ability to extract both spatial and temporal features better than traditional machine learning approaches that depend heavily on manual feature engineering (Tibrewal et al., 2021; Tibrewal et al., 2022). Deep learning approaches have shown promise for addressing the challenge of BCI inefficiency, with studies demonstrating that CNN models improve classification accuracy for all users but provide significantly larger improvements for low performers who struggle with traditional machine learning methods (Tibrewal et al., 2021; Tibrewal et al., 2022; Alimardani et al., 2023). Despite these advances, deep learning models face challenges including requirements for large training datasets, computational complexity, and the "black-box" nature that limits interpretability (Shuaibu et al., 2020; Shin et al., 2023). Recent works have emerged addressing these limitations through transfer learning approaches and mechanistic interpretability methods (Alimardani et al., 2023; Liang et al., 2024).

In this study, we focus on the “black box” problem in models trained for MI tasks, where their mechanisms and decision-making processes are often unexplainable and underexplored in these deep learning studies, which creates a significant barrier to BCI development and clinical adoption. To build on the solution to this problem, we must investigate the model’s internal workings and its links to the spatio-spectral features of the EEG signal. This is the motivation for our study, where we will be conducting exploratory analyses of Wang et al.’s Shallow CNN model trained for BCI MI applications. This model was chosen because of its high reported performance and smaller scale, which enables us to conduct more detailed analyses.

III. Methods

Dataset Overview

We utilize the BCI Competition IV Dataset 2b, a binary MI classification task (Left Hand vs. Right Hand). Data was recorded across five sessions for each subject. Following the published methods, sessions 1, 2, and 3 were used for training, and sessions 4 and 5 were used for testing and evaluation. The preprocessing pipeline, taken from Wang et. al, transforms the raw EEG signal into a Spatio-Spectral Image (SSI). The preprocessing steps are as follows:

1. Filtering & Resampling: Signals were resampled to 250Hz and band-pass filtered between 0.5Hz and 30.0Hz.
2. Epoching: The MI period was extracted from t=3s to t=7s relative to the start cue
3. SSI Generation: A Short-Time Fourier Transform (STFT) with a window size of 64 and a hop length of 14 was applied. The resulting magnitude spectrogram was resized using cubic interpolation to produce a 31 x 32 block per channel.
4. Stacking & Normalization: The three-channel blocks C3, Cz, and C4 were vertically stacked to form the final 93 x 32 SSI input image. This image was subjected to local normalization before being fed to the network.

Architecture Overview

The Shallow CNN architecture was implemented following the structure proposed by Wang et al., comprising two main components:

1. Feature Layer: A single convolutional layer (Conv2D, 16 filters, 3 x 3 kernel, 1 padding) followed by a 2 x 2 Average Pooling layer. While the paper by Wang et al. defines the overall structure, these specific hyperparameters were chosen to ensure the correct dimensionality reduction for the 93 x 32 input image.
2. MLP Classifier: A two-layer Multi-Layer Perceptron:
    - Hidden Layer: Linear (input = 16 x 46 x 16, output = HIDDEN_SIZE) with a Sigmoid activation.
    - Output Layer: Linear (input = HIDDEN_SIZE, output = 1) with a final Sigmoid activation.

Training

The model was trained for 100 epochs using Mean Squared Error (MSE) loss and the SGD optimizer with momentum (LR = LEARNING_RATE, Momentum = 0.9).
Grid-search tuning was employed to find model hyperparameters that yield the best accuracy, using this search space:

- LEARNING_RATE: 0.01, 0.1
- BATCH_SIZE: 8, 16, 32
- HIDDEN_SIZE: 16, 32, 64, 128, 256

Our best performing model had these hyperparameters:

- LEARNING_RATE: 0.01
- BATCH_SIZE: 16
- HIDDEN_SIZE: 64

And these metrics:

- Accuracy: 0.7435 ± 0.1451
- F1: 0.7476 ± 0.1427

This model was then used for our exploratory analysis.

Exploratory Analysis

We employ six analyses to study the trained model

1) Visualize Convolutional Filters (Weight Analysis): Direct visualization of the 3 x 3 kernel weights to identify local spatio-spectral patterns the network is trained to detect.
2) Visualize Activation Maps (Feature Map Analysis): Visualization of the convolutional output for a sample input to see where on the SSI each filter activates.
3) Analyze Learned Feature Importance (MLP Weight Analysis): Measuring the L2-norm of hidden layer weights across pooled locations to identify the most critical spatio-spectral regions driving the final decision.
4) Activation Distribution (T-SNE Visualization): Applying t-SNE to the hidden layer activations (100-dimensional output) to assess the separability and quality of the learned representations.
5) Max-Activating Input Patches (Filter Dominance): Identifying which of the 16 filters achieves the highest maximum pooled activation value across the dataset and therefore the most salient features.
6) Ablation Study on Input Channels (C3, Cz, C4): Zeroing out each EEG channel's corresponding rows in the SSI and measuring the resultant drop in test accuracy.

We carry out these analyses on the aggregate of all sessions and between the worst and best sessions.

IV. Results & discussion

a) Aggregate

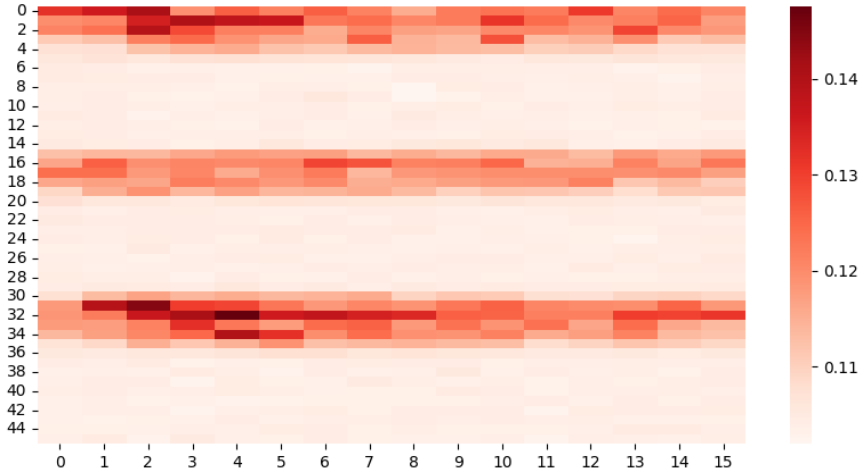


Fig 1: Aggregate Mean Feature Importance Map

The classification decision is driven by the C4 & C3 electrode (right and left side of the motor cortex), which exhibits the highest feature importance (darkest red), while the Cz (midline) electrode is much less prominent. Furthermore, the model relies on extracting the most discriminative features in early-to-mid-trial (columns 0-5) rather than utilizing the signal uniformly across the trial or the scalp.

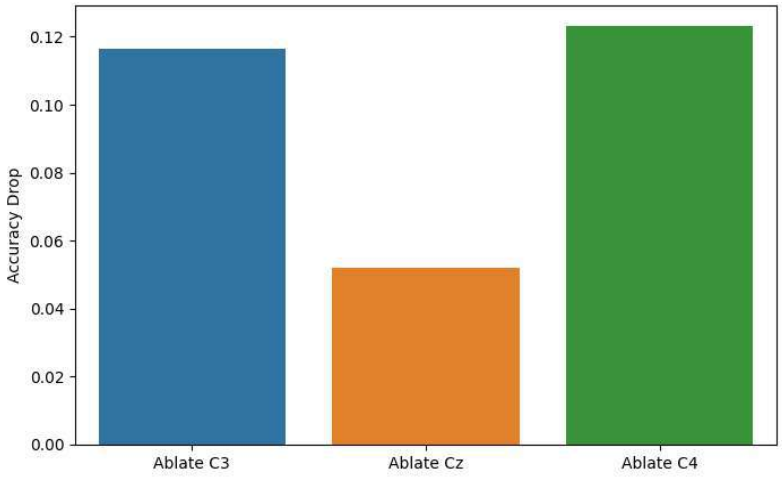


Fig 2: Aggregate Accuracy Drop from Ablation

Ablating the C4 and C3 caused the largest accuracy drop, indicating their features are the most critical for the final classification. Conversely, removing the Cz electrode caused the smallest drop, showing that the midline features are the least discriminative component for this motor imagery task.

b) Worst (Accuracy: 0.5321, F1: 0.5498) vs. Best (Accuracy: 0.9406, F1: 0.9404) Sessions



Fig 3: Learned Convolutional Filters (3x3 Kernel) - Worst Session

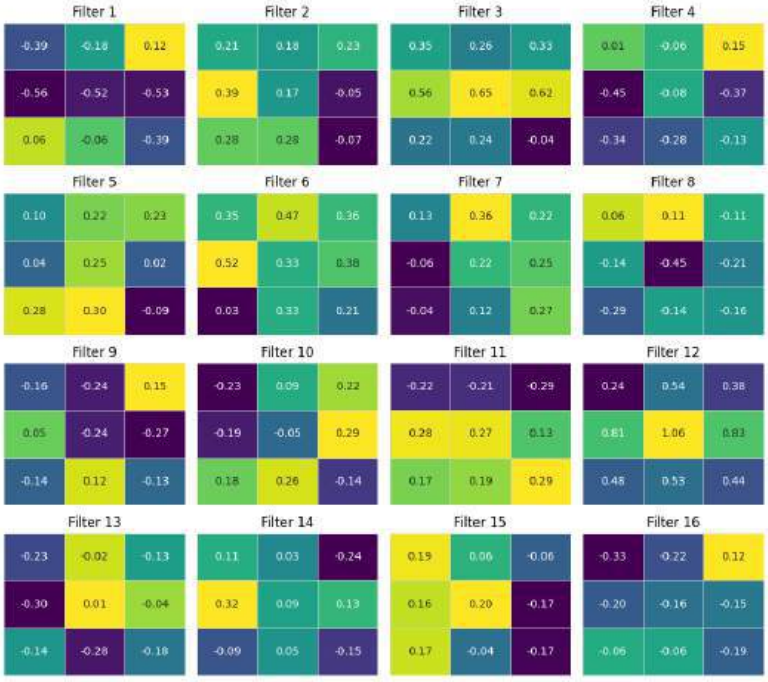


Fig 4: Learned Convolutional Filters (3x3 Kernel) - Best Session

These filters appear noisy. This is expected for SSI, where the features are intensity differences in adjacent time-frequency bins rather than geometric shapes.

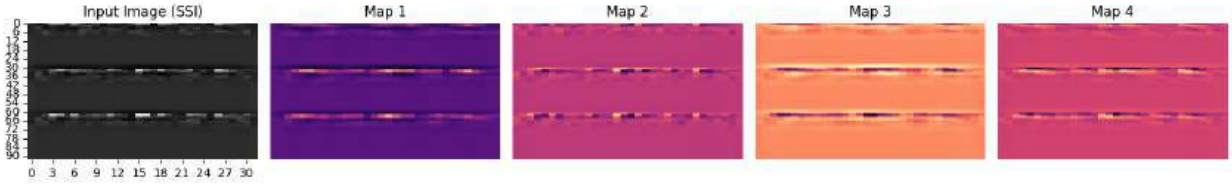


Fig 5: Input Image and First 4 Feature Maps - Worst Session

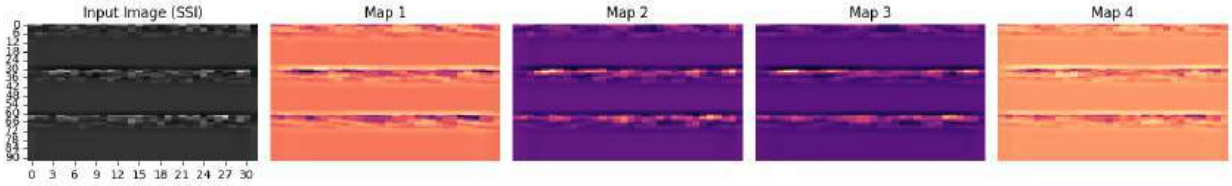


Fig 6: Input Image and First 4 Feature Maps - Best Session

The input image consists of three stacked blocks corresponding to electrodes C3, Cz, and C4. The feature maps (Maps 1–4) preserve this horizontal banding structure. Because the model has only one convolutional layer, it does not abstract the input into high-level objects. Instead, it performs simple filtering, highlighting specific frequency patches while suppressing background noise, passing a "cleaned" spectrogram to the dense layers.

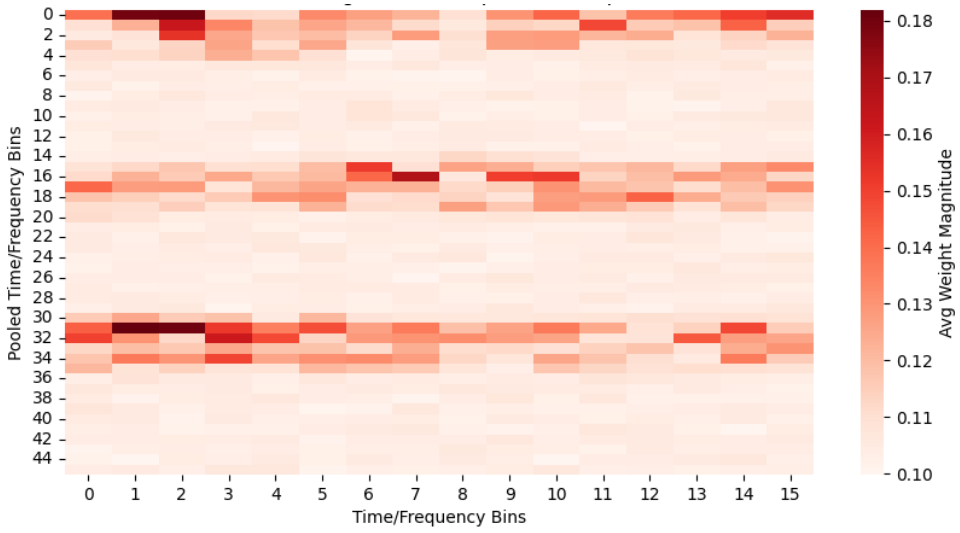


Fig 7: Average Feature Importance Map - Worst Session

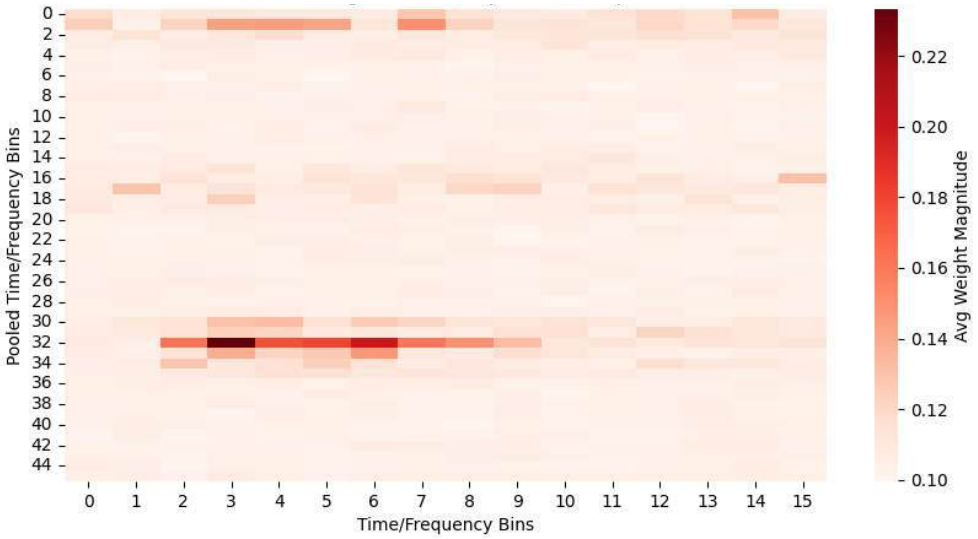


Fig 8: Average Feature Importance Map - Best Session

In the worst session, the model's decision is driven by the C4 & C3 electrode and relies on extracting features in early-to-mid-trial (columns 0-5), like in most sessions. Interestingly, in the best session, the model focuses only on the early-to-mid trial of the C4 electrode, ignoring almost everything else. This suggests that the model achieves better performance focusing on the C4 electrode as a discriminative feature while effectively ignoring other channels that acted as noise or distractors.

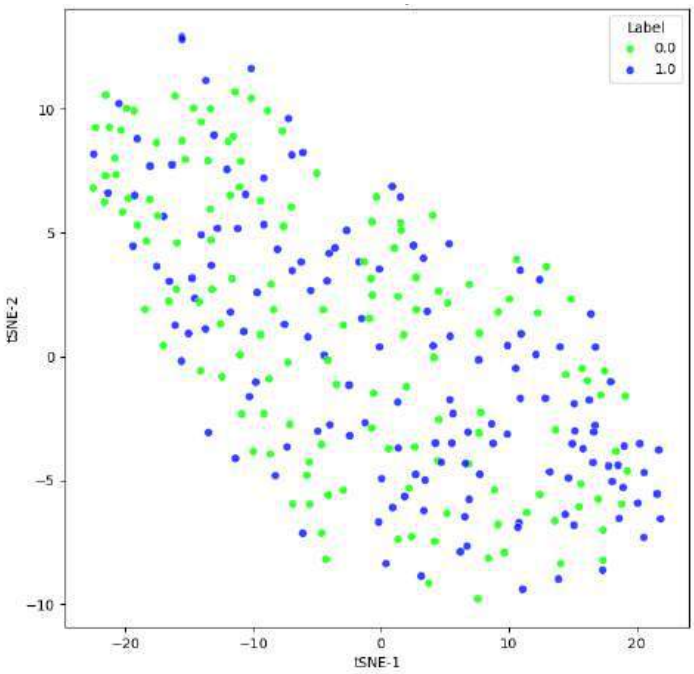


Fig 9: T-SNE of Hidden Layer Activations - Worst Session

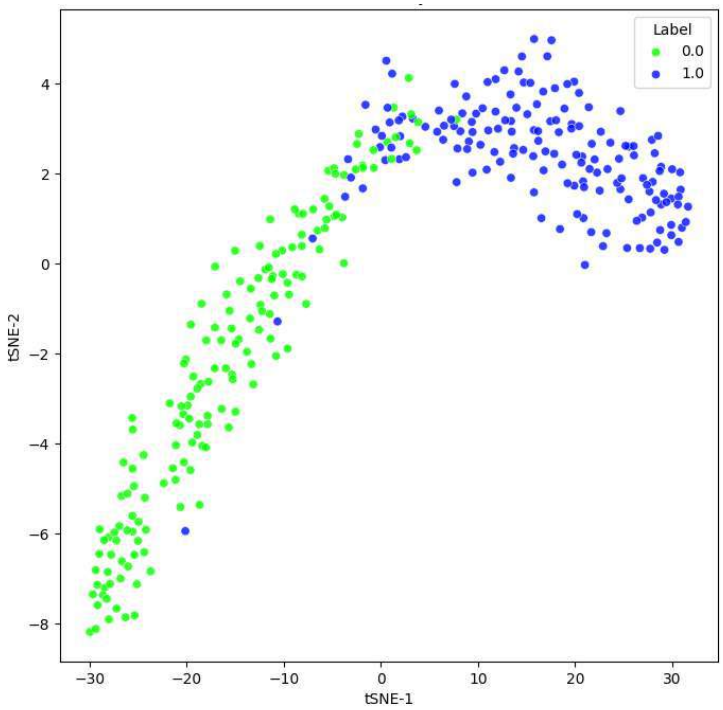


Fig 10: T-SNE of Hidden Layer Activations - Best Session

For the worst session, there is no clean gap between clusters. The center of the plot is a dense mix of overlapping blue and green points. For many trials, the model cannot distinguish the classes, resulting in an "ambiguous" decision boundary that limits the model's performance. In contrast, there is a clear, visible separation between the 2 classes in the best session.

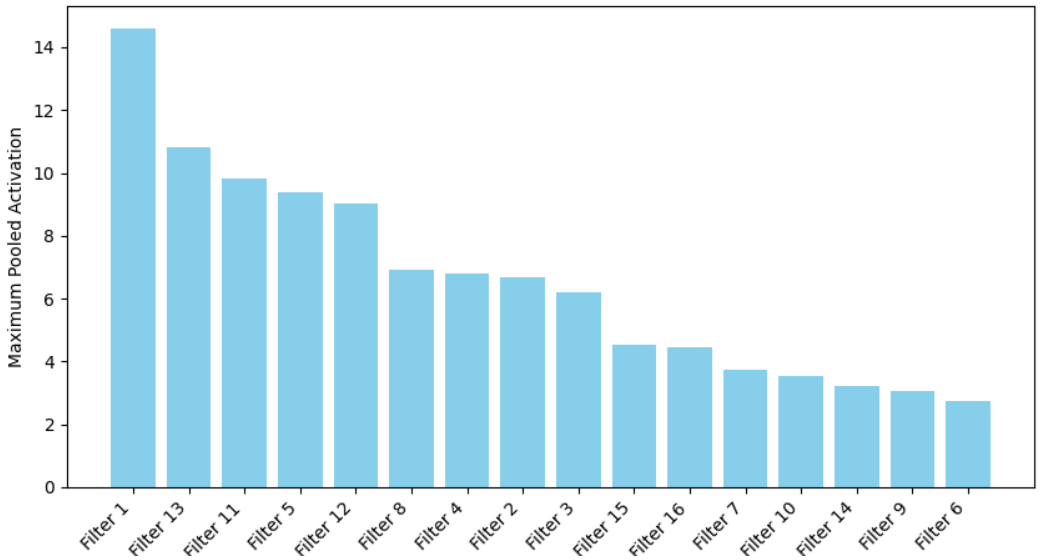


Fig 11: Average Feature Importance Map - Worst Session

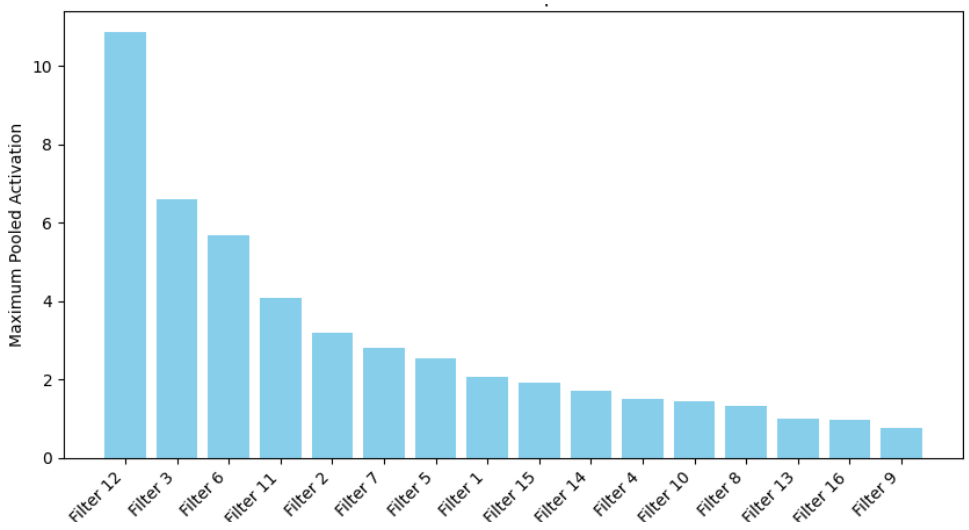


Fig 12: Average Feature Importance Map - Best Session

In the best session, the model is strongly influenced by a few filters and features, with a sharp drop-off in activation shown. In the worst session, there's a broader and more distributed feature usage. This indicates that effective classification is characterized by feature sparsity and concentration.

V. Conclusion & Future Work

This exploratory study on Shallow CNNs for MI classification produced findings about the model's internal mechanisms and how they differ in the worst-performing and best-performing sessions.

The key findings showed that the model's decision-making is strongly driven by features extracted from the C4 and C3 electrodes and relies on the signal from the early-to-mid-trial period, as seen in the aggregate plots. The model's filters are simple localized frequency detectors that preserve the horizontal banding structure of the C3, Cz, and C4 electrode inputs while suppressing background noise for better learning.

The best-performing session is characterized by a highly sparse and concentrated reliance on a few filters and feature maps, whereas in the worst-performing session, we see a broader and more distributed feature usage. In the best session, the model interestingly focuses almost only on the early-to-mid-trial period of the C4 electrode, emphasizing the need for isolating important features from noise and distractors. There is a clear separation between the 2 classes in the best session shown by the t-SNE analysis, which demonstrates better differentiation capabilities in this task.

Future work should focus on leveraging these insights as a guide to build more efficient models, potentially by implementing mechanisms (e.g., attention) to prioritize the critical C3/C4 channels and temporal segments, and by testing the effect of architecture modifications (e.g., adjusting the filter counts and other parameters).

VI. Acknowledgements

The author used publicly available data from the BCI Competition IV dataset 2b, available at: https://www.bbci.de/competition/iv/#dataset1

VII. Conflicts of interest

The author declares that there is no conflict of interest related to this work.

Works Cited

Al-Saegh, A., Dawed, S. A., & Abdul-Jabbar, J. M. (2020). Deep learning for motor imagery EEG-based classification: A review. Biomedical Signal Processing and Control, 63, 102172. https://doi.org/10.1016/j.bspc.2020.102172

Wang, T., Dong, E., Du, S., & Jia, C. (2019). A shallow convolutional neural network for classifying MI-EEG. In 2019 Chinese Automation Congress (CAC) (pp. 5837–5841). IEEE. https://doi.org/10.1109/CAC48633.2019.8996981

Zhang, X., Yao, L., Wang, X., Monaghan, J.J., & McAlpine, D. (2019). A Survey on Deep Learning based Brain Computer Interface: Recent Advances and New Frontiers. ArXiv, abs/1905.04149.

Gu, X., Cao, Z., Jolfaei, A., Xu, P., Wu, D., Jung, T., & Lin, C. (2020). EEG-Based Brain-Computer Interfaces (BCIs): A Survey of Recent Studies on Signal Sensing Technologies and Computational Intelligence Approaches and Their Applications. IEEE/ACM Transactions on Computational Biology and Bioinformatics, 18, 1645-1666.

Abibullaev, Berdakh et al. "Deep Learning in EEG-Based BCIs: A Comprehensive Review of Transformer Models, Advantages, Challenges, and Applications." IEEE Access 11 (2023): 127271-127301.

Ha, K., & Jeong, J. (2019). Motor Imagery EEG Classification Using Capsule Networks†. Sensors (Basel, Switzerland), 19.

Lionakis, E., Karampidis, K., & Papadourakis, G. (2023). Current Trends, Challenges, and Future Research Directions of Hybrid and Deep Learning Techniques for Motor Imagery Brain-Computer Interface. Multimodal Technol. Interact., 7, 95.

Rashid, M.M., Sulaiman, N., Majeed, A.P., Musa, R.M., Nasir, A.F., Bari, B.S., & Khatun, S. (2020). Current Status, Challenges, and Possible Solutions of EEG-Based Brain-Computer Interface: A Comprehensive Review. Frontiers in Neurorobotics, 14.

Abibullaev, B., Dolzhikova, I.N., & Zollanvari, A. (2020). A Brute-Force CNN Model Selection for Accurate Classification of Sensorimotor Rhythms in BCIs. IEEE Access, 8, 101014-101023.

Du, Y., & Liu, J. (2022). IENet: a robust convolutional neural network for EEG based brain-computer interfaces. Journal of Neural Engineering, 19.

Liang, G., Cao, D., Wang, J., Zhang, Z., & Wu, Y. (2024). EISATC-Fusion: Inception Self-Attention Temporal Convolutional Network Fusion for Motor Imagery EEG Decoding. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 32, 1535-1545.

Xu, B., Zhang, L., Song, A., Wu, C., Li, W., Zhang, D., Xu, G., Li, H., & Zeng, H. (2019). Wavelet Transform Time-Frequency Image and Convolutional Network-Based Motor Imagery EEG Classification. IEEE Access, 7, 6084-6093.

Amin, S.U., Alsulaiman, M., Muhammad, G., Bencherif, M.A., & Hossain, M.S. (2019). Multilevel Weighted Feature Fusion Using Convolutional Neural Networks for EEG Motor Imagery Classification. IEEE Access, 7, 18940-18950.

Tibrewal, N., Leeuwis, N., & Alimardani, M. (2021). The Promise of Deep Learning for BCIs: Classification of Motor Imagery EEG using Convolutional Neural Network. bioRxiv.

Tibrewal, N., Leeuwis, N., & Alimardani, M. (2022). Classification of motor imagery EEG using deep learning increases performance in inefficient BCI users. PLoS ONE, 17.

Alimardani, M., Kocken, S., & Leeuwis, N. (2023). End-to-End Deep Transfer Learning for Calibration-free Motor Imagery Brain Computer Interfaces. ArXiv, abs/2307.12827.

Shuaibu, Z., & Qi, L.J. (2020). Optimized DNN Classification Framework based on Filter Bank Common Spatial Pattern (FBCSP) for Motor-imagery-based BCI. International Journal of Computer Applications.

Shin, H., Yin, K., & Lee, S. (2023). Sparse Multitask Learning for Efficient Neural Representation of Motor Imagery and Execution. 2024 12th International Winter Conference on Brain-Computer Interface (BCI), 1-4.

Inconsistent but Not Invalid: Understanding Variations in ALS Risk Factor Research
By Xiang Ma

Abstract

Amyotrophic lateral sclerosis (ALS) is a neurodegenerative disease caused by both genetic and environmental factors. This study examines the associations between ALS and its major non-genetic risk factors such as air pollution, pesticide exposure, and biological sex. Although previous studies have reported inconsistent results, this paper contends that such inconsistencies arise not from the invalidity of the risk factors themselves but primarily from variations in research design and population characteristics, including differences in gender or racial inequality status across societies. This suggests that social inequality can distort data in biological research and underscores the importance of accounting for it in future ALS studies to obtain more accurate and representative conclusions.

Introduction

Amyotrophic lateral sclerosis (ALS) is a type of neurodegenerative disease closely related to age and the motor system. It is characterized by a progressive loss of motor neurons (MN) in either the brain cortex or other parts of the body, causing muscle weakness and atrophy that gradually increase in severity and spread to other areas (Masrori and Van Damme; Segura et al.; Zarei et al.). The typical age of onset of ALS is 58 to 63 years for sporadic ALS (sALS) and 40-60 years for familial ALS, and most would die within 20 to 48 months from onset, but 10 to 20 percent of ALS patients would survive for more than 10 years after onset (Chiò et al.; Ingre et al.). Eventually, this disease may affect multiple organs and organ systems, including the circulatory and digestive systems, by causing dysphagia or heart attacks through damage to related muscles (Onesti et al.; Kwon et al.). Breathing failure and cardiac dysfunction are the two most common causes of death of ALS patients in the United States, and, given that about 50% of ALS patients have some degree of mental and cognitive impairment, it can be determined that ALS is a multisystemic degenerative disease (Larson et al.; Ringholz et al.; Katerelos et al.). Despite the rarity of this disease (there were approximately 32,893 ALS cases in the United States in total in 2022), ALS incidence in the US is expected to increase by more than 10% to 36,308 by 2030, and ALS incidence worldwide is projected to reach 376,674 by 2040 (Arthur et al.; Mehta et al.).

Currently, three theories have been proposed to explain ALS. The first is the dying-forward theory, which states that ALS begins with the degeneration of upper motor neurons (MN) in the motor cortex and gradually spreads to lower MNs. A second theory is the dying back theory, which affirms that ALS begins with lower MN death, resulting in dysfunctional muscles and neuromuscular junctions. Finally, the independent degeneration hypothesis proposes that upper and lower MN degenerate at roughly the same rate and time (Lynch; van den Bos et al.; Hu et al.).

The pathogenesis of ALS is highly complex, influenced by multiple factors, and mostly unknown to humans. Glutamate receptor hyperstimulation, oxidative stress, mitochondrial dysfunction, impaired proteostasis, and aberrant RNA metabolism have all been identified as mechanisms contributing to ALS, among others (Hu et al.; Masrori and Van Damme; Zarei et al.; Cluskey and Ramsden). Studies have identified SOD1 on chromosome 21, TARDBP on chromosome 1, FUS on chromosome 16, and C9ORF72 on chromosome 9, among others, as the main risk genes of familial ALS (fALS) (Hu et al.; Zhou and Xu; Tolochko et al.; Nijs and Van Damme). The functions of these genes include converting superoxide to hydrogen peroxide or other harmless products, modulating gene expression and signaling, promoting DNA repair, and regulating synaptic function (Hu et al.; Zarei et al.; Suthar and Lee; Balendra and Isaacs; Wang et al.). Prion-like properties have also been observed in many ALS-related genes, particularly SOD1, TARDBP, and FUS, indicating that their mutated forms can readily aggregate and propagate to other proteins and cells.

Since only about 5% to 10% of all ALS cases are familial, non-genetic factors must also take a significant role in causing ALS (Barberio et al.). For example, obesity, biological sex, air pollution, pesticides, electric shock, head trauma, and even algal blooms have all been connected with increased ALS incidence. Despite the numerous factors involved, this essay will focus solely on air pollution, pesticides, and biological sex. Some studies have shown that air pollution, including O3 and CO, as well as certain pesticides, can lead to excessive oxidative stress in neurons (Lodovici and Bigagli; Hyunyoung Kim et al.). Males are usually reported as more likely to develop ALS, with a male-to-female ratio as high as 2.9:1 in some regions, though the gap is slowly closing in recent years (Longinetti and Fang).

There have been significant disagreements among the results of these studies, despite a general trend. For example, a population-based case-control study in the Netherlands found that air PM2.5 concentration is significantly positively correlated with ALS incidence. However, another cohort-based study in the US suggests that PM2.5, along with PM10, is not significantly related to ALS risk (Malek et al., “Long-Term Air Pollution”; Seelen et al.). In addition, a hospital-based cohort study in Africa reports a 2.9 to 1 male-to-female ratio, whereas a population-based study in northeastern Italy reports a 1.05:1 male-to-female ratio (Luna et al.; Palese et al.). Even though these studies are all peer-reviewed and conducted according to appropriate standards, the vast disparities among their results make it necessary to analyze the reasons behind them.

Through analysis of three non-genetic risk factors for ALS including air pollution, pesticides, and biological sex and by examining results across geographical regions, this essay argues that inconsistencies in research outcomes (whether in the existence or magnitude of associations) on these topics are not due to the invalidity of the stated risk factors but to differences in environment, study design, and population characteristics. This is important because these differences highlight the role and the need to promote social equality in biological research in order to avoid distortion of data and research results.

Air Pollution

Air pollution has long been considered a risk factor for ALS, but research results are mixed. Although some regional studies find air pollutants such as PM2.5, PM10, SO2, O3, CO, and NO2 to be significantly associated with ALS, research in other geographic regions has not extended these correlations to a global scale. This section will review some regional studies and analyze whether the differences are due to the invalidity of air pollution as a risk factor itself or differences in population and research procedures.

Primarily, numerous studies have already demonstrated that air pollution negatively impacts human health, particularly neuronal health, through multiple mechanisms. For example, particulate pollutants such as PM10 and PM2.5 appear to increase cytokine levels, including IL-1β and IL-6, which are well known to cause neurotoxicity via neuroinflammation, leading to neuronal death and microglial activation (Block and Calderón-Garcidueñas; Chen et al.; Manisalidis et al.). Microglial activation increases reactive oxygen species (ROS) and free radical concentration (Block and Calderón-Garcidueñas; Chen et al.; Manisalidis et al.). It also disrupts the blood-brain barrier (BBB), increasing the brain's susceptibility to foreign particles in the circulatory system that may damage it, among other effects (Block and Calderón-Garcidueñas; Chen et al.; Manisalidis et al.). This, in turn, manifests in reduced brain growth, cognitive impairment, an increased risk of stroke, and behavioral changes (Block and Calderón-Garcidueñas; Chen et al.; Manisalidis et al.). In some cases, tiny air pollutants such as nanoparticles can even interact directly with the nervous system by passing through alveolar and capillary walls into the circulatory system and crossing the BBB, resulting in their presence in the brain (Calderón-Garcidueñas et al.).

However, despite this plausibility, regional studies have reported conflicting associations between air pollution and ALS. Malek et al.'s 2023 study in the US is a cohort-based study using the Women's Health Initiative (WHI), a long-term national study funded by the National Institutes of Health (NIH). This study, which included 161,808 postmenopausal women aged 50 to 79, found no significant correlation between PM2.5 and PM10 concentrations and ALS mortality (Malek et al., "Long-Term Air Pollution"). The study encompassed 40 ALS-focused clinical centers in 24 states and the District of Columbia (Malek et al., "Long-Term Air Pollution"). Roughly 10 controls without ALS but with similar age, ethnicity, and region were selected for each of the 256 cases that died of ALS from 1993 to 2017 (Malek et al., "Long-Term Air Pollution"). Through systemic analysis of exposure to PM2.5, PM10, and PM10-2.5 of the cases and controls using air pollution databases, the researchers found no significant differences in air pollution exposure between the cases and controls (patients who died from ALS and healthy people similar to these patients) in 5-year, 7.5-year, and 10-year timeframes before the mortality of these ALS patients (Malek et al., "Long-Term Air Pollution"). This suggests that microparticle exposure is not significantly related to ALS mortality. Although the odds ratios for PM10-2.5 are greater than 1.0, they are not statistically significant (Malek et al., "Long-Term Air Pollution").

A similar study conducted in the Netherlands by Seelen et al. yielded completely different results. It enrolled 917 ALS patients from the Prospective ALS study in the Netherlands (PAN), which is estimated to capture about 81% of all ALS patients in the Netherlands (Seelen et al.). Air pollution exposure data collected at multiple sites in 2009 are used to derive concentrations of NO2, PM2.5, PM10, and PM2.5 absorbance (a measure of soot and black carbon), among others (Seelen et al.). Results show that ALS patients are significantly exposed to higher PM10, PM2.5 absorbance, NO2, and NOx levels, with p-values < 0.05 (Seelen et al.). A marginal correlation was observed with PM2.5 concentration (p-value $= 0.08$) (Seelen et al.). In summary, Seelen et al.'s study found significant relationships between multiple types of air pollution and ALS incidence, whereas Malek's study did not (Seelen et al.; Malek et al., "Long-Term Air Pollution").

This discrepancy is not due to the invalidity of air pollution as a risk factor, but rather to substantial differences between the research design and population characteristics. Primarily, as Malek et al.'s 2023 paper has pointed out, some of the pollutants Seelen et al.'s research has focused on, such as PM2.5 absorbance, NO2, and NOx, are "primary traffic-related pollutants" (Malek et al., "Long-Term Air Pollution"). Given that Seelen et al. focused on the Netherlands, a small, densely populated, highly urbanized country, their research seems to focus mostly on traffic-related pollutants with fewer confounding pollutants. On the other hand, in Malek et al.'s research, 24 states across the US are investigated, representing much greater diversity in pollutant sources, which may weaken the correlation between air pollution and ALS (since stronger and weaker sources are confounded together) (Malek et al., "Long-Term Air Pollution").

The racial makeup of participants in the studies is also important. The participants in Malek et al.'s study are predominantly non-Hispanic White, whereas the racial distribution of participants was not reported in the Dutch study. However, numerous studies have demonstrated that, especially in the US, regions with above-average White or Native American populations have lower levels of air pollution than those with above-average Asian, African American, Hispanic, or Latino populations (Jbaily et al.; Josey et al.; Tessum et al.). According to Jbaily et al., this disparity in exposure is even expanding over time. Therefore, since Malek et al.'s 2023 study involves mostly White people, they are probably less affected by air pollution than the participants of Seelen et al.'s study, which could weaken any correlation between air pollution and ALS. Plus, given that Seelen et al.'s study covers most ALS patients in the Netherlands (917 cases), it has much greater statistical power than Malek et al.'s 2023 research, which includes only 256 ALS cases. It is natural for a correlation to appear in the Dutch study but not in the American study. Thus, it is also necessary to select diverse populations, especially by race, when analyzing ALS risk by location.

Pesticides

Potential negative effects of pesticides have also been extensively investigated and are the principal reason for governmental limitations on their use. In addition to causing negative

"dermatological, gastrointestinal, respiratory, reproductive, endocrine, child growth, … and carcinogenic effects", systemic reviews have also found pesticides to be particularly related to neurodegeneration and neuronal apoptosis (Scorza). For example, biological pathways that metabolize and degrade toxic pesticide compounds and their interactions with mitochondria and endoplasmic reticular systems may produce ROS, which, via enzyme deactivation, lipid peroxidation (via formation of hydroxyl free radicals), and DNA damage, induce neuronal death (Lushchak et al.; Hongoeb et al.; Abdollahi et al.; Jabłońska-Trypuć). Effects more specific to neurons are also proposed. For example, not only do pesticides such as DDT induce oxidative stress and lipid peroxidation, but they also exhibit neurotoxic properties by blocking voltage-gated sodium channels, thereby hindering action potentials and even causing neuronal apoptosis (Lushchak et al.; Abdollahi et al.). Other pesticides, such as chlorpyrifos and organophosphorus pesticides (OPP), decrease acetylcholinesterase (AChE) activity, which originally functions as an enzyme that decomposes acetylcholine (Ach) to prevent overactivation of the postsynaptic membrane (Lushchak et al.; Abdollahi et al.; Greer et al.; Čadež et al.). Some other pesticides can reduce glutamate reuptake at the presynaptic membrane, inducing excitotoxic effects in neurons, a hallmark mechanism of ALS (Lushchak et al.; Vaccari et al.; Cattani et al.). These neurotoxic effects have brought a noticeable increase in risk of neurodegenerative diseases such as Alzheimer's Disease (AD), Parkinson's Disease (PD), and ALS (Kamel et al.; Zhu et al.; Van Maele-Fabry et al.; Yan et al.). Specifically for ALS, a meta-analysis of 6 peer-reviewed papers found a significant association between pesticide exposure and ALS risk. with an odds ratio (OR) of 1.88 (Malek et al., "Pesticide Exposure"). However, despite this general trend and numerous studies arguing for a correlation between pesticide exposure and ALS incidence, some research, such as that by Vinceti et al., has offered little support for such a relation, while others have (Vinceti et al.; Su et al.). An analysis of the reasons this disparity may have occurred is necessary.

Vinceti et al.'s study is a population-based case-control study conducted in Italy (specifically the provinces of Parma, Reggio Emilia, Catania, and Modena). Vinceti et al. first located the residential addresses of 703 ALS cases and 2737 controls using databases from the Italian Ministry of Finance Revenue Agency between 1998 and 2011, and then ascertained agricultural business activity from the same database. Additionally, rural regions and crop types are discerned from aerial photos provided by the Ministry of Agriculture for the said regions, which, combined with information on the specific pesticides used for each crop type, are used to derive each subject's pesticide exposure. The results do not support a significant correlation between pesticide exposure and ALS risk.

In contrast, Su et al.'s community-based case-control study successfully identified a correlation between pesticide exposure and ALS. By obtaining permission from patients visiting the University of Michigan ALS Clinic and recruiting via the National ALS Registry, 156 ALS cases participated in the study. The study also recruited 128 corresponding controls. By asking the participants to complete a questionnaire about residential history and occupational history among others, the researchers found that occupational exposure to pesticides is significantly

related to ALS in all four timeframes studied (W1: exposure ever happened in the entire occupational history; W2: exposure ever happened in the latest 10 years; W3: exposure ever happened in 10-30 years; W4: exposure ever happened more than 30 years ago).

This difference in results can be explained from multiple angles. Primarily, Vinceti et al. measured pesticide exposure only indirectly through proximity to crop acreage. Though it makes sense that pesticides can reach the human body from agricultural fields at a distance through aerial drift and spreading, the specific quantities and types of pesticides are highly variable across farms, even when they produce the same types of crops in the same province. It does not depend solely on local legislation but also on the specific conditions of each farm and, more simply, on traditions. Therefore, it is prone to misrepresentation of the variable of interest. For example, a field using heavier pesticide treatments may be relatively far from a residential area, while a field using relatively lighter pesticide treatments may be located nearby. In this study, the former's pesticide exposure would be considered lighter than the latter's, whereas the actual situation is much more complex. The misrepresentations that result from this may distort and conceal existing correlations, as may be the case in this research.

Additionally, studies have shown that laws regarding pesticide use are stricter in Italy than in the US. For instance, according to an international comparative analysis of the status of more than 500 agricultural pesticides, 72 pesticides are still allowed and used in the US but are already banned or in the process of complete phase-out in the European Union (EU), including Italy (Donley). Unlike the US, the EU has standardized pesticide risk indicators, such as the Harmonized Risk Indicators (HRIs) for notable hazardous substances, which every member state must calculate, submit, and publicize (Lane). Lacking risk indicators like the HRI and legalizing pesticides that the EU has already banned, the US is likely to have much looser governmental intervention in pesticide use than the EU. Therefore, the participants of Su et al.'s study may be exposed to more dangerous pesticides than the participants of Vinceti et al.'s study in general, which could diminish the strength of the correlation in Vinceti et al.'s study relative to Su et al.'s study because the effects of some dangerous pesticides that are allowed in the US and not in Italy (such as Bensulide, Paraquat, EPTC, Chloropicrin, etc) on ALS are only presented in Su et al.'s study but not in Vinceti et al.'s study (Donley).

Gender / Sex

Gender, however, has a more defined but also unclear relation with ALS. According to research on the subject, most papers report a male-to-female ratio of 1:1 to 2:1, while a 2021 meta-analysis of 39 studies found that the overall pooled male-to-female ratio is approximately 1.35 (Fontana et al.; Longinetti and Fang). However, there have been research results with starkly contrasting results. For instance, a study conducted in Africa reported a ratio of 2.9:1, whereas a study in Italy reported a ratio of 1.05:1 (Longinetti and Fang).

Multiple mechanisms have been proposed to explain the lower female incidence rates reported in research. Primarily, female sex hormones such as estradiol have been proven to alleviate the development and symptoms of ALS. Administration of estradiol in transgenic ALS

mice is shown to demonstrate neuroprotective properties by improving MN performance, reducing MN death, decreasing microglial presence, diminishing NLRP3 inflammasome activation, and increasing synaptic plasticity; on the other hand, ovariectomy on female SOD1 transgenic ALS mice, which significantly decreased estradiol concentration, has accelerated ALS progression (Heitzer et al.; Groeneveld et al.; Handley et al.; Jong et al.). MNs have been shown to express estrogen receptors that, when activated by estradiol, reduce the risk of neuronal apoptosis (Cardona-Rossinyol et al.). Progesterone has similar effects: administering different doses of PG to transgenic ALS mice significantly delays motor degeneration and extends lifespan compared with the control group (Jean H. Kim et al.). Given that premenopausal women have substantially higher estrogen and progesterone concentrations than men, they would naturally have lower ALS incidence rates than men. However, as estrogen and progesterone levels in women drop to a similar level as men after menopause, "no evidence for a neuroprotective role of estrogen in postmenopausal women with ALS was found" (Rudnicki).

Given that research largely supports greater male susceptibility to ALS, the differences in results between Palese et al.'s study in northeastern Italy and Luna et al.'s study in Africa are likely due to differences in populations and research methods. Luna et al. conducted a multicenter, hospital-based cohort study (since a population-based study is impractical in Africa given the local socioeconomic conditions) including nine medical centers across eight African countries (Algeria, Tunisia, Mauritania, Senegal, Burkina Faso, Togo, Benin, South Africa) and collected data from 185 patients (114 from Northern Africa, 41 from Western Africa, 30 from Southern Africa) from 2005 to 2017 in total. The male-to-female ratio of ALS incidence found from this study is 2.9:1. The study of Palese et al., however, is population-based, collecting patient information from "Regional Health Databases (Hospital Discharge, Health coverage exemptions, Mortality and Residence Databases), the G2 Clinical Database, the archives of all neurology departments in Friuli-Venezia Giulia, the regional register of the nonprofit Italian ALS association (AISLA)". This is much more comprehensive than Luna et al.'s study, since the Regional Health Databases include information on all local residents, effectively targeting all people in the FVG area. In sum, 444 ALS incidence cases were identified between 2002 and 2014, and the male-to-female ratio found in this study is 1.05:1.

The most obvious difference between the studies is the populations – one set in the highly developed country of Italy and the other in developing countries in Africa. Therefore, average life expectancy is vastly different: that of Algeria, Tunisia, Mauritania, Senegal, Burkina Faso, Togo, Benin, and South Africa in 2010 (which is within the timeframe of Luna et al.'s study) are 74.1, 74.4, 65.7, 64.2, 56.3, 57.2, 58.4, and 58.9, respectively, while that of Italy is 82, which is significantly higher than all countries involved in Luna et al.'s research (Federal Reserve Bank of St. Louis). In fact, Italy has the oldest population in Europe. Given the neuroprotective effects of estrogen and progesterone, premenopausal women, who have significantly higher concentrations of these hormones than men, would have lower risks of ALS. However, as they age and experience menopause, their chances of developing ALS continuously increase as the neuroprotective effects of these hormones diminish. The longer women are able to live beyond

menopause in a country on average, the higher the possibility of their developing ALS, and the closer the gap of ALS incidence between the genders becomes, as demonstrated by the closer gap in Italy compared with Africa.

Differences in gender status could also play a role. For example, an analysis of 105,025 patients admitted to an Ethiopian rural hospital yielded a male-to-female admissions ratio of 1.4:1 if pregnancy-related issues are not considered. This result echoes other studies and indexes pointing out that Africa has much lower levels of gender equality than developed European countries such as Italy, since systemic gender inequality may lead to women receiving fewer and later treatment than men for chronic diseases such as ALS, which results in underdiagnosis and for women and an illusion that substantially fewer women have ALS than men (United Nations Development Programme; Williams et al.; World Economic Forum). Plus, the much smaller sample size in the African study (185 ALS cases) compared to the Italian study (444 ALS cases) makes it more prone to sampling error; therefore, the Italian study seems closer to the actual gender ratio than the African study.

Conclusion

This paper, through an analysis of three non-genetic risk factors for ALS, namely 1) air pollution, 2) sex, and 3) pesticides, has highlighted inconsistencies in research outcomes across different geographical regions. This paper argues that these discrepancies are not due to the invalidity of the stated risk factors themselves but stem from differences in research design and population characteristics. Specifically, air pollution studies have produced contrasting results due to differences in geographic scope, racial inequality, and unequal sample sizes. Similarly, the pesticide-ALS relation varies across research designs, depending on exposure measurement (e.g., using proximity to agricultural areas as a proxy for pesticide exposure vs. using direct questionnaires) and pesticide regulations. In the case of sex, while most, if not all, studies consistently show a higher ALS incidence in males, the strength of this correlation varies significantly, which is likely influenced by regional demographic factors such as life expectancy, hormonal changes, gender inequality, and differences in sample size.

As the problem of social or international inequality (racial inequality in air pollution, gender inequality in medical care, and legislative inequality between countries on pesticides) has been shown to distort research data and, therefore, the conclusions derived from it, it warrants concrete action. At least, social or international inequality has to be recognized as a factor that greatly influences research results in biology and be discussed more often in research.

These findings highlight that understanding ALS requires more than biological discoveries. It demands comprehensive knowledge of social, environmental, and methodological factors in each study. More discussion of these complexities would substantially improve the applicability of ALS research in real life and its contribution to finding better prevention, diagnosis, and treatment for all ALS patients and communities.

Works Cited

Abdollahi, Mohammad, et al. “Pesticides and Oxidative Stress: A Review.” Medical Science Monitor, vol. 10, no. 6, June 2004.

Arthur, Karissa C., et al. “Projected Increase in Amyotrophic Lateral Sclerosis from 2015 to 2040.” Nature Communications, vol. 7, no. 1, Aug. 2016, https://doi.org/10.1038/ncomms12408.

Balendra, Rubika, and Adrian M. Isaacs. “C9orf72-Mediated ALS and FTD: Multiple Pathways to Disease.” Nature Reviews Neurology, vol. 14, no. 9, Aug. 2018, pp. 544–58, https://doi.org/10.1038/s41582-018-0047-2.

Barberio, Julie, et al. “Estimated Familial Amyotrophic Lateral Sclerosis Proportion.” Neurology. Genetics, vol. 9, no. 6, Wolters Kluwer, Dec. 2023, https://doi.org/10.1212/nxg.0000000000200109.

Block, Michelle L., and Lilian Calderón-Garcidueñas. “Air Pollution: Mechanisms of Neuroinflammation and CNS Disease.” Trends in Neurosciences, vol. 32, no. 9, Sept. 2009, pp. 506–16, https://doi.org/10.1016/j.tins.2009.05.009.

Brann, Darrell W., et al. “Neurotrophic and Neuroprotective Actions of Estrogen: Basic Mechanisms and Clinical Implications.” Steroids, vol. 72, no. 5, May 2007, pp. 381–405, https://doi.org/10.1016/j.steroids.2007.02.003.

Čadež, Tena, et al. “Assessment of Four Organophosphorus Pesticides as Inhibitors of Human Acetylcholinesterase and Butyrylcholinesterase.” Scientific Reports, vol. 11, no. 1, Nov. 2021, https://doi.org/10.1038/s41598-021-00953-9.

Calderón-Garcidueñas, Lilian, et al. “Long-Term Air Pollution Exposure Is Associated with Neuroinflammation, an Altered Innate Immune Response, Disruption of the Blood-Brain Barrier, Ultrafine Particulate Deposition, and Accumulation of Amyloid β-42 and α-Synuclein in Children and Young Adults.” Toxicologic Pathology, vol. 36, no. 2, Feb. 2008, pp. 289–310, https://doi.org/10.1177/0192623307313011.

Cardona-Rossinyol, Andrea, et al. “Neuroprotective Effects of Estradiol on Motoneurons in a Model of Rat Spinal Cord Embryonic Explants.” Cellular and Molecular Neurobiology, vol. 33, no. 3, Jan. 2013, pp. 421–32, https://doi.org/10.1007/s10571-013-9908-9. Accessed 14 Dec. 2022.

Cattani, Daiane, et al. “Developmental Exposure to Glyphosate-Based Herbicide and Depressive-like Behavior in Adult Offspring: Implication of Glutamate Excitotoxicity and Oxidative Stress.” Toxicology, vol. 387, July 2017, pp. 67–80, https://doi.org/10.1016/j.tox.2017.06.001.

Chen, Fu, et al. “Breathing in Danger: Understanding the Multifaceted Impact of Air Pollution on Health Impacts.” Ecotoxicology and Environmental Safety, vol. 280, July 2024, p. 116532, https://doi.org/10.1016/j.ecoenv.2024.116532.

Chiò, Adriano, et al. “Prognostic Factors in ALS: A Critical Review.” Amyotrophic Lateral Sclerosis, vol. 10, no. 5-6, Jan. 2009, pp. 310–23, https://doi.org/10.3109/17482960802566824.

Cluskey, S., and D. B. Ramsden. “Mechanisms of Neurodegeneration in Amyotrophic Lateral Sclerosis.” Molecular Pathology, vol. 54, no. 6, 2001, pp. 386–92.

Dardiotis, Efthimios, et al. “Body Mass Index and Survival from Amyotrophic Lateral Sclerosis.” Neurology: Clinical Practice, vol. 8, no. 5, Oct. 2018, pp. 437–44, https://doi.org/10.1212/CPJ.0000000000000521.

Donley, Nathan. “The USA Lags behind Other Agricultural Nations in Banning Harmful Pesticides.” Environmental Health, vol. 18, no. 1, June 2019, https://doi.org/10.1186/s12940-019-0488-0.

Federal Reserve Bank of St. Louis. “FRED Economic Data.” Stlouisfed.org, Federal Reserve Bank of St. Louis, 2025, fred.stlouisfed.org/.

Fontana, Andrea, et al. “Time-Trend Evolution and Determinants of Sex Ratio in Amyotrophic Lateral Sclerosis: A Dose–Response Meta-Analysis.” Journal of Neurology, vol. 268, no. 8, Feb. 2021, pp. 2973–84, https://doi.org/10.1007/s00415-021-10464-2.

Greer, Justin B., et al. “Effects of Chlorpyrifos on Cholinesterase and Serine Lipase Activities and Lipid Metabolism in Brains of Rainbow Trout (Oncorhynchus Mykiss).” Toxicological Sciences, vol. 172, no. 1, July 2019, pp. 146–54, https://doi.org/10.1093/toxsci/kfz167. Accessed 29 June 2023.

Groeneveld, G. J., et al. “Ovariectomy and 17β-Estradiol Modulate Disease Progression of a Mouse Model of ALS.” Brain Research, vol. 1021, no. 1, Elsevier BV, Aug. 2004, pp. 128–31, https://doi.org/10.1016/j.brainres.2004.06.024. Accessed 29 Aug. 2025.

Handley, Emily E., et al. “Estrogen Enhances Dendrite Spine Function and Recovers Deficits in Neuroplasticity in the PrpTDP-43A315T Mouse Model of Amyotrophic Lateral Sclerosis.” Molecular Neurobiology, vol. 59, no. 5, Springer Science+Business Media, Mar. 2022, pp. 2962–76, https://doi.org/10.1007/s12035-022-02742-5. Accessed 9 Nov. 2024.

Heitzer, Marius, et al. “Administration of 17β-Estradiol Improves Motoneuron Survival and Down-Regulates Inflammasome Activation in Male SOD1(G93A) ALS Mice.” Molecular Neurobiology, vol. 54, no. 10, Dec. 2016, pp. 8429–43, https://doi.org/10.1007/s12035-016-0322-4. Accessed 18 Nov. 2021.

Hongoeb, Juthamas, et al. “Herbicide-Related Health Risks: Key Mechanisms and a Guide to Mitigation Strategies.” Journal of Occupational Medicine and Toxicology, vol. 20, no. 1, Springer Science and Business Media LLC, Feb. 2025, https://doi.org/10.1186/s12995-025-00448-7.

Hu, Yushu, et al. “Pathological Mechanisms of Amyotrophic Lateral Sclerosis.” Neural Regeneration Research, vol. 19, no. 5, Medknow, Aug. 2023, pp. 1036–44, https://doi.org/10.4103/1673-5374.382985.

Ingre, Caroline, et al. “Risk Factors for Amyotrophic Lateral Sclerosis.” Clinical Epidemiology, vol. 7, no. 7, Feb. 2015, p. 181, https://doi.org/10.2147/clep.s37505.

Jabłońska-Trypuć, Agata. “Pesticides as Inducers of Oxidative Stress.” Reactive Oxygen Species, 2017, https://doi.org/10.20455/ros.2017.823. Accessed 29 Nov. 2018.

Jbaily, Abdulrahman, et al. “Air Pollution Exposure Disparities across US Population and Income Groups.” Nature, vol. 601, no. 7892, Jan. 2022, pp. 228–33, https://doi.org/10.1038/s41586-021-04190-y.

Jong, Sonja, et al. “Endogenous Female Reproductive Hormones and the Risk of Amyotrophic Lateral Sclerosis.” Journal of Neurology, vol. 260, no. 2, Springer Science+Business Media, Sept. 2012, pp. 507–12, https://doi.org/10.1007/s00415-012-6665-5. Accessed 29 Aug. 2025.

Josey, Kevin P., et al. “Air Pollution and Mortality at the Intersection of Race and Social Class.” New England Journal of Medicine, vol. 388, no. 15, Mar. 2023, https://doi.org/10.1056/nejmsa2300523.

Kamel, Freya, et al. “PESTICIDE EXPOSURE and AMYOTROPHIC LATERAL SCLEROSIS.” Neurotoxicology, vol. 33, no. 3, June 2012, pp. 457–62, https://doi.org/10.1016/j.neuro.2012.04.001. Accessed 17 May 2021.

Katerelos, Adamantios, et al. “Cognitive Function in Amyotrophic Lateral Sclerosis: A Cross-Sectional and Prospective Pragmatic Clinical Study with Review of the Literature.” Neurological Sciences, vol. 45, no. 5, Springer Science+Business Media, Dec. 2023, pp. 2075–85, https://doi.org/10.1007/s10072-023-07262-1. Accessed 13 Jan. 2025.

Kim, Hyunyoung, et al. “Air Pollution and Central Nervous System Disease: A Review of the Impact of Fine Particulate Matter on Neurological Disorders.” Frontiers in Public Health, vol. 8, Dec. 2020, https://doi.org/10.3389/fpubh.2020.575330.

Kim, Jean H., et al. “Autophagy Activation and Neuroprotection by Progesterone in the G93A-SOD1 Transgenic Mouse Model of Amyotrophic Lateral Sclerosis.” Neurobiology of Disease, vol. 59, Elsevier BV, Nov. 2013, pp. 80–85, https://doi.org/10.1016/j.nbd.2013.07.011.

Kwon, Soonwook, et al. “Increased Risk of Myocardial Infarction in Amyotrophic Lateral Sclerosis: A Nationwide Cohort Study in South Korea.” Journal of the Neurological Sciences, vol. 454, Elsevier, Oct. 2023, p. 120829, https://doi.org/10.1016/j.jns.2023.120829.

Lane, David. “Comparing Integrated Pest Management Approaches: European Union vs. United States.” Journal of Integrated Pest Management, edited by Jeffrey Davis, vol. 16, no. 1, Oxford University Press (OUP), 2025, https://doi.org/10.1093/jipm/pmaf021. Accessed 30 Aug. 2025.

Larson, Theodore, et al. “Causes of Death among United States Decedents with ALS: An Eye toward Delaying Mortality.” Annals of Clinical and Translational Neurology, vol. 10, no. 5, Wiley, Mar. 2023, pp. 757–64, https://doi.org/10.1002/acn3.51762.

Lodovici, Maura, and Elisabetta Bigagli. “Oxidative Stress and Air Pollution Exposure.” Journal of Toxicology, vol. 2011, 2011, pp. 1–9, https://doi.org/10.1155/2011/487074.

Longinetti, Elisa, and Fang Fang. “Epidemiology of Amyotrophic Lateral Sclerosis.” Current Opinion in Neurology, vol. 32, no. 5, Oct. 2019, pp. 771–76, https://doi.org/10.1097/wco.0000000000000730.

Luna, Jaime, et al. “Clinical Features and Prognosis of Amyotrophic Lateral Sclerosis in Africa: The TROPALS Study.” Journal of Neurology, Neurosurgery & Psychiatry, vol. 90, no. 1, Jan. 2019, pp. 20–29, https://doi.org/10.1136/jnnp-2018-318469.

Lushchak, Volodymyr I., et al. “Pesticide Toxicity: A Mechanistic Approach.” EXCLI Journal, vol. 17, Leibniz Research Centre for Working Environment and Human Factors, 2018, pp. 1101–36, https://doi.org/10.17179/excli2018-1710.

Lynch, Karen. “Pathogenesis and Presentation of ALS: Examining Reasons for Delayed Diagnosis and Identifying Opportunities for Improvement.” The American Journal of Managed Care, vol. 29, no. 7 Suppl, June 2023, pp. S104–11, https://doi.org/10.37765/ajmc.2023.89390.

Malek, Angela M., et al. “Long-Term Air Pollution and Risk of Amyotrophic Lateral Sclerosis Mortality in the Women’s Health Initiative Cohort.” Environmental Research, vol. 216, Elsevier BV, Jan. 2023, pp. 114510–10, https://doi.org/10.1016/j.envres.2022.114510.

Malek, Angela M., et al. “Pesticide Exposure as a Risk Factor for Amyotrophic Lateral Sclerosis: A Meta-Analysis of Epidemiological Studies.” Environmental Research, vol. 117, Aug. 2012, pp. 112–19, https://doi.org/10.1016/j.envres.2012.06.007.

Manisalidis, Ioannis, et al. “Environmental and Health Impacts of Air Pollution: A Review.” Frontiers in Public Health, vol. 8, no. 14, Feb. 2020, pp. 1–13, https://doi.org/10.3389/fpubh.2020.00014. NCBI.

Masrori, P., and P. Van Damme. “Amyotrophic Lateral Sclerosis: A Clinical Review.” European Journal of Neurology, vol. 27, no. 10, July 2020, pp. 1918–29, https://doi.org/10.1111/ene.14393.

Mehta, Paul, et al. “Amyotrophic Lateral Sclerosis Estimated Prevalence Cases from 2022 to 2030, Data from the National ALS Registry.” Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration, Taylor & Francis, Jan. 2025, pp. 1–6, https://doi.org/10.1080/21678421.2024.2447919.

Nijs, Melissa, and Philip Van Damme. “The Genetics of Amyotrophic Lateral Sclerosis.” Current Opinion in Neurology, vol. 37, no. 5, Ovid Technologies (Wolters Kluwer Health), Aug. 2024, pp. 560–69, https://doi.org/10.1097/wco.0000000000001294.

Onesti, Emanuela, et al. “Dysphagia in Amyotrophic Lateral Sclerosis: Impact on Patient Behavior, Diet Adaptation, and Riluzole Management.” Frontiers in Neurology, vol. 8, no. 94, Mar. 2017, https://doi.org/10.3389/fneur.2017.00094.

Palese, Francesca, et al. “Epidemiology of Amyotrophic Lateral Sclerosis in Friuli-Venezia Giulia, North-Eastern Italy, 2002–2014: A Retrospective Population-Based Study.” Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration, vol. 20, no. 1-2, Nov. 2018, pp. 90–99, https://doi.org/10.1080/21678421.2018.1511732. Accessed 11 Dec. 2019.

Ringholz, G. M., et al. “Prevalence and Patterns of Cognitive Impairment in Sporadic ALS.” Neurology, vol. 65, no. 4, Aug. 2005, pp. 586–90, https://doi.org/10.1212/01.wnl.0000172911.39167.b6.

Rudnicki, Stacy A. “Estrogen Replacement Therapy in Women with Amyotrophic Lateral Sclerosis.” Journal of the Neurological Sciences, vol. 169, no. 1-2, Elsevier BV, Oct. 1999, pp. 126–27, https://doi.org/10.1016/s0022-510x(99)00234-8. Accessed 19 Mar. 2024.

Scorza, Fulvio Alexandre, et al. “Pesticide Exposure and Human Health: Toxic Legacy.” Clinics, vol. 78, Faculdade de Medicina / USP, Jan. 2023, pp. 100249–49, https://doi.org/10.1016/j.clinsp.2023.100249.

Seelen, Meinie, et al. “Long-Term Air Pollution Exposure and Amyotrophic Lateral Sclerosis in Netherlands: A Population-Based Case–Control Study.” Environmental Health Perspectives, vol. 125, no. 9, Sept. 2017, p. 097023, https://doi.org/10.1289/ehp1115. Accessed 26 May 2021.

Segura, Tomás, et al. “Symptoms Timeline and Outcomes in Amyotrophic Lateral Sclerosis Using Artificial Intelligence.” Scientific Reports, vol. 13, no. 1, Jan. 2023, p. 702, https://doi.org/10.1038/s41598-023-27863-2.

Su, Feng-Chiao., et al. “The Role of Environmental Toxins on ALS: A Case-Control Study of Occupational Risk Factors.” JAMA Neurology, vol. 73, no. 7, July 2016, pp. 803–11, https://doi.org/10.1001/jamaneurol.2016.0594. Accessed 9 Dec. 2020.

Suthar, Sharad Kumar, and Sang-Yoon Lee. “The Role of Superoxide Dismutase 1 in Amyotrophic Lateral Sclerosis: Identification of Signaling Pathways, Regulators, Molecular Interaction Networks, and Biological Functions through Bioinformatics.” Brain Sciences, vol. 13, no. 1, Multidisciplinary Digital Publishing Institute, Jan. 2023, pp. 151–51, https://doi.org/10.3390/brainsci13010151.

Tessum, Christopher W., et al. “PM2.5 Polluters Disproportionately and Systemically Affect People of Color in the United States.” Science Advances, vol. 7, no. 18, Apr. 2021, https://doi.org/10.1126/sciadv.abf4491.

Tolochko, Christina, et al. “Amyotrophic Lateral Sclerosis: Pathophysiological Mechanisms and Treatment Strategies (Part 2).” International Journal of Molecular Sciences, vol. 26, no. 11, May 2025, p. 5240, https://doi.org/10.3390/ijms26115240. Accessed 27 Aug. 2025.

United Nations Development Programme. HDR 2025 Statistical Annex: Gender Inequality Index (GII) Table. 2025.

Vaccari, Andrea, et al. “Dithiocarbamate Pesticides Affect Glutamate Transport in Brain Synaptic Vesicles.” Journal of Pharmacology and Experimental Therapeutics, vol. 288, no. 1, American Society for Pharmacology and Experimental Therapeutics, Jan. 1999, pp. 1–5, https://doi.org/10.1016/s0022-3565(24)37916-9. Accessed 30 Aug. 2025.

van den Bos, Mehdi A. J., et al. “Pathophysiology and Diagnosis of ALS: Insights from Advances in Neurophysiological Techniques.” International Journal of Molecular Sciences, vol. 20, no. 11, June 2019, p. 2818, https://doi.org/10.3390/ijms20112818.

Van Maele-Fabry, Geneviève, et al. “Occupational Exposure to Pesticides and Parkinson’s Disease: A Systematic Review and Meta-Analysis of Cohort Studies.” Environment International, vol. 46, Oct. 2012, pp. 30–43, https://doi.org/10.1016/j.envint.2012.05.004.

Vinceti, Marco, et al. “Pesticide Exposure Assessed through Agricultural Crop Proximity and Risk of Amyotrophic Lateral Sclerosis.” Environmental Health, vol. 16, no. 1, BioMed Central, Aug. 2017, https://doi.org/10.1186/s12940-017-0297-2. Accessed 1 May 2023.

Wang, Wen-Yuan, et al. “Interaction of FUS and HDAC1 Regulates DNA Damage Response and Repair in Neurons.” Nature Neuroscience, vol. 16, no. 10, Sept. 2013, pp. 1383–91, https://doi.org/10.1038/nn.3514.

Williams, Eunice, et al. “Women’s Economic Empowerment in Sub-Saharan Africa: Evidence from Cross-National Population Data.” Demographic Research, vol. 47, no. 15, Sept. 2022, pp. 415–52, https://doi.org/10.4054/demres.2022.47.15.

World Economic Forum. Global Gender Gap 2024 Insight Report. June 2024, www3.weforum.org/docs/WEF_GGGR_2024.pdf.

Yan, Dandan, et al. “Pesticide Exposure and Risk of Alzheimer’s Disease: A Systematic Review and Meta-Analysis.” Scientific Reports, vol. 6, Sept. 2016, https://doi.org/10.1038/srep32222.

Zarei, Sara, et al. “A Comprehensive Review of Amyotrophic Lateral Sclerosis.” Surgical Neurology International, vol. 6, no. 1, Nov. 2015, p. 171, https://doi.org/10.4103/2152-7806.169561.

Zhou, Wan, and Renshi Xu. “Current Insights in the Molecular Genetic Pathogenesis of Amyotrophic Lateral Sclerosis.” Frontiers in Neuroscience, vol. 17, Aug. 2023, p. 1189470, https://doi.org/10.3389/fnins.2023.1189470.

Zhu, Qiaochu, et al. “Risk Factors Associated with Amyotrophic Lateral Sclerosis Based on the Observational Study: A Systematic Review and Meta-Analysis.” Frontiers in Neuroscience, vol. 17, Frontiers Media, May 2023, https://doi.org/10.3389/fnins.2023.1196722. Accessed 13 Mar. 2024.

The Dual Implications of Music Listening to Individuals at a Societal, Emotional, and Neurological Level - A Review of Existing Literature By Zihan Liu

Abstract Draft

Music is a universally communicated language that engages several brain regions whilst evoking emotional, cognitive, and social responses. It is often recognized as a complex mechanism that can serve as either a beneficial or destructive tool. Multiple pieces of research highlight music's positive influences on individuals, such as its abilities to improve the brain health of those with neurodegenerative disorders, but there is also a portion of literature that examines the destructive aspects of music listening on our neurobiology and social behaviour, such as music's role in provoking extreme sadness or anger. However, existing research fails to holistically examine how aspects of music can generally influence the positive or negative valence of behavioural outcomes. Therefore, this narrative review examines how different types of music can activate certain brain regions and neural networks that underlie various positive and negative behavioural responses. To do so, this paper will include analyses of the literature of both empirical data and systematic reviews pertaining to positive and negative influences of music on brain regions. This can help individuals listen to music that supports their mental state and well-being more effectively. From a clinical perspective, this review can also be beneficial because it can help establish which types of music are more beneficial in music therapy and support those with neurodegenerative disorders.

Keywords music, neurodegeneration, addiction, sleep, emotion, torture, misogyny, neural correlates, behavioural implications

Section 1: Introduction

Music has evolved to become a critical part of modern day society, with adults listening to an average of 20.7 hours of music weekly, which is roughly 3 hours daily (Lachance et al.) . Existing research suggests that music is capable of evoking a spectrum of different emotions, varying from aggression (Chen et al.) and sadness (Garrido et al.) to inducing healthy sleep (Cordi et al.,) and potentially enabling preventions against neurodegeneration (Jiménez-Palomares et al.). Yet, there has been little distinction between exactly what features of music can lead to positive or negative effects. Therefore, this review aims to explore which certain characteristics of songs can beneficially influence the brain and behaviours, and what factors can result in negative alterations of neural circuits and social behaviours.

Additionally, music stimulates neural networks across different brain regions such as the auditory cortex, the reward system involved in emotional processing and motivation (Brodal et al.), and the hippocampus (Koelsch). However, how musical features, such as the lyrical content, genre, and influence our neurobiology and behaviours remains inadequately linked. Moreover, the individual characteristics of listeners and the social context in which the music is experienced

could be a potential factor to examine when evaluating whether music listening provides positive or negative effects.

By understanding the connection between music genres and their societal, neural, and behavioural influences, this review can guide individuals to acknowledge the consequences, whether beneficial or harmful, of music listening. From a clinical perspective, understanding the functions of certain types of music on the brain can enhance the effectiveness of music therapy–a common form of therapy known to stimulate the brain–for patients suffering from neurodegenerative diseases or mental illnesses.

This paper uses literature from searches on PubMed, Google Scholar, and various journal websites such as Frontiers, Nature Neuroscience, and Scientific Reports. Moreover, only literature regarding the positive and negative implications of music listening, neural networks, the link between music and behaviours, and the long-term effects of music were considered in this review, which implies that the scope of research used in this paper is focused only on its central themes and keywords. The papers used in this narrative review are mainly papers published in recent years to ensure that the review contains up-to-date information that utilizes advanced research methods. However, data from older time periods were also included in this paper for the purpose of evaluating older methods in obtaining data in the field of neuroscience, observing how findings may develop and change, and understanding foundational studies or theories that shaped our understanding of music.

The sections that follow aim to provide a holistic overview of the impacts of music on various societal, individual, and neurological elements. Firstly, in Section 2, the known benefits of music listening on our cognition, neural circuits, and behaviours will be explored alongside the specific features of music listening that enable these benefits to take effect. Subsequently, in Section 3, the disadvantageous and potentially harmful aspects of music listening on our neural networks and behaviours will be investigated, whilst also considering how different genres, forms, or styles of music can impact this. Finally, this paper will explore limitations of this review and its clinical implications, societal implications, and possible future directions of research in this field.

Section 2: Beneficial Forms of Music Listening

Numerous studies show that music listening has positive effects on the brain, particularly in the contexts of sleep, neurodegeneration, and emotional processing and induction. Cordi and colleagues (2019) discovered that listening to relaxing music can enhance the subjective sleep quality of individuals (Cordi et al., ‘Effects of Relaxing Music on Healthy Sleep’) which can be explained due to how rhythmic music creates slow oscillations in the brain that are beneficial for restorative sleep (Gao et al.). Further evidence also suggests that music listening serves as a therapeutic mechanism for patients suffering from neurodegenerative disorders such as Alzheimer's Disease (Bleibel et al.).

(a) Benefits of Music Listening on Sleep

Sleep is critical for the basic functioning of our body, as it helps with the restoration of brain areas, maintaining cognitive performance, and supporting our psychological health (Worley). However, recent estimates show that roughly 850 million adults, or 16.2% of the global population, meet the criteria for insomnia, marking it as the most common sleep disorder (Benjafield et al.). Given the benefits of sleep on our body, research has recently been investigating if music can play an influence on the quality of sleep.

Current studies investigating sleep have determined that relaxing rhythms generally improve the subjectively rated sleep quality of individuals. Additionally, participants who listened to relaxing music before sleeping spent less time in the lightest stage of non-rapid eye movement (NREM) sleep; subsequently, high-frequency brain activity decreased during deeper sleep (Cordi et al., 'Effects of Relaxing Music on Healthy Sleep'). From these findings, it could be indicated that individuals who listen to relaxing genres of music before sleep experience changes in brain oscillations; this can result in calmer and less disrupted sleep, which overall enables longer periods of time in quality sleep and deeper sleep stages.

Furthermore, according to recent studies, there is evidence supporting music's ability to improve the brain's memory consolidation while strengthening neural networks during sleep (Fabbri et al.). After listening to rhythmic sound stimuli during slow-wave sleep, there is a high prevalence of slow oscillations in auditory brain regions. The entrainment of slow oscillations and rhythmic music shows the brain's neuroplasticity through how it processes and responds to repetitive auditory stimuli (Gao et al.). Slow oscillations help improve memory consolidation and learning during sleep by coordinating other key sleep rhythms, such as sleep spindles and hippocampal sharp-wave ripples, and their ability to strengthen or weaken synapses (Massimini et al.).

Soothing forms of music may be linked to increased quality of sleep because it activates the parasympathetic nervous system (PNS) whilst reducing sympathetic nervous system activity (SNS) (Hu et al.). The PNS promotes relaxation through lowering heart rates and blood pressure, while the SNS is a system that activates the body's stress response. (Weissman and Mendes). Music can also activate memories and emotions; thus, relaxing music can redirect individuals' attention away from stress and towards the calming feelings brought by the music (Bragança et al.). This illustrates how music not only influences sleep through shifting our neurobiology, but it may also be due to its influence on our mental state.

(b) Benefits of Music Listening on Emotional Processing

Feelings of anger, agitation, and frustration are regular emotions felt by virtually the entire population, and music could potentially be a tool to help channel these emotions without causing undesirable consequences. According to Sharman & Dingle (2015), listening to extreme metal music from their music playlist that matches individuals' physiological arousal when exposed to angry circumstances can increase positive emotions. This is because listening to music may induce a feeling of power, enabling individuals to regulate their anger whilst feeling active and inspired. Moreover, participants stated that music from their own playlist enhances

their happiness and well-being (Sharman and Dingle), which suggests that the types of music that enable individuals to process feelings of anger rely heavily on individuals' subjective preferences and listening habits.

Emotional responses may also result from calm and motivational genres of music, which increases activation in the prefrontal cortex area of the brain. Studies have found that the motivational songs provoked more emotionally positive feelings, whereas calm songs led to a more relaxed state in individuals, as they were reported to have a decrease in heart rate (Bigliassi et al.). Through the use of functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIR) scans, it was shown that the emotional induction and regulation activates the prefrontal cortex (Glotzbach et al.). This shows how calm and motivational genres of music can help with emotional regulation and emotional induction in individuals.

Additionally, when songs with prosocial music are played, individuals seem to display lower levels of aggression, negative judgment, and hostility compared to those who listen to songs that do not contain lyrics that inflict positive or negative emotions (Greitemeyer). In both social and private settings, these findings can provide evidence in support of the idea that songs that carry prosocial connotations and positive lyrics can contribute towards prosocial behaviours.

Furthermore, music enables individuals to alleviate the discomfort of anger whilst mitigating some potential dangers. FakhrHosseini & Jeon (2019) researched how angry drivers respond to emotional music, which was categorized in the study as music that can evoke any form of emotion, and discovered that music reduces the risk of dangerous driving behaviours. Through investigating angry drivers' heart rates, oxygenation levels in the prefrontal cortex, and self-report questionnaires, it was found that emotional music can help the angry drivers to react at a similar level as drivers who are emotionally neutral (FakhrHosseini and Jeon). This demonstrates how emotional genres of music can induce feelings that help individuals with higher anger levels manage their anger more effectively. As a result, this can improve driving performance, which shows how music could potentially reduce acts of aggression that are the result of anger.

(c) Benefits of Music Listening on Neurodegenerative Disorders

Music therapy is well known as a form of non-invasive remedy for patients suffering from neurodegenerative disorders such as Alzheimer's Disease (AD). Music can act as a therapeutic tool due to its ability to positively influence verbal fluency, memory, and language by inducing neuroplasticity, thus helping to modulate emotions and enable the brain recovery process for patients suffering from AD (Bleibel et al.). Bleibel et al. further discovered that Active Music Intervention (AMI), which involves the direct participation of patients to engage in musical activities, is beneficial for cognitive and emotional processes, while Receptive Music Intervention (RMI), which involves listening to pre-recorded music or live performances, is more advantageous for evoking feelings of relaxation. One way of interpreting Bleibel and colleagues' results is that the direct participation of individuals engages regions of the brain involved in

motor, sensory, auditory and executive functions, which can stimulate our cognition on a greater scale. This interpretation is supported by Ito et al. (2022), who found that AMI requires higher cognitive demands and social components compared to passive listening (Ito et al.). On the other hand, RMI does not require physical engagement, and thus the areas of brain stimulation are concentrated on more emotional brain circuits. This allows listeners to fully immerse themselves in their feelings. Bruscia and colleagues (2020)'s study also provided consistent findings, where it was discovered that RMI influences the hypothalamus-pituitary-adrenal axis in a way that reduces cortisol, which is a stress hormone in the body, and instead increases physiological relaxation (Giordano et al.).

Music allows the brain to combine sound, rhythm, and motor coordination, which can help patients with AD to develop neural pathways that link perception and action closely; subsequently, music can also help engage certain neural pathways that were initially impaired (Schlaug). This highlights how music can support patients' recovery journey through activating neural connections that connect brain regions.

Furthermore, music's ability to decelerate the neurodegeneration in patients suffering from AD can be explained by music's ability to retrieve memories, evoke emotions, and alleviate stress. Matziorinis & Koelsh (2022) state that music can store memories and emotions that are associated with certain events; thus, memories can be retrieved alongside the emotions induced at an event by music. Through fMRI scans, it was shown that music listening is linked to changes in the activity within the anterior hippocampal formation, which is a region in the brain involved in autobiographical memory (Matziorinis and Koelsch). Given that AD patients commonly suffer from difficulties with autobiographical memory retrieval (EL HAJ et al.), music therapy can help with the recall of certain memories and potentially even drive the preservation of memories.

Additionally, music also triggers the reward system, which promotes the release of dopamine; this process degrades amyloid-beta plaque accumulation, which can be helpful for patients with AD. Through the use of Positron Emission Tomography (PET) scans, it was found that music stimulates regions in the reward system, such as the ventral striatum and amygdala, which trigger a release of dopamine (T. Zaatar et al.). Mice studies further revealed that the release of dopamine in the brain can allow amyloid-beta to break down and degrade (Watamura et al.). This is critical in helping AD patients because there is a strong correlation between the amount of amyloid-beta in the brain and neurodegeneration (Benilova et al.); thus, a reduction in levels of amyloid-beta plaque could lead to positive outcomes and potentially slow down the process of cognitive impairment for patients with AD.

Section 3: Destructive Forms of Music Listening

Although music can provide a plethora of benefits for its listeners, it can also bring various negative, destructive, or damaging effects. Precisely, this section explores music's relationship with other addictions, music as an addiction in itself, the correlation between music and negative emotions, music as a form of torture, and music's involvement in misogyny.

(a) Music and Other Addictive Behaviours

The connection between addictive behaviours and music can be viewed through two separate lenses; some scholars argue that there is a link between music listening and addiction to substances, while others argue that music itself can be a form of addiction.

First, the potential that music can encourage the development of another addiction, such as alcohol or substance abuse, will be explored. Multer et al. (2010) discovered that there is a positive correlation between personal preference for urban (such as rhythm and blues, rap, and hip-hop) and hard genres of music and behaviours associated with substance use, both individually and in group settings. On the other hand, "adult-oriented music" such as jazz, classical, and pop music was negatively correlated to substance use (Mulder et al.). These findings are supported by Chen et al. (2006)'s findings, where it was also concluded that rap music can significantly and positively predict an individual's use of alcohol, liquor, and marijuana. Furthermore, individuals who listen to techno and reggae genres of music are also significantly and positively correlated with alcohol usage (Chen et al.).

The strong relationship between various genres of music and substance usage could be because roughly 17% of lyrics within a song–especially rap–contain references to alcohol. These forms of music commonly associate drinking with wealth, luxury, crime, violence, and sexual activity, yet only 9% of songs that mention alcohol addresses the consequences of drinking (Bonnie et al.). Another possibility to explain the high correlation between preference for urban and hard genres of music could be due to individual personalities or lifestyle preferences. For instance, those who enjoy energetic guitar music may find joy in defying adult authority, hence they also engage in substance usage, or those who drink alcohol could enjoy going to areas that play loud music, such as clubs, which is why they like hard genres of music (Mulder et al.). However, it is not certain whether preference towards certain music genres impacts the formation of other addictions, or if addictions impact individuals' preference towards specific music genres.

Another consideration that needs to be addressed is the potential that music is largely unrelated to addiction. This is because an individual's music taste and personality are tightly interconnected (Rentfrow and Gosling). Thus, the correlation between music genre preference and substance addiction may not indicate that there is a causal relationship between the two elements. Instead, differing personalities between individuals could impact musical preferences and, in turn, be associated with tendencies to engage in addictive behaviours.

(b) Music as an Addiction

Secondly, the possibility that music itself is an addiction will be evaluated. Cockrill et al. (2011) posited that the increased accessibility and prevalence of music in modern-day society could influence individuals to compulsively listen to music to the point where it becomes an addiction. To demonstrate this, experiments found that participants who listened to music showed several addictive traits, and over 80% of participants changed their daily routine to

ensure that they were able to listen to music (Cockrill et al.). In particular, loud music appears to be an addictive genre of music, as Schmuziger et al. (2012) state. This could be because music stimulates brain regions that release dopamine, hence making listeners feel good and continuously seek music (Schmuziger et al.).

Moreover, music listening activates similar neurochemical pathways as addiction, which could explain why individuals may develop behaviours that are similar to those seen in substance abuse. During music listening, the basal ganglia–a region of the brain involved in movement, habit formation, and reward processing(Seger and Spiering)–experiences reduced communications with other areas in the brain's reward system, such as the nucleus accumbens and ventral striatum, without impacting the internal connectivity within each system individually (Brodal et al.) . The reduced connectivity between the basal ganglia and the rest of the reward system suggests that neural pathways linking brain regions involved in habit formation to reward processing become more automatic, hence requiring less effort. This implies that the brain actively alters the way it perceives rewarding stimuli like music, thus causing music listening to become a habitual behaviour over time. Furthermore, weakened connectivity could suggest that the pleasurable feelings induced by music listening become less responsive over repeated exposure, indicating that music listeners will require more stimulation to reach the same level of pleasurable emotions. This is comparable to the concept of building a tolerance, as seen in addictive behaviours (Sivils et al.) . Moreover, music listening also triggers the dorsal striatum and the amygdala (Brodal et al.), which are regions in the reward system that trigger the anticipation of reward (Jauhar et al.) and emotional processing (Jang and Kragel) , respectively. Similarly, the dorsal striatum, amygdala, and regions within the basal ganglia (specifically the ventral pallidum) are also impacted when engaging in addictive behaviours (Koob and Volkow).

However, the argument that music can be an addiction has not been extensively evaluated, and the exact genres, forms, moods, and duration of exposure that could lead to this are yet to be pinpointed. Additionally, although music may trigger the reward system in similar ways as addiction, this may not necessarily indicate that music is an addiction. This is because dopamine, despite its involvement in addiction, is not an entirely harmful neurotransmitter for our body; in fact, healthy releases of dopamine can help with motivation, mood, memory, and mental health (Bastioli et al.). Therefore, although there is a potential for music listening to be an addiction, more research regarding music and addiction must be done.

(c) Influences of Music on Negative Emotions

Music, particularly sad genres of music, is known to be capable of inducing emotions of sadness in listeners. However, the understanding between music and sadness is very conflicting, as countless individuals continue to choose to listen to sad genres of music despite it evoking negative emotions. Therefore, in the subsection, how music can induce feelings of sadness, and why individuals listen to sad songs despite their subsequent negative emotions, will be explored. Studies show that sad music can indeed evoke feelings of sadness within listeners. Vuoskoski & Eerola (2012) discovered that unfamiliar sadness-inducing songs can result in sad emotional

states among participants who had a personality trait of empathy. Moreover, participants' abilities to recall unpleasant autobiographical memories increased when listening to self-selected sadness-inducing music, with 47% of participants claiming that they thought about sad memories. On the other hand, unfamiliar sad-inducing songs are reported to induce sadness through creating visual imagery (Vuoskoski and Eerola). These findings show that sad genres of music, regardless of whether it is self-chosen or chosen by the experimenter, can evoke feelings of sadness. Moreover, this study also shows that personality factors (such as empathy) can be an indicator of the extent of sadness induced in the participant when listening to sad music. However, in Vuoskoski & Eerola (2012), 91.5% of the self-selected sad music contained lyrics, which could be a potential limitation to the study. This is because Brattico et al. (2011) were able to use fMRI scans to conclude that lyrics are an important factor in inducing feelings in music (Brattico et al.). Therefore, this could mean that a sad melody is not necessarily correlated with sad emotions, but rather the gloomy lyrics that allow sadness to be induced.

Additionally, sadness induced by music can form negative behaviours and thus result in adverse consequences for society. Garrido et al. (2017) discovered that sad music can negatively impact individuals and groups of people who are diagnosed with depression by intensifying their negative emotions. The study also suggests that, after listening to sad music, individuals–particularly depressed individuals with maladaptive coping styles–have an increased tendency to engage in group rumination. This is mainly done to help cope with the negative thoughts and memories that arise from sad music. These ruminative desires are especially prevalent in groups, as music allows the collective sharing of negative emotions, which can exaggerate maladaptive thought patterns (Garrido et al.). The fact that coping styles and mental disorders play a role in the effects of music shows that biological factors also play a significant role in determining the consequences of music listening. Moreover, Garrido et al. (2017) also show the potential dangers that could arise from listening to sad genres of music. Thus, this highlights how sad genres of music can lead to negative influences on individuals and societies.

(d) Influences of Music on Misogyny

Certain genres of music can provoke misogynistic behaviours, attitudes, or views among individuals. Thus, in this subsection, the music contexts and conditions that perpetuate misogyny will be investigated.

Barongan & Hall (1995) conducted an investigation into whether rap music with misogynistic lyrics is linked to misogynistic views or sexual aggression. It was discovered that the men who listened to misogynous rap music were 23% more likely to decide on showing sexual-violent or assaultive film vignettes rather than a neutral vignette to a female confederate compared to men who listened to rap music that did not have misogynous lyrics (Barongan and Hall). These findings show how lyrics in music that surround a particular theme can influence the listeners to internalize the same theme. This can demonstrate the correlation between listening to misogynistic music genres and the display of misogynistic behaviours.

Additional literature supports findings that misogynistic song lyrics can correlate to misogynistic views, but it also demonstrates how such lyrics can increase aggressive behaviour. According to Fischer & Greitemeyer (2006), men who were exposed to misogynistic music administered more hot chilli sauce–which is an act of violence and aggression–to a female confederate compared to men who listened to music that does not have misogynistic lyrics. Additionally, men who listened to misogynistic music also ascribe women with more negative characteristics than those who listened to neutral music. In the same study, the findings are seen to also apply to women, as women who listened to male-hating songs acted more violently towards men than women who listened to neutral music (Fischer and Greitemeyer). This shows how misogynistic song lyrics can provoke changes in both the cognition and behaviour of men towards women. Moreover, this can also indicate that when individuals listen to songs that contain negative lyrics of the opposite sex, the listener tends to display distaste regardless of the sex of the listener, showing that these effects are universal.

On a neurological level, research from scholars has proposed that listening to music with negative misogynistic content can activate brain regions involved with pleasure. In Parker (2014), it was proposed that misogynistic lyrics can trigger dopamine release in some listeners, thus evoking emotionally pleasurable feelings. As a result, listeners may begin to habitually choose to listen to songs with misogynistic lyrics over time, which can encourage shifts in perspective, actions, and attitudes, and thus result in listeners mimicking misogynistic behaviours (Parker).

(e) Influences on Torture

Previously, there have been cases where music was reportedly used as a form of psychological torture. In this subsection, the means of using music as a means to harm others will be explored, alongside the conditions that allow music to be classified as torture.

Historically, music torture was evident in Greek prison camps, the War on Terror in 2001, Nazi concentration camps, and during the abuse of slaves in the United States (Hirsch). Cusick (2008) highlights that music torture's few main purposes are to interfere with prisoners' ability to form coherent thoughts, to disrupt prisoners' ability to understand the concept of time, and to overwhelm prisoners with sound. Above all, the primary intention of using music torture during detention camps is to withdraw prisoners from their sense of reality (Cusick).

Tortuous music can be classified by a range of characteristics, as it varies from the volume and duration of the noise exposure to the external factors which the music is listened to. When the Greek military Junta ruled Greece, music was frequently used as an 'instrument of terror', where music was played at extremely high volumes for prolonged periods of time (Papaeti). Aside from loud and repetitive music, literature also shows that when music is accompanied by various negative contexts, conditions, and practices, it could be a determinant on whether it constitutes a form of torture. Literature from scholars shows that music torture also occurs when individuals are subject to abuse, punishments, humiliation, and inhuman acts while listening to music, because this can result in psychological and physical trauma (Ma). Following

the principles of classical conditioning, which believes that learning is established over time due to association, individuals can develop psychological trauma to music. For learning to happen in classical conditioning, a neutral stimulus (whether it's an event, an object, or an individual) is paired with either a pleasant or unpleasant outcome; as a result, the individual may develop associations between the stimulus and the outcome, which urges them to actively seek out or avoid the stimulus depending on whether the outcome is pleasurable or not (Hermann and Sperl). According to Eelen (2018), classical conditioning can explain how traumatic mechanisms are linked to psychological distress and post-traumatic stress disorder (PTSD). This is because when music–which acts as a neutral stimulus–is paired with abuse and torture, the victim may associate music with the negative emotions experienced during the torture. Consequently, the victim may face unpleasant emotional and physical responses in response to music (Eelen). This could show how exposure to music torture may lead to victims associating music with abuse, hence resulting in long-term fear towards music.

According to Grant (2014), there are five pathways to using music as a form of torture. First, the "Sensory Deprivation Pathway" is when victims are stripped of their ability to interact and engage with their senses; in this pathway, music is used to disorient, distress, and deprive victims of their surroundings. Second, the "Military Tradition Pathway" refers to when music is used in military contexts, such as concentration camps, to force victims into producing music. Third, the "Political Communication Pathway" involves victims being coerced into listening to politically charged music; the purpose of this is to indoctrinate the victims' minds through imposing certain political ideologies by using music as a form of propaganda. Fourth, the "Humiliation Pathway" is when music is used as a tool for mockery and humiliation, as victims are forced to listen to music that is culturally offensive, unpleasant, or mentally exhausting. This pathway aims to use music to evoke feelings that undermine the victim's morals and identity, thus causing feelings of shame and powerlessness. Lastly, the fifth pathway is the "Power Performance Pathway", which is when music is used as a form of authority and dominance by using music as a form of control over victims (Grant).

Moreover, torture–even in the form of music–can result in long-lasting psychological consequences. Liddell et al. (2022) conducted a series of fMRI scans and were able to conclude that torture exposure altered the activity in the left central executive network, reduced the connectivity between core intrinsic brain networks, and reduced grey matter (Liddell et al.). Changes in activity in the left central executive network (CEN) can result in impaired behavioral regulation and self-control, which can lead to difficulties with decision making, organizing information, and cognition (Weiland et al.). Additionally, reduced connectivity between core intrinsic brain regions is correlated with detrimental impacts on individuals' cognition, emotion, and behaviour. According to Filippi et al. (2017), the core intrinsic brain regions are made up of the CEN, default mode network (DMN), and salience network (SN), which are crucial areas of the brain that manage cognition, emotion, and behaviour. Thus, reduced connectivity between these regions can disrupt the brain's ability to switch between internal thoughts that are managed by the DMN and goal-directed processing by the CEN, which can overall lead to slower

processing speed, impaired memory, and cognitive decline. These traits are also evident in patients with neurodegenerative diseases and brain injuries, such as Alzheimer's disease (Filippi et al.). This illustrates how using music as torture could potentially lead to long-lasting psychological disorders.

Conclusion

In conclusion, music can be both beneficial and harmful to individuals and societies, depending on the musical context and individual differences in music listening. This review examines the plethora of positive influences that music can bring for sleep, emotional processing, and neurological disorders, whilst also highlighting the role of music genres, mental states, and individual aspects in determining the factors that enable music to be beneficial. In particular, Section 2 of this paper delves into the beneficial aspects of music listening, which shows that music listening can evoke internal feelings (such as causing a feeling of power that can help with emotional processing). Moreover, this paper highlights how calm genres of music are generally seen to be beneficial in a multitude of aspects, such as sleep and emotional processing. Furthermore, as exemplified in Section 3 of this review, the harmful aspects of music listening on our neural correlates, addiction, dependence, negative emotions, and misogyny were also investigated. This section shows how lyrics with negative connotations can influence individuals to display behaviors such as addiction, misogyny, and sadness. Overall, some important features of music that readers can take from this paper are that the influence of music is not polarized – there is no definite effect that will take place following music listening. If used moderately and in healthy ways, music can serve as a neurologically beneficial tool, as evidenced in Section 2, where research supports the idea that music can help patients with Alzheimer's Disease. On the contrary, it's also important for readers to acknowledge that all forms of music can be abused if listened to in extreme musical contexts, as evident in Section 3 of this paper, which shows how music addictions can be formed. Overall, this review has shed light on the importance of understanding how to utilize music in different environmental and societal contexts.

Although there is a number of experimental data that illustrates the function of music on sleep, neurodegeneration, and emotional processing, existing literature seems to largely neglect the negative functions of music on neural correlates, individual actions, and crowd behaviour. This is a large limitation of this review because there is a scarce number of experiments that explore the direct link between music and various elements holistically. Thus, future research can focus on examining whether there is a true correlation between music and addiction. Despite existing papers showing that music stimulates similar regions of the brain as addictive behaviours, there are minimal empirical papers that establish the relationship, which could also be a potential route for future exploration. Moreover, further efforts can be made to understand the connection between sadness and music listening; for example, future studies can aim to determine whether sadness induced by music is due to the sorrowful melody or the miserable lyrics. Another future direction could be to understand the direct link between music, torture, and neural correlates. This is because there is a negligible number of empirical papers that explore how music is used as a form of torture and its long-term implications.

Works Cited

Barongan, Christy, and Gordon C. Nagayama Hall. 'The Influence Of Misogynous Rap Music On Sexual Aggression Against Women'. Psychology of Women Quarterly, vol. 19, no. 2, June 1995, pp. 195–207. SAGE Journals, https://doi.org/10.1111/j.1471-6402.1995.tb00287.x.

Bastioli, Guendalina, et al. 'Voluntary Exercise Boosts Striatal Dopamine Release: Evidence for the Necessary and Sufficient Role of BDNF | Journal of Neuroscience'. The Journal Of Neuroscience, 2022, https://www.jneurosci.org/content/42/23/4725.

Benilova, Iryna, et al. 'The Toxic Aβ Oligomer and Alzheimer's Disease: An Emperor in Need of Clothes'. Nature Neuroscience, vol. 15, no. 3, Jan. 2012, pp. 349–57. PubMed, https://doi.org/10.1038/nn.3028.

Benjafield, Adam V., et al. 'Estimation of the Global Prevalence and Burden of Insomnia: A Systematic Literature Review-Based Analysis'. Sleep Medicine Reviews, vol. 82, Aug. 2025, p. 102121. ScienceDirect, https://doi.org/10.1016/j.smrv.2025.102121.

Bigliassi, Marcelo, et al. 'How Motivational and Calm Music May Affect the Prefrontal Cortex Area and Emotional Responses: A Functional Near-Infrared Spectroscopy (fNIRS) Study'. Perceptual and Motor Skills, vol. 120, no. 1, Feb. 2015, pp. 202–18. SAGE Journals, https://doi.org/10.2466/27.24.PMS.120v12x5.

Bleibel, Malak, et al. 'The Effect of Music Therapy on Cognitive Functions in Patients with Alzheimer's Disease: A Systematic Review of Randomized Controlled Trials'. Alzheimer's Research & Therapy, vol. 15, Mar. 2023, p. 65. PubMed Central, https://doi.org/10.1186/s13195-023-01214-9.

Bonnie, Richard J., et al. 'Alcohol in the Media: Drinking Portrayals, Alcohol Advertising, and Alcohol Consumption Among Youth'. Reducing Underage Drinking: A Collective Responsibility, National Academies Press (US), 2004. www.ncbi.nlm.nih.gov, https://www.ncbi.nlm.nih.gov/books/NBK37586/.

Bragança, Guilherme Francisco F., et al. 'Synesthesia and Music Perception'. Dementia & Neuropsychologia, vol. 9, no. 1, Mar. 2015, pp. 16–23. DOI.org (Crossref), https://doi.org/10.1590/S1980-57642015DN91000004.

Brattico, Elvira, et al. 'A Functional MRI Study of Happy and Sad Emotions in Music with and without Lyrics'. Frontiers in Psychology, vol. 2, 2011, p. 308. PubMed, https://doi.org/10.3389/fpsyg.2011.00308.

Brodal, Hans P., et al. 'Listening to Rhythmic Music Reduces Connectivity within the Basal Ganglia and the Reward System'. Frontiers in Neuroscience, vol. 11, Mar. 2017, p. 153. PubMed Central, https://doi.org/10.3389/fnins.2017.00153.

Chen, Meng-Jinn, et al. 'Music, Substance Use, and Aggression'. Journal of Studies on Alcohol, vol. 67, no. 3, May 2006, pp. 373–81. PubMed, https://doi.org/10.15288/jsa.2006.67.373.

Cockrill, Antje, et al. 'Music Consumption: Lifestyle Choice or Addiction'. Journal of Retailing and Consumer Services, The Future of Music Retailing, vol. 18, no. 2, Mar. 2011, pp. 160–66. ScienceDirect, https://doi.org/10.1016/j.jretconser.2010.12.003.

Cordi, Maren Jasmin, et al. ‘Effects of Relaxing Music on Healthy Sleep’. Scientific Reports, vol. 9, no. 1, June 2019, p. 9079. www.nature.com, https://doi.org/10.1038/s41598-019-45608-y.
———. ‘Effects of Relaxing Music on Healthy Sleep’. Scientific Reports, vol. 9, no. 1, June 2019, p. 9079. www.nature.com, https://doi.org/10.1038/s41598-019-45608-y.
Cusick, Suzanne G. Musicology, Torture, Repair. 2008. Zotero.
Eelen, Paul. ‘Classical Conditioning: Classical Yet Modern’. Psychologica Belgica, vol. 58, no. 1, 2018, pp. 196–211. PubMed Central, https://doi.org/10.5334/pb.451.
EL HAJ, Mohamad, et al. ‘Autobiographical Memory Decline in Alzheimer’s Disease’. Ageing Research Reviews, vol. 27, May 2016, pp. 15–22. PubMed Central, https://doi.org/10.1016/j.arr.2016.02.002.
Fabbri, Marco, et al. ‘Music Cue during Slow Wave Sleep Improves Visuospatial Memory Consolidation’. Journal of Sleep Research, vol. 34, no. 3, June 2025, p. e14372. PubMed, https://doi.org/10.1111/jsr.14372.
FakhrHosseini, S. Maryam, and Myounghoon Jeon. ‘How Do Angry Drivers Respond to Emotional Music? A Comprehensive Perspective on Assessing Emotion’. Journal on Multimodal User Interfaces, vol. 13, no. 2, June 2019, pp. 137–50. Springer Link, https://doi.org/10.1007/s12193-019-00300-3.
Filippi, Massimo, et al. ‘Brain Network Connectivity Differs in Early-Onset Neurodegenerative Dementia’. Neurology, vol. 89, no. 17, Oct. 2017, pp. 1764–72. PubMed Central, https://doi.org/10.1212/WNL.0000000000004577.
Fischer, Peter, and Tobias Greitemeyer. ‘Music and Aggression: The Impact of Sexual-Aggressive Song Lyrics on Aggression-Related Thoughts, Emotions, and Behavior Toward the Same and the Opposite Sex’. Personality and Social Psychology Bulletin, vol. 32, no. 9, Sept. 2006, pp. 1165–76. SAGE Journals, https://doi.org/10.1177/0146167206288670.
Gao, Lixia, et al. ‘Entrainment of Slow Oscillations of Auditory Thalamic Neurons by Repetitive Sound Stimuli’. The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, vol. 29, no. 18, May 2009, pp. 6013–21. PubMed, https://doi.org/10.1523/JNEUROSCI.5733-08.2009.
Garrido, Sandra, et al. ‘Group Rumination: Social Interactions Around Music in People with Depression’. Frontiers in Psychology, vol. 8, Apr. 2017. Frontiers, https://doi.org/10.3389/fpsyg.2017.00490.
Giordano, Filippo, et al. ‘Receptive Music Therapy to Reduce Stress and Improve Wellbeing in Italian Clinical Staff Involved in COVID-19 Pandemic: A Preliminary Study’. The Arts in Psychotherapy, vol. 70, Sept. 2020, p. 101688. PubMed Central, https://doi.org/10.1016/j.aip.2020.101688.
Glotzbach, Evelyn, et al. ‘Prefrontal Brain Activation During Emotional Processing: A Functional Near Infrared Spectroscopy Study (fNIRS)’. The Open Neuroimaging Journal,

vol. 5, May 2011, pp. 33–39. PubMed Central, https://doi.org/10.2174/1874440001105010033.

Grant, Morag Josephine. Pathways to Music Torture. 2014. Zotero.

Greitemeyer, Tobias. ‘Exposure to Music with Prosocial Lyrics Reduces Aggression: First Evidence and Test of the Underlying Mechanism’. Journal of Experimental Social Psychology, vol. 47, no. 1, Jan. 2011, pp. 28–36. ScienceDirect, https://doi.org/10.1016/j.jesp.2010.08.005.

Hermann, Christiane, and Matthias F. J. Sperl. ‘Classical Conditioning’. Handbook of Clinical Child Psychology: Integrating Theory and Research into Practice, Springer Nature Switzerland AG, 2023, pp. 425–57. Autism and Child Psychopathology Series. APA PsycNet, https://doi.org/10.1007/978-3-031-24926-6_21.

Hirsch, Lily E. ‘Musical Torture’. Insulting Music: A Lexicon of Insult in Music, edited by Lily E. Hirsch, Springer International Publishing, 2022, pp. 171–79. Springer Link, https://doi.org/10.1007/978-3-031-16466-8_14.

Hu, Shun-Ping, et al. ‘Effect of Sleep Ambient Music on Sleep Quality and Mental Health in College Students: A Self-Controlled Study’. Frontiers in Psychology, vol. 14, July 2023. Frontiers, https://doi.org/10.3389/fpsyg.2023.1171939.

Ito, Erika, et al. ‘The Effect of Music-Based Intervention on General Cognitive and Executive Functions, and Episodic Memory in People with Mild Cognitive Impairment and Dementia: A Systematic Review and Meta-Analysis of Recent Randomized Controlled Trials’. Healthcare, vol. 10, no. 8, Aug. 2022, p. 1462. PubMed Central, https://doi.org/10.3390/healthcare10081462.

Jang, Grace, and Philip A. Kragel. ‘Understanding Human Amygdala Function with Artificial Neural Networks | Journal of Neuroscience’. The Journal Of Neuroscience, 2025, https://www.jneurosci.org/content/45/18/e1436242025.

Jauhar, S., et al. ‘Brain Activations Associated with Anticipation and Delivery of Monetary Reward: A Systematic Review and Meta-Analysis of fMRI Studies’. PLOS ONE, vol. 16, no. 8, Aug. 2021, p. e0255292. PLoS Journals, https://doi.org/10.1371/journal.pone.0255292.

Jiménez-Palomares, María, et al. ‘Benefits of Music Therapy in the Cognitive Impairments of Alzheimer’s-Type Dementia: A Systematic Review’. Journal of Clinical Medicine, vol. 13, no. 7, Apr. 2024, p. 2042. PubMed, https://doi.org/10.3390/jcm13072042.

Koelsch, Stefan. ‘Brain Correlates of Music-Evoked Emotions’. Nature Reviews Neuroscience, vol. 15, no. 3, Mar. 2014, pp. 170–80. DOI.org (Crossref), https://doi.org/10.1038/nrn3666.

Koob, George F., and Nora D. Volkow. ‘Neurocircuitry of Addiction’. Neuropsychopharmacology, vol. 35, no. 1, Jan. 2010, pp. 217–38. www.nature.com, https://doi.org/10.1038/npp.2009.110.

Lachance, Kelly-Ann, et al. ‘Listening Habits and Subjective Effects of Background Music in Young Adults with and without ADHD’. Frontiers in Psychology, vol. 15, Jan. 2025. Frontiers, https://doi.org/10.3389/fpsyg.2024.1508181.

Liddell, Belinda J., et al. ‘Torture Exposure and the Functional Brain: Investigating Disruptions to Intrinsic Network Connectivity Using Resting State fMRI’. Translational Psychiatry, vol. 12, Jan. 2022, p. 37. PubMed Central, https://doi.org/10.1038/s41398-022-01795-3.

Ma, M J Grant. The Illogical Logic of Music Torture. vol. 23, 2013. Zotero.

Massimini, Marcello, et al. ‘The Sleep Slow Oscillation as a Traveling Wave’. The Journal of Neuroscience, vol. 24, no. 31, Aug. 2004, pp. 6862–70. PubMed Central, https://doi.org/10.1523/JNEUROSCI.1318-04.2004.

Matziorinis, Anna Maria, and Stefan Koelsch. ‘The Promise of Music Therapy for Alzheimer’s Disease: A Review’. Annals of the New York Academy of Sciences, vol. 1516, no. 1, Oct. 2022, pp. 11–17. PubMed Central, https://doi.org/10.1111/nyas.14864.

Mulder, Juul, et al. ‘Is It the Music? Peer Substance Use as a Mediator of the Link between Music Preferences and Adolescent Substance Use’. Journal of Adolescence, vol. 33, no. 3, June 2010, pp. 387–94. DOI.org (Crossref), https://doi.org/10.1016/j.adolescence.2009.09.001.

Papaeti, Anna. ‘Music, Torture, Testimony: Reopening the Case of the Greek Junta (1967–1974)’. The World of Music, vol. 2, no. 1, 2013, pp. 67–89. JSTOR.

Parker, Louisa Antwanett. ‘Role of Misogynous Rap Music on African American Married Millennials’. General Psychology, 2014. Zotero.

Rentfrow, Peter J., and Samuel D. Gosling. ‘Message in a Ballad: The Role of Music Preferences in Interpersonal Perception’. Psychological Science [United Kingdom], vol. 17, no. 3, 2006, pp. 236–42. APA PsycNet, https://doi.org/10.1111/j.1467-9280.2006.01691.x.

Schlaug, Gottfried. ‘Part VI Introduction’. Annals of the New York Academy of Sciences, vol. 1169, July 2009, pp. 372–73. PubMed Central, https://doi.org/10.1111/j.1749-6632.2009.04869.x.

Schmuziger, Nicolas, et al. ‘Is There Addiction to Loud Music? Findings in a Group of Non-Professional Pop/Rock Musicians’. Audiology Research, vol. 2, no. 1, July 2012, p. e11. PubMed Central, https://doi.org/10.4081/audiores.2012.e11.

Seger, Carol A., and Brian J. Spiering. ‘A Critical Review of Habit Learning and the Basal Ganglia’. Frontiers in Systems Neuroscience, vol. 5, Aug. 2011. Frontiers, https://doi.org/10.3389/fnsys.2011.00066.

Sharman, Leah, and Genevieve A. Dingle. ‘Extreme Metal Music and Anger Processing’. Frontiers in Human Neuroscience, vol. 9, May 2015, p. 272. PubMed Central, https://doi.org/10.3389/fnhum.2015.00272.

Sivils, Andy, et al. ‘Striatonigrostriatal Spirals in Addiction’. Frontiers in Neural Circuits, vol. 15, Dec. 2021. Frontiers, https://doi.org/10.3389/fncir.2021.803501.

T. Zaatar, Muriel, et al. ‘The Transformative Power of Music: Insights into Neuroplasticity, Health, and Disease’. Brain, Behavior, & Immunity - Health, vol. 35, Dec. 2023, p. 100716. PubMed Central, https://doi.org/10.1016/j.bbih.2023.100716.

Vuoskoski, Jonna K., and Tuomas Eerola. ‘Can Sad Music Really Make You Sad? Indirect Measures of Affective States Induced by Music and Autobiographical Memories.’ Psychology of Aesthetics, Creativity, and the Arts, vol. 6, no. 3, Aug. 2012, pp. 204–13. DOI.org (Crossref), https://doi.org/10.1037/a0026937.

Watamura, Naoto, et al. ‘The Dopaminergic System Promotes Neprilysin-Mediated Degradation of Amyloid-β in the Brain’. Science Signaling, vol. 17, no. 848, Aug. 2024, p. eadk1822. science.org (Atypon), https://doi.org/10.1126/scisignal.adk1822.

Weiland, Barbara J., et al. ‘Reduced Left Executive Network Functional Connectivity Is Associated With Alcohol Use Disorders’. Alcoholism, Clinical and Experimental Research, vol. 38, no. 9, Sept. 2014, pp. 2445–53. PubMed Central, https://doi.org/10.1111/acer.12505.

Weissman, David G., and Wendy Berry Mendes. ‘Correlation of Sympathetic and Parasympathetic Nervous System Activity during Rest and Acute Stress Tasks’. International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology, vol. 162, Apr. 2021, pp. 60–68. PubMed Central, https://doi.org/10.1016/j.ijpsycho.2021.01.015.

Worley, Susan L. ‘The Extraordinary Importance of Sleep: The Detrimental Effects of Inadequate Sleep on Health and Public Safety Drive an Explosion of Sleep Research’. Pharmacy and Therapeutics, vol. 43, no. 12, Dec. 2018, p. 758. pmc.ncbi.nlm.nih.gov.

How the Vietnam War Affected the Identity and Belonging of Vietnamese People at Home and Abroad Across Generations By Mya Nguyen

Abstract

This paper explores how the Vietnam War and its aftermath have shaped Vietnamese identity and nationalism across generations, both domestically and in the diaspora. Drawing on historical context, archival material, literature, and interviews with a diverse group of Vietnamese people domestically and abroad, I analyze how war-related policies, such as forced migration, re-education camps, and discrimination produced conditions of poverty, displacement, and emigration. These factors continue to further impact identity formation today. While the first generation preserved culture and language as markers of belonging, the second generation developed hybrid identities that balanced host-country integration with cultural pride. For the third generation, particularly those attending international schools in Vietnam, identity has become even more fluid, marked by tensions between feeling "less Vietnamese," negotiating language loss, and redefining what it means to belong through food, familial ties, and lived experience. I argue that Vietnamese identity is hybrid and constantly changing due to historical memory, migration, globalization, and the political-economic structures of the Vietnamese state. Ultimately, this research demonstrates how war and its legacies reverberate beyond the battlefield, influencing not only national belonging but also Vietnam's future in a globalized world.

Introduction

The individual and familial experiences of the Vietnam War continue to shape Vietnamese identity and nationalism across generations. With each new generation, identity continues to evolve, impacted by time, the blending of cultures, and a developing Vietnam. Understanding the variety of perspectives of Vietnamese individuals is vital to understanding how the nation of Vietnam's voice and place in this world might change. As an increasing number of Vietnamese are gaining influence domestically and abroad, these demographic changes may affect the nation's expanding impact in international affairs. Personally, the Vietnam War and its parties shaped the early lives of my parents, who came from opposing sides of the conflict, instilling the different values that they have ingrained in me today. Furthermore, this research is significant as I have grown up, despite living in Vietnam, navigating two distinct cultural environments: a traditional Vietnamese identity and a more globalized Vietnamese perspective that seems to be emerging in younger generations. Many Vietnamese who fled and immigrated to different countries during and after the war have similar experiences, begging the question: how has the Vietnam War, time, globalization, and diaspora influenced national belonging? What might these changing identities mean for Vietnam's cultural cohesion and political future? By examining these generational shifts through ethnographic interviews and bibliographical meta-analyses, this paper explores how outcomes of and proximity to the war

continue to affect the personal and national identities and the language of Vietnamese people at home and abroad.

Historical Context

To understand the effects of the Vietnam War on Vietnamese identity and language, we must first understand what occurred during the conflict. The historical context section of this research paper focuses primarily on the events that preceded the war, rather than recounting events of the actual war. These events better demonstrate the instability and forces affecting the Vietnamese government, which led to a struggling economy, famine, and discrimination. This led to differences in sentiment towards the government–depending on who had priority in receiving food and jobs– and emigration, and thus identity and belonging of people within Vietnam and the diasporic communities. After French colonial rule in French Indochina, spanning from the 1800s, Japan ousted the French in 1945 following five years of shared occupation of Hanoi, Vietnam's capitol. In the same year, the United States detonated two atomic bombs on Hiroshima and Nagasaki, marking the end of World War II and Japan's surrender. In the power vacuum that followed, control of Hanoi, passed from Japan to emperor Bao Dai in a short-lived Vietnamese constitutional monarchy to Ho Chi Minh, the leader of the northern Vietnamese guerilla organization, and the Viet Minh, who declared independence as the Democratic Republic of Vietnam (hereafter referred to as North Vietnam) (Vietnamese Heritage Museum). This organization, composed mostly of communists, fought for Vietnamese independence against foreign forces.

Shortly thereafter, the French seized Southern Vietnam and the First Indochina War began (1946 to 1954). The decisive win for the Viet Minh in the Battle of Dien Bien Phu in May 1954 initiated a peace agreement between the two parties, named the Geneva Accords of July 1954. The agreement concluded that North Vietnam was to be ruled by Ho Chi Minh; South Vietnam or the State of Vietnam was to be ruled by the French; and the different nations were to be split at the 17th parallel by a Demilitarized Zone, resulting in immediate ceasefire. Elections between the two nations would be held in 1956, to reunite the country.

However, the last agreement would never transpire as Ngo Dinh Diem, a US-backed Southern Vietnamese prime minister who came into power in 1995, would then rename the State of Vietnam into the Republic of Vietnam, opposing reunification. Having been previously captured by Ho Chi Minh, Diem was a fervent anti-communist. In response, in 1960, North Vietnam established the National Liberation Front, otherwise known as the Viet Cong, to defeat Ngo Dinh Diem and invade South Vietnam. In South Vietnam, although having successfully integrated hundreds of thousands of Northern Vietnamese refugees, Diem became unpopular, with his discrimination against Buddhists in a majority-Buddhist nation, "heavy-handed and ineffective" military tactics, and overusing rule-by-law strategies, detaining all who he felt threatened his power. Accordingly, US President John F. Kennedy supported a military coup d'etat in 1963, which passed control to the military junta and then to the unreliable and unstable dictator Nguyen Khanh. In 1965, the United States deployed American troops in Operation

Rolling Thunder to directly support South Vietnam, along with South Korean troops. After 10 years of conflict, the war drew to an end in 1975 with the fall of Saigon, when the North Vietnamese tanks rolled through the gates of the Independence Palace. According to family accounts, my mother was nearby, witnessing this historical moment, underscoring the war's immediacy in personal memory.

The war concluded with reuniting the two Vietnams and renaming it the Socialist Republic of Vietnam, which has lasted since. The conflict mirrored broader Cold War tensions, serving as a proxy struggle among major powers such as the Soviet Union, China, the United States, and South Korea. The Vietnam War was a representation of the relations and sentiment between world powers during the Cold War, transforming from an ideological civil conflict into becoming a proxy war.

U.S. Secretary of State Dean Acheson, in a meeting on May 8, 1950, noted that the United States believed that the Soviet's communist ideology was mutually exclusive with nationalism and democracy. This justified America's involvement in the war, which, ultimately, was about Vietnamese people taking back power over Vietnam (Acheson). For the Soviet Union and People's Republic of China, support for North Vietnam and their success in spreading communist ideology represented their competition for influence in Southeast Asia. A 1965 CIA report noted that that Liu Ning, a senior Chinese Communist Party Spokesman presumably accused the Soviet Union of "making gestures of support for Vietnam" and devising "little stunts" while simultaneously secretly colluding with the US to promote "peace talks," insinuating the violation of their agreements with North Vietnam. Similarly, the same document reported that Moscow accused China of being "willing to sacrifice the interests of [North Vietnam] in its drive to capture leadership of the world Communist movement and to discredit Soviet policy," and warned against "imitating those inclined toward adventurism," as they provide military support to North Vietnam without inciting a conflict with the United States. This indicated that the Vietnam War, in addition to symbolizing the conflict between the United States and the Soviet Union, also mirrored the tension between the two Communist powers, sharpening the "already bitter Sino-Soviet competition" (CIA). For South Korean President Pak Chong Hui, aiding the United States in the Vietnam War provided many benefits including increasing his legitimacy with the South Korean populace after a controversial rise to power and economic growth. South Korea made over $300 trillion, according to The Korean National Chamber of Commerce. Involvement in the war also prevented US disengagement after the end of the Korean Civil War in 1953. Specifically, South Korea received "economical and military assistance" in the Brown Memorandum. Pak Chong Hiu also believed in South Vietnam's freedom against communist powers, which paralleled South Korea's fight against the North Korean leadership's dictator and Leninist ideology, justifying involvement in the war based on ideological differences (Sears; Kim).

Beyond being the product of meddling world powers, the Vietnam War started with the "stunning defeat and departure" of the French after over 1000 years of French colonial rule, which had left a "sudden, and nearly disastrous political vacuum," which had prevented the

creation of a consolidated government (Latham).

In 1975, Vietnam and the Soviet Union agreed on the "coordination" of "economic plans" but indicated its intentions for relations with other countries, including those in the West and China (Keleman). However, with trade embargoes from the United States and its allies, Vietnam became more economically and militarily dependent on the Soviet Union, joining COMECON, an organization that coordinated "the economic development of the eastern European countries belonging to the Soviet bloc," in 1978 (Britannica). This military assistance allowed Vietnam to retaliate against Khmer Rouge attacks along Vietnam's south western border with Kampuchea, now Cambodia. In January 1979, Vietnam overthrew and replaced the Khmer Rouge, which was an ally of China, with a pro-Hanoi government that "could be counted on to support Soviet policy." This furthered Soviet-Vietnamese relations and allowed the Soviet Union to increase its influence in Southeast Asia. After the fall of the Soviet Union, Russia and Vietnam continue to have economic and military relations (Horn). In response to Vietnam's actions against an ally, China briefly attacked Vietnam's north border in 1979. These two conflicts constituted the Third Indochina War.

During the Vietnam War, the U.S. military used more than 50 million liters of Agent Orange, an herbicide mixture called dioxin, in Operation Ranch Hand to defoliate and clear the jungle. Agent Orange was deployed in order to expose Viet Cong locations (Britannica). The World Health Organization classified TCDD, a form of dioxin, as a human carcinogen, meaning it can cause cancer. A Vietnamese government-owned publishing house, the Vietnam News Agency (VNA) estimates that 4.8 million Vietnamese were exposed to Agent Orange, with over 3 million "victims" presumably fatalities. Recently, the same source estimates that 90% of people affected by Agent Orange are unemployed, and 70% of affected families are impoverished. Furthermore, American, Korean, and New Zealand soldiers were also exposed to Agent Orange and suffered its effects (VNA).

In addition to the detrimental effects to human lives, Agent Orange may have negatively affected the environment and wildlife. In fact, Agent Orange "immediately destroyed natural ecosystems by breaking ecological structure and nutrient web, resulting in pollution of environment and deteriorations of habitats and declination of biodiversity." Though all of the ecological effects can not be attributed to Agent Orange alone, as other factors such as bombing and other methods of habitat destruction may decrease biodiversity and have environmental effects (Dang et Ho). However, the resulting pollution may have persisting effects to the livelihoods of farmers and fishers in South Vietnam today, although specific statistical data is unclear.

After the war, Vietnam faced a period of famine, where at the time, the Vietnamese government attributed to factors beyond its control: drought; floods; pests; and lack of fishing boats, stolen by deserters. Additionally, Mai Luong, the then vice director of the Agricultural Ministry's international cooperation department further cites war-related factors– from both the Vietnamese-American War and the Sino-Vietnamese war of 1979, such as damage to irrigation

systems, killings of livestock, and destruction of thousands of acres of harvestable land (Chapman).

However, other sources ascribed this famine to how, during the war, both North and South Vietnam relied heavily on food imports from their respective allies. Desbaratas states "one-third of the pre-1975 cultivated acreage… and total domestic production of foodstuffs had declined to 11.6 million tons of grain equivalent." Regardless, to illustrate the country's dire situation, Luong stated that Vietnam, in 1979, needed 3.8 million tons more of food crops than it was producing, which the Soviet Union and other nations including India and Indonesia were expected to help. The Soviet Union supplied 1.5 million tons of food, leaving yet a 2.3 million ton deficit (Chapman). In 2015, the Vietnamese news agency Tuoi Tre, which is associated with the Ho Chi Minh Communist Youth Union, stated that this food shortage was "later attributed to mistakes in state management." Specifically, the collectivization of agriculture, decreased incentives to produce more food, and caused farmers opposed to the new regime to protest by only producing enough food to sustain their families (Tuoi Tre). This seems to correspond with what Vietnamese people now believe, as MB, a member of the first generation diaspora, recounts that "each person only got 9kg of rice." When rice became scarce, the government would supplement it with "bobo—a kind of grain, now mostly used as animal feed" or sweet potatoes.

Moreover, post-war, the unemployment rate skyrocketed, which then became Vietnam's "biggest immediate problem," in the 1980s. Specifically, 8 million people were unemployed, with 1.5 million of them in Saigon alone (Desbarats). All of this contributed to the poverty in Vietnam, where 70% of its citizens were legally impoverished (Goscha 399).

Furthermore, this was exacerbated by the state of Vietnam's economy post-war. The Vietnamese government implemented the socialist centrally planned economic system in the south, two years after official reunification, in 1978. It was modeled off of Stalin's and Zedong's systems in their respective countries. This change only came about as a reaction to the biggest ethnic minority in Vietnam, the Chinese community or the "Hoa", trading with farmers, essentially, taking away rice that belonged to the government (Desbarats). Similarly, the Vietnamese government abolished private land ownership, making amendments to the constitution in 1980, as well as nationalizing businesses (Hansen). This disproportionately affected the Hoa community, as many owned businesses and were artisans.

The Hoa who owned businesses had three options: keep their businesses, but work as "state employees"; find new jobs, commonly as farmers; or leave Vietnam (Desbarats). Moreover, there were periods where mainly the Hoa and those who had forged papers to show Chinese-descent were encouraged to leave because of government fears of political opposition, support for People's Republic of China. From April to June 1978 alone, 90,000-100,000 Hoa fled to China. In interviews, those in North Vietnam recalled the Vietnamese government attempting to persuade them to not leave the country. Those who chose to leave the country through official channels had to pay the Vietnamese government, who, thus, gained the wealth of the Hoa community. Although the Vietnamese government implemented semi-legal ways for Hoa who wished to leave to return to China, this exodus was not advantageous for Vietnam because many

Hoa were crucial skilled workers. Additionally, the Vietnamese government treated the Hoa as essentially Vietnamese citizens in an attempt to disencourage loyalty to China. Throughout this period, the emigration of Hoa from Vietnam fluctuated due to external factors. In one Geneva conventions, the countries which received those who left encouraged Vietnam to slow down the exodus. In another, China refused Hoa entry after July 12th 1978, even going as far as to demand Vietnam to take them back (Porter).

In addition to this emigration of people, the Vietnamese government encouraged internal population redistribution, with goals of economic, demographic, internal, and external security– specifically, attacking unemployment, as well as preventing political uprisings. The Vietnamese government created New Economic Zones (NEZs) and New Economic Areas (NEAs), which were zones intended for agricultural development. These zones were often inhospitable and were declared fertile by the government, despite crops never having been cultivated there. The government, who viewed this as a "movement of poor and unemployed city dwellers," moved "voluntary" settlers into those zones, as well as to increase agricultural production and reduce famine. However, the then Provisional Revolutionary Government of the Republic of South Vietnam aimed to move those who the government deemed "a threat to the revolution" away from the cities, "breaking up potential nuclei of urban-based opposition." In Southern Vietnam, the government incentivized citizens to move to those rural areas with a three-month rice supply, later offering nothing, and forcing repatriation to rural villages. Similarly, loyalists were moved to sensitive areas, which posed a security problem, including the Central Highlands, where the Montagnard tribes dwelled, and Saigon. The Vietnamese government encouraged loyal Northerners to move to South Vietnam, where they could "monitor… untrustworthy Southern populations," as the Southern urban middle class "posed a threat" to the Socialist regime. Overall, the Vietnamese government planned to relocate 10 million people by the end of 1999 (Desbarats).

While these policies were framed as efforts to alleviate unemployment and promote rural development, they systematically discriminated against certain social, regional, and ethnic groups. Former officials of the Republic of Vietnam, members of the Southern urban middle class, and those with family ties to anti-communist forces were disproportionately forced into New Economic Zones under the guise of "voluntary" resettlement. The government's classification of these individuals as threats to revolutionary stability justified the relocation of thousands to underdeveloped and inhospitable areas. Southerners were not only stripped of their urban livelihoods but often placed under the surveillance of loyal Northern cadres, reinforcing regional hierarchies and mistrust. These relocations and exclusions reveal how the state's population management strategies were deeply rooted in political and ethnic discrimination, rather than purely economic necessity. Additionally, after the war, the people had "lý lịch," which means background, profile, and more recently, a resume. When applying to government funded universities and jobs, a background check was conducted on the person on whether their parents had worked for the old regime. If they did, they'd have "bad lý lịch," and it would be extremely difficult for them to get that position (Le).

MB, an older Vietnamese person I met while conducting interviews for this project, recounts tales of their students who had fathers and uncles who fought against the current regime, despite being qualified and intelligent, failing to get into public universities. He stated that "universities screened based on political background. No matter how good you were, you couldn't study" certain professions such as "medicine or dentistry." MB–a pseudonym for an older diasporic Vietnamese person who lived through the Vietnam War–attributes this to their familial ties to political opponents. Furthermore, they mention that, because of their history–they had deserted North Vietnam to live in South Vietnam before 1975– and not-as-strong Northern accent, they felt discriminated against for abandoning the regime, which had made them "very angry," and thus has influenced them to move abroad for better opportunities and fairer treatment from the state. Moreover, there was and continues to be censorship and lack of freedom of speech and press in Vietnam, where after the war, the government tried to heavily control aspects of Vietnamese life, such as education and religion, by burning books, silencing teachers, and shutting down churches and religious practices, instead creating a cult of personality around Ho Chi Minh (Asia Pacific Curriculum). Lastly, soldiers or any high ranking officials in the old, South Vietnamese regime were sent to "re-education camps," with those who ranked higher receiving more severe punishments and a longer sentence. My grandfather was an interpreter for foreign troops and he was sentenced to less than six months of re-education. My grandfather has since passed away, so I've been unable to ask him about his experience, and my family has not elaborated about his experience. These camps were often located in inhospitable areas of Vietnam, so the conditions were inhumane. Furthermore, people in these re-education camps endured torture, brainwashing, and slavery, as well as murder. About one million people had some form of "re-education" by the new Vietnamese government (Asia Pacific Curriculum).

Those affected by this discrimination may have differing opinions on the government, which may have affected decisions to move their families abroad, thus impacting the identities of them and their future offspring. For Vietnamese immigrants who were South Vietnamese military officials and political leaders–people against the current regime–and moved to Western countries, such as the United States, they and their families have often adopted anti-communist attitudes. (Koh).

In December 1986, the Vietnamese government significantly changed its economic policies, going from centrally planned to a capitalist-style market economy with little government intervention, which is called Đổi Mới, Vietnamese for renovation. Additionally, this ended the collectivization of agriculture, and overall has resulted in astounding success. Vietnam is now the world's second-largest coffee exporter and third-largest rice exporter, going from a GDP of $26.34 billion in 1986 to $429.72 billion in 2023 (Hanh; Uyen; World Bank Group). Thus, the living conditions and lives of the Vietnamese have significantly improved (Asia Pacific Curriculum).

First-generation Vietnamese refugees fled abroad due to political pressure, such as the previously mentioned re-education camps, forced relocations to NEZs, and lack of basic resources. Often, these people were referred to as "boat people" due to their method of escape:

boats. These refugees often risked starvation, pirates, and storms. Over 250,000 refugees passed through camps in Malaysia alone (UNHRC). These camps, in descending order of amount of Indochinese boat people seeking their first asylum, located in Malaysia, Hong Kong, Indonesia, Thailand, Philippines, Japan, and others, served as mid-way-points to hold people while they acquired documentation or sponsors to settle in other countries (UN High Commissioner for Refugees). By the late 1990s, over 755,000 Vietnamese refugees had been resettled in other countries, while around 81,000 voluntarily returned to Vietnam (UNHRC). The final destinations of resettlement of these people, likewise, included the United States, Australia, Canada, France, the United Kingdom, as well as others (UN High Commissioner for Refugees). Most of the settlers in the mentioned countries originated from South Vietnam, while most settlers in Thailand and East Germany were supporters of liberation movements, such as President Ho Chi Minh's efforts throughout the French and Vietnam wars (Nguyen; Sripana). Regardless of location, resettlement posed numerous challenges, including language barriers, particularly for first generation immigrants, unemployment, and the loss of professional credentials, which limited their economic opportunities and reinforced social isolation (Subramaniam et Rajoo). To support integration, various host countries established resettlement programs, including language classes, employment assistance, and cultural orientation sessions (UC Davis). Despite these supports, the psychological toll of war and displacement persisted. Longitudinal studies show elevated rates of PTSD, depression, and anxiety among refugees even decades after resettlement, particularly among those who endured trauma during migration or imprisonment (Vaage et al).

Identity and Belonging

The conventional approach to understanding the factors that influence one's identity may be ethnicity, citizenship, language, and geographical location. The one I will discuss is the social relationship between those of their host country, the diasporic, and those of their country of origin. Modern technology and globalization has led to the rise of "transmigrants" or people who keep social relations with both their host and home countries (Nguyen). Additionally, place may be conceptualized through "processes of place-making and community formation" (Nguyen).The culmination of this may create a hybrid identity, which Bhabha calls the third space. The third space is fluid and ever-changing, that is different to the original identity and is expressed through one's relationships or interactions in daily life (Hall). This allows marginalized communities and minorities to claim "a part of the cultural space" in their host country, empowering their cultural identity (Yazdiha 36). With this understanding of identity, language does not directly play a role. Instead, language may influence through its impact on the quality or ability to have relationships with coethnics or people of the host culture.

For third-generation Vietnamese international school students, the Vietnam War itself feels like distant history, something more learned than lived. Their understanding often comes secondhand through family stories or classroom conversations rather than personal impact. As one of my interviewees, Naomi Pham explained, "sometimes in class when we talk about it or in movies, I'm like, oh yeah, I think about it, and it's like it's crazy how it happened. But other than

that, not really." Similarly, another interviewee, DK, reflected, he knows "more about the aftermath" and "how society changed after the war." Otherwise, he and his family "don't discuss it directly." Another interviewee, Sam Nguyen, added: "Personally, I don't feel affected by it but hearing enough stories about the war can somewhat help me understand how tough things were." This sense of distance doesn't erase family memory, however. WN, another interviewee, shared: "My mom tells me my grandmother got into a re-education camp during" the war, which is why she thinks they moved to Orange County, California. For others, the war serves as background to how Vietnam is seen today. Another interviewee, Vanessa Kieu, described how she has "a good amount of knowledge on the Vietnam War with learning it from both my family and also in school. Although I will say that it doesn't really have that much of an impact on me. I still have thoughts on its importance and how it has shaped Vietnam today."

For these students, identity is most clearly negotiated through everyday practices and schooling rather than through the Vietnam War itself. Being Vietnamese often means food, family, and pride. WN explained that "things that make me feel Vietnamese are eating Vietnamese food, being Vietnamese is being born here and having family from here and having it be part of your culture." Others echoed that pride, with AT, another interviewee, describing "being Vietnamese means being proud." Yet, the international school setting complicates this sense of belonging. Almost all participants admitted that going to an international school made them feel "less Vietnamese," since it distanced them from public-school peers and from cultural expectations. Naomi Pham noted that after transferring from a Vietnamese public school, she felt that she is "not as educated" so she doesn't feel like she fits in with other public school Vietnamese kids. Vanessa Kieu shares that for her, being Vietnamese is "just to understand the culture and to be proud of the fact that you are Vietnamese." In contrast with her parents, who believe that understanding Vietnamese history is important, she believes that "although our history does define a big part of our country, we have so much to us and our country in the present day such as certain traditions, people and hospitality we can offer. You don't even need to necessarily know Vietnamese." Meanwhile, Sam Nguyen felt the opposite, affirming that "I still speak [Vietnamese] with my parents… I feel Vietnamese, because my family is Vietnamese and I grew up here." As these testimonies demonstrate, those of this generation vary significantly in their identities and being Vietnamese, as well as what quantifies that. These varying relationships to language, combined with the cultural hybridity of being Vietnamese at home but international at school, underscore how third generation identity is fluid and situational, shifting depending on context, peers, and linguistic competence (for some).

Diasporic communities in Western countries often develop an adapted ethnic identity, as a result of continued exposure to the host culture (Sansone; Hiền). Vietnamese refugees in the US formed tight clusters, such as in the communities of Little Saigon in Southern California, to maintain security and form a sense of belonging despite being in a foreign nation. At the same time, they adjusted their practices to adapt to the dominant culture while retaining traditions such as family hierarchy as their cultural core (Hiền 447). Rutledge observes that the resilience, adaptability, and resistance to change characterizes the "distinctiveness of the Vietnamese

communities," highlighting how cultural identity is preserved despite pressures to assimilate (Rutledge, cited in Hiền). These dynamics play out differently across generations. The first and so-called "one and a half" generation often live in-between cultures, behaving as Americans outside the home but maintaining Vietnamese language and customs at home. This reflects their dual adaptation (Hiền 449). By contrast, many second-generation Vietnamese Americans, growing up fully immersed in American schools and peers, rejected Vietnamese traditions altogether, with some later regretting their inability to speak the language when reconnecting with Vietnam after the 1986 economic reforms (Koh; Hiền). The third generation often negotiates yet another complex identity: while they may be fluent only in English and feel "in-between," they still remain marked by Vietnamese culture in family expectations and racial identity. As Hiền's interlocutor, Andrew Trần explained, he is "neither an American nor Vietnamese" but instead carries a hybrid identity defined by both cultures and belonging fully to neither (Hiền 452). This "dual identity" creates tensions within families as elders sometimes fear younger generations, seeing them as overly Americanized, while youth themselves wrestle with feeling permanently foreign in both the U.S. and Vietnam.

Another Vietnamese diasporic community is located in Thailand. Those who sought refuge in Thailand since the nineteenth century tended to be patriots and pro-communists. Due to their ideology and geography, the Vietnamese community in Thailand have had different influences and factors shaping their identity. From the 1940s to the 1990s, Vietnamese refugees had previously spent time in Laos and have learned the language, which made learning Thai easier. Despite this, they had not been integrated into Thai society once situated there. They only received citizenship and permanent residency after the 1990s. This had caused unsatisfaction within Thai Viet Kieus– Vietnamese diaspora in Thailand– where there seemed to be a desire to return home within the first and early second generation. Those of the second generation grew up attending Thai schools for a short period of time and thus spoke better Thai and integrated more into Thai culture and society than their parents did. They also participated in Vietnamese cultural practices and spoke Vietnamese at home, which was essential to the creation of their hybrid identities of being Vietnamese-Thai. The second generation grew up having been discriminated against by the Thai government and thus taught the third generation to "hide their Vietnamese ethnicity and fit in more with the host society" (Nguyen 11). Although there are variations in this attitude, due to the overall sense of forced assimilation, the third generation spoke little Vietnamese and were further integrated into Thai culture. These people, now, identify as Thai, yet feel that they "lack..something" (Nguyen 12). There is an overall sentiment within the second generation of Viet Kieu in Thailand that the ability to use Vietnamese is essential for Vietnamese ethnicity, thus identity. On the other hand, the third generation of Viet Kieu in northeast Thailand believe that language is not essential to the cultivation of personal identity; instead, the participation in Vietnamese cultural customs and continued awareness and pride in their cultural identity is enough for a hybrid identity (Nguyen).

An interesting dynamic between pro- and anti-communist diaspora in Germany, illustrates how identity fractures continue to persist decades after migration. There, migrants still

play into stereotypes of regional divides—North versus South, uptight versus relaxed— as markers of belonging and legitimacy (Su). These dynamics mirror tensions between Vietnamese people in Vietnam and abroad, where DK–a pseudonym for a teenager in Vietnam, attending an international school–feels that Viet Kieu have a "pretty bad" reputation within Vietnam, "because of the politics." DK feels that there is a sentiment among the country that Viet Kieu abandoned the regime and are "very anti-Vietnamese to the point that they wouldn't even call themselves communist" and "wouldn't even associate with the country nowadays." This complicates definitions of what it means to be Vietnamese, nowadays. While some abroad communities reimagine South Vietnam as an idealized counterpart to what they see as a flawed political system, younger generations both in Vietnam and abroad increasingly define their Vietnameseness less by political allegiance or accent and more by cultural connection, family relationships, and lived experience.

Conclusion

French colonial rule and Japanese occupation left a political vacuum that led to instability and shaped the divide between a communist North Vietnam and a French-US-backed South Vietnam. This ultimately led to the war and these differences in identity and belonging. Vietnam became a proxy for the ideological battle between the United States and the Soviet Union. Moreover, the Eurasian communist powers the USSR and People's Republic of China fought to have close ties with Hanoi in order to expand their influence and consolidate power in Southeast Asia. On April 30, 1975, North Vietnam invading Saigon set the country up for a poorly planned economy, famine, and discrimination for over ten years. Furthermore, the forced internal migration, lý lịch, collectivization, and abolition of private businesses shaped the lives of first and second generation survivors of the war. This influenced over 755,000 people to face the dangers of migration and resettle abroad in hopes of better lives and opportunities for themselves and their children (UNHRC). As these displaced communities rebuilt their lives in new environments, their identities inevitably became hybrid, shaped not only by memories of war and displacement but also by the cultural influences of their host societies. This demonstrates how Vietnamese identity is not static but fluid–continuously reshaped across generations by new factors such as travel and information technology, increased globalization, and transnational ties.

The potential impact of these shifts in identity and goals, of specifically the third upper middle class generation, there may be net emigration, due to better education and work opportunities abroad. This leads to human capital flight or what researchers Balmer, Godwin, and Gregory coined as "brain drain" of the educated and highly skilled, which may hinder or slow development of Vietnam's society and economy. Conversely, since Đổi Mới, Vietnam has received foreign investment from both multinational corporations and repatriations from Viet Kieu, developing the economy. Additionally, tourism, specifically from Viet Kieu, continues to be a big industry and contributes to the economy. With more foreign influence and globalization, it also may be possible for Vietnam's society to integrate more Westernized characteristics or values. This could possibly lead to a future shift in government and political leaders, which may

incorporate such values. However, as Acemoglu and Robinson argue in *Why Nations Fail*, nations with inclusive economic institutions but extractive political systems face long-term instability. Vietnam's growing economy coexists with a one-party state that limits political pluralism, raising the question of whether future pressures from globalization and Viet Kieu investment could strain this balance and create tensions between economic laissez-faire and political control.

To build on these findings, future studies may wish to take more samples, with a wider variety and number of participants than what I was able to achieve. Specifically, this study lacks ethnographical interviews with those of the third generation still in Vietnam. Having attended an international school while being Vietnamese has hinted to this incorporation of Western values as a part of society. Like with the second and third generation of Viet Kieu and those who have attended an international school, identity is evolving, meaning different things for some than what traditionally may be thought of as identity. It is fluid and will continue to be shaped by globalization, migration, memory, and economic opportunities.

Works Cited

Asia Pacific Curriculum. "Vietnam after the War." Asia Pacific Curriculum, asiapacificcurriculum.ca/learning-module/vietnam-after-war#teacher-resource. Accessed 24 Sept. 2025.

Balmer, B., Godwin, M., & Gregory, J. (2009). THE ROYAL SOCIETY AND THE "BRAIN DRAIN": NATURAL SCIENTISTS MEET SOCIAL SCIENCE. Notes and Records of the Royal Society of London, 63(4), 339–353. http://www.jstor.org/stable/40647309

Bhabha, H. K. (1990). DissemiNation: time, narrative and the margins of the modern nation. In H. K. Bhabha (Ed.), Nation and Narration (pp. 291-322). Routledge. https://doi.org/10.4324/9780203388341

Central Intelligence Agency. (1965, September 3). Status of Soviet and Chinese military aid to North Vietnam [PDF]. https://www.cia.gov/readingroom/docs/DOC_0000652931.pdf

Chapman, William. "Vietnamese Officials Describe Shortage of Food as Critical." The Washington Post, 14 Aug. 1979, www.washingtonpost.com/archive/politics/1979/08/15/vietnamese-officials-describe-shortage-of-food-as-critical/c2e2a88a-e749-4a9b-919e-8a74045594e7/.

"Chapter 4: Flight from Indochina." State of the World's Refugees: Human Displacement in the New Millennium, , e-book ed., Oxford University Press, 2006.

Dang, Huynh Huy, and Hai Thanh Ho. "Effects of Herbicides Used in the War into Natural Ecosystems and Biodiversity in Vietnam." Biochemical and Molecular Mechanisms, e-book ed. Originally published in Organohalogen Compounds, vol. 68, 2006.

Dean Acheson, "Sponsoring French Colonialism (Acheson Statement Excerpt, May 8, 1950)," in Vietnam: History, Documents and Opinions on a Major World Crisis, ed. Marvin E. Gettleman (Greenwich CT: Fawcett Pub, 1965), 89.

Desbarats, J. (1987). Population Redistribution in the Socialist Republic of Vietnam. Population and Development Review, 13(1), 43–76. https://doi.org/10.2307/1972120

The Editors of Encyclopaedia Britannica (2019, January 24). Comecon. Encyclopedia Britannica. https://www.britannica.com/topic/Comecon

The Editors of Encyclopaedia Britannica (2025, August 26). Agent Orange. Encyclopedia Britannica. https://www.britannica.com/science/Agent-Orange

Gareth Porter (1980) Vietnam's Ethnic Chinese and the SinoVietnamese conflict, Bulletin of Concerned Asian Scholars, 12:4, 55-60, DOI: 10.1080/14672715.1980.10405230

Goscha, Christopher. Vietnam: A New History. Basic Books, 2016.

Hall, S. (2003). Cultural Identity and Diaspora. In J. E. Braziel and A. Mannur (Eds.), Theorizing Diaspora: A Reader (pp. 233-246). Blackwell Publishing.

Hanh, Vu Nguyen. "Vietnamese Coffee Market: A Deep Dive into Its Consumers, Challenges, and Prospects." Vietnam Briefing, 28 Feb. 2025, www.vietnam-briefing.com/news/vietnam-coffee-market-a-deep-dive-into-its-consumers-challenges-and-prospects.html/.

Hansen, K. (2013). Land Law, land rights, and land reform in Vietnam: A deeper look into "land grabbing" for public and private development. Retrieved 12 September 2025, from SIT Digital Collections website: https://digitalcollections.sit.edu/isp_collection/1722

Hiền, N. T. (2016). Cultural Adaptation, Tradition, and Identity of Diasporic Vietnamese People: A Case Study in Silicon Valley, California, USA. Asian Ethnology, 75(2), 441–459. http://www.jstor.org/stable/asianeth.75.2.441

Horn, R. C. (1978). Soviet-Vietnamese Relations and the Future of Southeast Asia. Pacific Affairs, 51(4), 585–605. https://doi.org/10.2307/2757238

Kelemen, P. (1984). Soviet Strategy in Southeast Asia: The Vietnam Factor. Asian Survey, 24(3), 335–348. https://doi.org/10.2307/2644070

Kim, S. J. (1970). South Korea's Involvement in Vietnam and Its Economic and Political Impact. Asian Survey, 10(6), 519–532. https://doi.org/10.2307/2642884

Koh, P. S. I. (2012). Vietnam s Familiair Strangers: Narratives of Home, Homeland and Belonging Among Second Generation Viet Kieu in Sai Gon. [PhD-Thesis - Research and graduation internal, Vrije Universiteit Amsterdam]. Vrije Universiteit.

Latham, M. E. (2006). Redirecting the Revolution? The USA and the Failure of Nation-Building in South Vietnam. Third World Quarterly, 27(1), 27–41. http://www.jstor.org/stable/4017657

Le, Dat. "Reunification without Reconciliation: A Glimpse into the Social Conflicts and Integration Process in Postwar Vietnam." The Vietnamese Magazine, 30 Apr. 2022, www.thevietnamese.org/2022/04/reunification-without-reconciliation-a-glimpse-into-the-social-conflicts-and-integration-process-in-postwar-vietnam/#:~:text=Upon%20its%20takeover%20of%20the,Photo:%20manhhai/%20Flickr.

Nguyen, Q.T. (2008). Ho Chi Minh Sites in Thailand: Their Significance and Potential Problems for Thai-Vietnamese Relations. Journal of Mekong Societies, 5(1), 77- 96.

Nguyen, Tu Anh Nhi. "Cultural Continuity and Fragments of Diaspora: A Comparative Study of Identity Construction by Second and Third Generations of Overseas Vietnamese in Northeast Thailand." ASR Chiang Mai University: Journal of Social Sciences and Humanities, 2023. Research Gate, https://doi.org/10.12982/CMUJASR.2023.011.

O'Donnell, Matt, et al. "Vietnamese American Experiences." Edited by Marika Manos et al. We Are California, camodelcurricula.ucdavis.edu/vietnamese-american-experiences/vietnamese-resettlement-community-building. Accessed 24 Sept. 2025.

Public Information Section. "UNHCR and Malaysia Close Camp for Vietnamese Boat-people." www.unhcr.org/news/news-releases/unhcr-and-malaysia-close-camp-vietnamese-boat-people.

"Republic of Vietnam." Vietnamese Heritage Museum, vietnamesemuseum.org/our-roots/republic-of-vietnam/. Accessed 11 Sept. 2025.

Sansone, Livio. Blackness without Ethnicity: Constructing Race in Brazil. Palgrave Macmillan New York, 2003.

Sears, Jade. "The Domestic and Geopolitical Ramifications of the Vietnam War on South Korea." The General Assembly Review, vol. 2, no. 1, 2021. Research Gate, https://doi.org/10.5206/tgar.v2i1.10520.

Sripana, T. (2013). Tracing Ho Chi Minh's Sojourn in Siam. Southeast Asian Studies, 2(3), 527-558. https://englishkyoto-seas.org/wp-content/uploads/05_sripana. pdf

SU, P. H. (2017). "There's No Solidarity": Nationalism and Belonging among Vietnamese Refugees and Immigrants in Berlin. Journal of Vietnamese Studies, 12(1), 73–100. https://www.jstor.org/stable/26377936

Tuoi Tre. "'Hunger Era' in Vietnam – P1: Job's Tears during Late 1970s-80s." Tuoi Tre News, 21 Apr. 2015, news.tuoitre.vn/hunger-era-in-vietnam-p1-jobs-tears-during-late-1970s-80s-10319872.htm

Uyen, Phuong. "Vietnam's Rice Exports Deliver Strong Yield." Vietnam Investment Review, 5 Sept. 2024, vir.com.vn/vietnams-rice-exports-deliver-strong-yield-114135.html&link=autochanger.

Vaage, A. B., Thomsen, P. H., Silove, D., Wentzel-Larsen, T., Van Ta, T., & Hauff, E. (2010). Long-term mental health of Vietnamese refugees in the aftermath of trauma. British Journal of Psychiatry, 196(2), 122–125. doi:10.1192/bjp.bp.108.059139

Vietnamese Heritage Museum. "Republic of Vietnam." Vietnamese Heritage Museum, vietnamesemuseum.org/our-roots/republic-of-vietnam/. Accessed 1 Oct. 2025.

VNA Publishing House. "50 Years of Agent Orange/dioxin Disaster in Vietnam." Socialist Republic of Vietnam: Ministry of National Defence, 28 Sept. 2012, mod.gov.vn/en/intro/detail/!ut/p/z0/dYqxDoIwFEW_xvHltVigHWFwMMZEYwx0MYUWqEIr2Bg-X6KTMU73nJOLEguUTj1tq4L1TvWLlzK5bLL9kec0I-S0i8ghZ-dYiHTNRIpblG3vq8_VXsdRZihr74KZAxaD1yvyULAsGPdG48CHzkxfAn5qfwJo62fr_nWoOzPYWvUrIlTc0CihYCreAIspAy60Al3phpCUC0YTvN9k-QLs57D7/. Accessed 12 Sept. 2025.

World Bank. "GDP (current US$) - Viet Nam." World Bank, 2024. World Bank Group, data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=VN&name_desc=true.

Yazdiha, H. (2010). Conceptualizing Hybridity: Deconstructing Boundaries Through the Hybrid. Formations, 1(1), 31-38.

Major Factors That Affect the Stock Market and How Companies Use It to Their Advantage By Aariz Jiwani

Abstract

My research paper is about companies and how their financial decisions affect the stock price. I will include what the stock market is, along with the decisions they made to influence the stock market. My research matters because the stock market is something that influences our daily lives, which provides investment opportunities, enables growth and innovation, and gives people a chance for people to build their wealth. The method that I plan to use is to do deep research on how the stock market works, and focus on 2 main factors: The total market and individual companies. We will be using a comparison study, financial analysis, and specific case studies around those companies. The results I expect to gain from this project are a list of factors that drive major stock market movements, financial and PR decisions companies have made, deeper knowledge of the overall stock market, and how specific companies influence the stock market. I want to be more knowledgeable about how to use the stock market. I also want to show individuals how companies are using the stock market to their advantage. Furthermore, I want to determine what factors have helped companies in the past, what factors help companies in the present, and what factors will help companies in the future regarding the stock market.

History

The stock market is a financial marketplace where individuals and institutions buy and sell shares of publicly traded companies. It facilitates the trading of stocks, which represent a share of ownership in a company, allowing investors to participate in the company's growth. Essentially, it's a system that connects buyers and sellers of these shares, determining their prices based on market demand and supply. The stock market was created out of the need to fund large ventures and distribute risk among investors. It evolved from informal trading of shares into regulated institutions that support modern capitalism by connecting investors with businesses. The stock market was created as a way to allow companies to raise money from investors and for investors to buy and sell ownership stakes in those companies. Its origins go back centuries, evolving through trade, finance, and the development of joint-stock companies. This occurred in medieval Europe, especially in Italy, France, and the Low Countries, where trade expanded significantly. Large international trade fairs became key marketplaces for goods and financial instruments. Merchants from across Europe and the Mediterranean met to exchange currencies, settle debts, and arrange credit. Merchants often pooled capital in temporary partnerships (known as commenda in Venice), where one partner funded a voyage and another conducted the trade. This was a precursor to joint-stock investing, allowing shared profits and limited liability in case of failure. Florence, Venice, and Genoa were early financial powerhouses. Their merchants pioneered complex banking and credit systems. The Medici Bank (founded in 1397) in Florence became one of the most powerful banks in Europe, financing popes and monarchs. This progression led to banking innovations such as bills of exchange being developed and

double-entry bookkeeping being invented. Bills of exchange were written orders promising to pay a specific amount of money in another city or country. This reduced the risk of carrying gold or silver long distances. Double-entry bookkeeping, which was developed in Italy (notably by Luca Pacioli in 1494), made it easier to track large-scale business activities. Later, Italian city-states began issuing government bonds to finance wars and public works. These bonds could be traded in secondary markets—essentially, early versions of fixed-income securities. In Venice and Genoa, a class of investors and brokers emerged who bought and sold these debt instruments, foreshadowing a bond market. Between the 1300s through the 1500s, long-distance trade expanded through the Hanseatic League and the exploration of the Portuguese and Spanish. The Hanseatic League is a powerful trading alliance of merchant guilds across Northern Europe. Members facilitated secure trade routes, offered credit, and shared profits from long-distance shipping ventures. The Portuguese and Spanish exploration resulted in the opening of global sea routes, increasing the scale and risk of trade. This created a need for larger, long-term capital investment, which primitive partnerships and local banks could no longer efficiently support. By the late 1500s, especially in the Netherlands and England, a new idea took shape: Form a permanent company (not dissolved after a single voyage), raise money by selling shares of ownership, and allow those shares to be bought and sold (creating liquidity for investors). This model allowed risk to be shared by a large group and created incentives for passive investors to participate.

Then, a shift occurred that made this model true. The Vereenigde Oostindische Compagnie (VOC) was created in 1602 by the Dutch government to dominate trade in Asia. The VOC was granted a 21-year monopoly on Dutch trade in the East Indies (modern Indonesia and beyond). Innovations during the 21-year monopoly are that they were the first company to issue shares to the general public, the investors received dividends based on profits from global trading ventures, and their shares could be freely traded on a formal market in Amsterdam. Initially, VOC shares were traded informally by brokers. But due to high demand and trading volume, a formal marketplace emerged—what we now call the Amsterdam Stock Exchange. The exchange allowed traders to meet at a central location to buy and sell VOC shares. Also, prices were set by supply and demand, rather than by the company itself. The exchange also allowed secondary trading (between investors) allowing people to enter or exit their investment at any time. Additional features in the market include permanent capital, transferable shares, shared risk, regulated venues, and speculative trading: permanent capital funded long-term, high-risk global ventures, transferable shares created liquidity and a public market, shared risk made investing accessible beyond elites, regulated venues increased transparency and investor trust, and speculative trading led to price discovery and created market dynamics. This combination of: Joint-stock structure, Public investment, Tradable shares, and a centralized marketplace was the foundation of the modern stock market system. It allowed for the creation of large corporations, professional investors, and eventually, massive global capital flows. Shortly after this, stock trading in London began informally, but then in 1773, the London Stock Exchange was formally established. More stock exchanges started to pop up as 24 brokers signed the Buttonwood

Agreement in New York, founding what became the New York Stock Exchange (NYSE). The stock ticker is also introduced. According to Capital, A stock ticker is a report of the price of certain securities, updated continuously throughout the trading session by the various stock market exchanges. This led to the rise of industrial capitalism, stock markets financing infrastructure projects, and causing stock speculation to become more common. Industrial capitalism is an economic system that emerged during the Industrial Revolution, characterized by large-scale factory production, private ownership of the means of production, and wage labor. In the early 1900s, the stock market was volatile, which meant that it experienced sudden, unpredictable changes. This was caused by war and the Great Depression. Multiple recessions occurred, which led to unemployment. The rising percentage of unemployment led to investors losing trust in those companies, quickly selling those shares. The rapid withdrawal led to the crash of the stock market. This is when governments intervene in stock exchanges. After WWII, significant recovery was made, including the creation of NASDAQ, the first electronic stock exchange. Looking at the 1900s, investors knew the market would be changing constantly, which still happens even today.

Later, there was a surge of IPOs, and the rise of ETFs changed the market. An IPO is when a company posts its shares on the market. An Exchange Traded Fund (ETF) is a type of investment fund that holds a basket of assets, such as stocks, bonds, or commodities, and trades on stock exchanges like individual stocks. The stock market evolved from a localized platform for trading voyage-based ventures into a highly complex, globalized financial system. Major technological, political, and economic shifts have repeatedly reshaped its structure and role in the global economy.

Today

Today, there are approximately 55,000 companies traded on the global stock market. The stock market today works as a global, technology-driven marketplace where buyers and sellers trade shares of publicly listed companies. According to NASDAQTrader, around $300 billion worth of shares are exchanged everyday with approximately 50 million trades everyday. While the basic principles remain the same as in the past (supply and demand, ownership, risk/reward), the modern stock market operates with high-speed systems, global connectivity, and sophisticated investor tools. Companies list their initial public offerings (IPOs), and their shares are traded on stock exchanges. Orders are matched automatically, and prices are dependent on basic principles such as supply and demand. My research paper will be talking about a specific stock exchange called the NYSE (New York Stock Exchange.) In the NYSE, I will specifically focus on 5 companies: Apple, Tesla, Marriott International, Costco, and Walmart.

Macro Factors

The stock market as a whole is influenced by many factors that contribute to its growth or decline. Six key drivers are GDP, inflation, interest rates, unemployment rates, government policies, and investor sentiment. These factors interact closely, and removing any one of them

would significantly alter how the market functions. They not only work together but also impact one another—for instance, interest rates play a crucial role in regulating inflation. Understanding these macroeconomic variables is essential because they collectively shape economic performance by influencing consumer spending, business investment, and overall market confidence. Changes in GDP reflect the health of economic output, while inflation and interest rates affect purchasing power and borrowing costs. Unemployment rates signal labor market conditions, and government policies can either stimulate or restrain economic growth through fiscal and monetary measures. Furthermore, investor sentiment often reflects broader economic expectations, driving market volatility. Therefore, analyzing these interconnected macroeconomic factors provides valuable insights into the mechanisms that drive economic cycles and long-term growth.

GDP is the total monetary or market value of all the finished goods and services produced within a country's borders in a specific time period. Depending on the state of the GDP, the market will be affected positively or negatively. If it is an economic growth, the economy will have higher income averages, lower unemployment rates, lower government borrowing, improved public services, environmental protection, and economic development. The negative effects of economic growth are unequal wealth distribution. During the U.S. recovery from the 2008 financial crisis, GDP growth from 2009–2019 aligned with the S&P 500's average annual return of ~13.6%.

Inflation is an increase in the average price of goods and services in terms of money. This increase is measured using a price index, typically a consumer price index. While moderate inflation can be beneficial, high and unpredictable inflation can be extremely damaging to an economy. It erodes purchasing power, creates uncertainty, and can lead to economic instability. Therefore, central banks strive to maintain a low and stable rate of inflation. In an inflationary environment, unevenly rising prices inevitably reduce the purchasing power of some consumers, and this erosion of real income is the single biggest cost of inflation.

Inflation can also distort purchasing power over time for recipients and payers of fixed interest rates. An example of this is **U.S. CPI** (Consumer Price Index) and **S&P 500**: In 2022, when U.S. inflation reached 9.1% (June), the S&P 500 fell ~20% from January to September.

An interest rate is the amount of interest due per period, as a proportion of the amount lent, deposited, or borrowed. Lowering interest rates can stimulate economic growth by making borrowing cheaper, encouraging businesses to invest and expand, and increasing consumer spending. This can lead to increased hiring, higher asset prices, and improved market sentiment. However, if rates are too low for too long, it can also lead to excessive borrowing and inflation. Higher interest rates can negatively impact the economy by increasing borrowing costs for consumers and businesses, potentially slowing down spending and investment, and potentially leading to job losses. An example of this was in the late 2024s when the Federal Reserve implemented a series of interest rate cuts totaling 1 percentage point. This lowered the federal funds rate to a target range of 4.25%. The cuts occurred in 3 steps: on September 18, 2024, the

rate was reduced to 4.75%–5.00%; on November 7, 2024, it was lowered again to 4.50%–4.75%; and on December 18, 2024, it dropped further to 4.25%–4.50%.

The unemployment rate represents the number of unemployed people as a percentage of the labor force (the labor force is the sum of the employed and unemployed). The unemployment rate is calculated as: (Unemployed ÷ Labor Force) x 100. (US Bureau of Labor Statistics) Unemployment is generally considered a dependent variable. This means that unemployment rates are influenced by other economic factors, which are considered the independent variables. This can lead to Higher Economic Output which means more people working means more goods and services are produced. This boosts overall productivity and contributes directly to GDP growth. Employed individuals have more disposable income. This fuels demand for goods and services, driving business revenue and potentially leading to more job creation. Low unemployment often signals a strong economy, which can boost business. This leads to innovation, capacity building, and hiring. People and businesses feel more secure about the future, which supports both spending and investment. But, fewer people working means less production of goods and services. Unemployed individuals have lower incomes, which in turn reduces overall demand in the economy, a key driver of GDP. High unemployment can lower business investment due to reduced demand expectations. In the Summer of 2025, the US economy experienced low unemployment. The rate remained at approximately 4.1%. The tight labor market boosted consumer spending and reinforced business confidence, supporting economic growth as companies invested, expanded capacity, and hired more workers. Major banks reported that consumer finances remained healthy due to low unemployment rates. Although this was the case, there were early warning signs. Wage for lower income workers began to slow along with rising debt amongst middle and low income workers who had credit cards. Lower income households expressed concerns about their ability to sustain spending if conditions weakened. This combination demonstrated the pros and cons of low unemployment rates.

Government policies are sets of guidelines, rules, or principles that governments use to guide decisions and actions, aiming to achieve specific goals or outcomes. Government policies can positively impact the economy by promoting stability, growth, and social welfare. Policies like fiscal stimulus during recessions, investments in infrastructure, and monetary policies that control inflation can lead to increased employment, consumer spending, and overall economic expansion. Government policies, while often intended to improve economic outcomes, can sometimes have negative impacts on the economy. These can include stifling innovation due to overregulation, increasing costs for businesses, and potentially leading to unintended consequences like higher prices or decreased productivity. For instance, during a recession, governments might implement expansionary fiscal policy by cutting taxes or increasing spending to stimulate economic activity. Conversely, during periods of high inflation, they might implement contractionary fiscal policy by raising taxes or decreasing spending to cool down the economy. Similarly, monetary policy tools like interest rate adjustments can influence borrowing costs, investment, and overall economic growth. Under the Biden administration's *Investing in*

America agenda which was driven by the Infrastructure Investment and Jobs Act, the CHIPS and Science Act, and the Inflation Reduction Act, the US Government made large scale investments stimulating economic growth and improving long term capacity. They invested up to one trillion dollars in private investment and over 756 billion dollars in public infrastructure spending by early 2025. They invested in roads, transit upgrades, clean water systems, and energy grids. This created jobs, boosted consumer spending, and enhanced productivity which aligned with the idea that government policy can promote stability, growth, and social welfare. However, these policies came with its cons. The combined fiscal measures are projected to add trillions of national debt. This depicts how government policies created to strengthen the economy, has its downfalls as well.

Investor sentiment refers to the overall attitude, mood, or feeling that investors have about the financial markets or specific assets at a given time. It reflects how optimistic (bullish) or pessimistic (bearish) investors feel, regardless of actual fundamentals like earnings, interest rates, or economic indicators. Investor sentiment is not a driver of GDP growth in the strictest sense, but it acts as a behavioral signal that can amplify or dampen macroeconomic trends. It can be used as an early-warning indicator for future economic expansion or contraction. Depending on how investor sentiment is, determines how a company performs. In 2021, the video game retailer GameStop experienced a dramatic surge in its stock price, rising approximately 1,500% over a period of two weeks. This phenomenon, dubbed the "meme stock" craze, was primarily driven by social media hype and coordinated efforts from retail investors, rather than a significant improvement in the company's financial performance.

Case Studies

Now that we have discussed all the macro factors that significantly impact the economy, we will examine how these factors affect individual companies and their operations. The 5 companies I have chosen to do an individual case study on are Marriott International, Tesla, Costco, Walmart, and Apple.

Marriott International, one of the world’s largest hotel chains, was severely impacted by the COVID-19 pandemic as global travel bans and border closures brought the tourism industry to a halt. In Q2 2020, the company reported a 58.5% drop in global RevPAR (Revenue per Available Room), its worst quarter on record, and total revenues fell from $20.97 billion in 2019 to $10.57 billion in 2020, nearly halving the business in a single year. CEO Arne Sorenson remarked, “The COVID-19 pandemic is having a more severe and sustained financial impact on Marriott’s business than 9/11 and the 2008 financial crisis combined.” The restrictions also delayed hotel openings and forced Mariott to lay off about two thirds of its corporate workforce. This created significant cash flow challenges and required Mariott to restructure. In response, the company implemented cost-cutting measures, deferred non-essential projects, enhanced health and safety protocols, and invested in digital technologies to facilitate contactless check-ins. Recovery was supported by government programs, including over $170 million for employee retention and healthcare reimbursements. Marriott also diversified revenue streams through

initiatives like Tribute Portfolio Homes and loyalty programs. As travel gradually resumed, Marriott stabilized operations and continued expanding its footprint, operating over 6,161 hotels in the United States by mid-2025, strengthening its long-term resilience in the hospitality industry.

Apple, the world's most valuable and well-known tech company, produces cellphones, laptops, and headphones, and has a major influence on the US economy. Its global supply chain which heavily relies on China, has long faced the challenges of tariffs. These pressures aren't just temporary, but have created a long term impact on the company. In 2019, the US imposed a 15% tariff on products like the iPhone, Apple Watch, and AirPods which raised costs by billions. Analysts warned that a full 25% tariff could reduce earnings per share by up to three dollars annually. CEO Tim Cook noted in a Q3 2019 earnings call that "Our view on tariffs is that they show up as a tax on the consumer and wind up resulting in lower economic growth, and sometimes can bring about significant risk of unintended consequences." To keep prices low and to maintain its brand value, Apple decided to diversify its manufacturing footprint by opening factories in countries such as Vietnam and India while continuing operations in China with strategic adjustments to comply with government policies. Apple also strengthened partnerships with key suppliers in South Korea and Japan to ensure its supply chain remained stable. Despite these pressures, Apple leveraged its strong brand loyalty, 85% retention rate, and pricing control to maintain customer trust and market share.

Tesla, which is led by Elon Musk, designs and manufactures electric vehicles, battery storage systems, and solar products. They have the goal of accelerating the world's transition to sustainable energy. Its business model is highly dependent on investor sentiment, which caused extreme volatility from 2020 to 2021. At the time, the low-interest rate environment and meme stock enthusiasm pushed shares from 130 dollars to over 1200 dollars. Musk created tweets such as the going private tweet. He also acquired Twitter. This created views of CEO distraction affecting investor confidence. Additionally, Tesla's operations and profitability are influenced by government policies. Musk's direct engagement with policymakers and public statements have sometimes shaped regulatory outcomes, but they also expose the company to political risk. From 2022 to 2023, Federal Reserve interest rate hikes cooled sentiment which reduced the present value of future profits along with slowing the demand. The Q2 2023 US deliveries was down 6.6% year-over-year. Tesla focused on controlling production costs, managing cash flow, and maintaining product development timelines while balancing goals.

Walmart, the largest retailer in the U.S., was uniquely positioned during the pandemic to benefit from rising unemployment and government stimulus policies. As job losses surged in early 2020, which were peaking at 14.7% unemployment in April 2020, Americans turned to Walmart for low-cost essentials. This, combined with stimulus checks, helped Walmart post a 5.6% increase in U.S. same-store sales in FY2021, reaching $93.2 billion in Q4 2020, up from $84.2 billion the year prior. CFO Brett Biggs stated: "Government stimulus was a big driver for our customers and for our sales." However, the aftermath of the stimulus also created a tight labor market, raising wages and costs. By 2022, Walmart had to increase average wages to over

$17/hour, which CFO John David Rainey said created “unexpected cost pressures.” So while early unemployment benefited sales, Walmart was later squeezed by labor shortages and wage inflation, demonstrating how macroeconomic employment shifts can cut both ways for large retailers. Walmart has implemented several initiatives to support workforce development and employee growth. Its Live Better U program offers associates access to education and training at no cost, enabling them to earn certificates and degrees to advance their careers. In addition, community grants from Walmart and the Walmart Foundation fund organizations focused on workforce development and related initiatives in communities where the company operates. Walmart also owns Sam’s Club, a membership-based warehouse chain similar to Costco, which contributes to job creation and generates funding that can support employee wages. Programs such as High School Internships provide early career opportunities, giving students practical experience while supporting local workforce development. Collectively, these initiatives help Walmart strengthen its labor force, enhance employee skills, and contribute to community economic growth.

Costco’s reputation for price stability and value became its greatest strength during inflationary spikes in 2022-2023, especially when essential goods like eggs experienced severe price volatility. Due to avian flu outbreaks and supply chain bottlenecks, egg prices in the U.S. rose by up to 60% year-over-year at their peak in early 2023. While many retailers passed on these costs, Costco worked aggressively to shield customers. An example is limiting egg purchases per member in some regions to manage inventory. According to CFO Richard Galanti, “Our members trust us to keep prices in check, and we’re willing to take some margin hit to do that.” Despite inflation, Costco’s revenue grew to $242 billion in 2023, up 6% year-over-year, thanks in part to members turning to Costco for bulk deals. Gross margins only dipped slightly — from 11.7% to 11.2%, showing Costco absorbed costs rather than pass them along. This disciplined inflation response enhanced member loyalty and reinforced Costco’s brand promise amid macroeconomic stress, proving that strategic pricing during inflation can be a competitive weapon. From 2022 to 2025, Costco has effectively addressed inflationary pressures by leveraging its unique business model, operational efficiencies, and strategic pricing. A significant portion of the company’s revenue comes from membership fees, which support its low-margin pricing strategy, while its private label, Kirkland Signature, allows Costco to offer high-quality products at lower prices by negotiating directly with suppliers and reducing marketing expenses. Operational efficiencies, including direct relationships with producers, alternative sourcing, high inventory turnover, and cross-docking methods, help minimize costs and ensure consistent product availability. Costco also limits product selection and focuses on bulk purchasing, giving it negotiating power to keep prices stable despite rising costs. Additionally, the company adapts to changing market conditions by diversifying offerings, including cellphones and gift cards, expanding store hours, and using technology to improve efficiency. These strategies have allowed Costco to maintain affordability and shopper loyalty even as inflation increased during this period, demonstrating resilience in the face of economic pressures.

Works Cited

Federal Reserve. (2025, July 30). Federal Reserve issues FOMC statement [Press release]. Board of Governors of the Federal Reserve System. https://www.federalreserve.gov/

Federal Reserve. (2025, July 31). The Federal Reserve Board and FOMC release economic projections. Board of Governors of the Federal Reserve System. https://www.federalreserve.gov/

Sorenson, A. (2020, March 19). A message from our CEO on COVID-19. Marriott International. https://news.marriott.com/

Apple Inc. (2019, June 17). Letter to U.S. Trade Representative regarding proposed tariffs on Apple products. Apple Inc. https://www.apple.com/newsroom/

Cook, T. (2019, July 30). Apple Inc. Q3 2019 earnings call transcript. Apple Inc. https://www.apple.com/newsroom/

Tesla Inc. (2022, October 19). Q3 2022 Tesla earnings call transcript. Tesla Inc. https://ir.tesla.com/

Musk, E. (2018, August 7). Am considering taking Tesla private at $420. Funding secured. [Tweet]. X (formerly Twitter). https://twitter.com/elonmusk

Walmart Inc. (2023). Live Better U: Education benefits for associates. Walmart Corporate. https://corporate.walmart.com/

Walmart Foundation. (2023). Community grants program. Walmart Foundation. https://walmart.org/

Costco Wholesale Corporation. (2023). Annual report 2023. Costco Wholesale. https://investor.costco.com/financials

Bomey, N. (2023, February 14). Why egg prices skyrocketed and how Costco kept prices steady. USA Today. https://www.usatoday.com/

U.S. Bureau of Labor Statistics. (2025). CPI inflation data (2022–2025). U.S. Department of Labor. https://www.bls.gov/cpi/

Petram, L. (2014). The world's first stock exchange: How the Amsterdam market for Dutch East India Company shares became a modern securities market, 1602–1700. Columbia University Press.https://cup.columbia.edu/book/the-worlds-first-stock-exchange/9780231163781

World's First Stock Exchange. (2020, September 1). About this blog. https://www.worldsfirststockexchange.com/2020/09/01/about-this-blog/

Historic UK. (n.d.). The South Sea Bubble. Historic UK. https://www.historic-uk.com/HistoryUK/HistoryofEngland/South-Sea-Bubble/

Wheelock, D. C. (2016, February 5). Crisis chronicles: The long depression and the panic of 1873. Liberty Street Economics (Federal Reserve Bank of New York). https://libertystreeteconomics.newyorkfed.org/2016/02/crisis-chronicles-the-long-depression-and-the-panic-of-1873/

Simeone, N. (2013, Spring). The depression you never heard of. Brandeis Magazine. https://www.brandeis.edu/magazine/2013/spring/inquiry/depression.html

Business Insider. (2025, May). Vintage photos of Black Monday, the 1987 stock market crash. Business Insider. https://www.businessinsider.com/vintage-photos-black-monday-market-crash-2025-5

MarketWatch. (2025, March 10). The dot-com bubble peaked 25 years ago this week — are investors today falling into the same trap? MarketWatch. https://www.marketwatch.com/story/the-dot-com-bubble-peaked-25-years-ago-this-week-are-investors-today-falling-into-the-same-trap-4f0cf81a

Nasdaq. (n.d.). Daily market summary. Nasdaq Trader. https://www.nasdaqtrader.com/Trader.aspx?id=DailyMarketSummary

Brandeis University. (2013). The panic of 1837, America's worst financial crisis. Brandeis Magazine. https://www.brandeis.edu/magazine/2013/spring/inquiry/depression.html#:~:text=The%20Panic%20of%201837%2C%20America%27s%20worst%20financial,up%20and%20business%20slowed%20to%20a%20crawl.

Business Insider. (2025, May). Vintage photos of Black Monday, the 1987 stock market crash. https://www.businessinsider.com/vintage-photos-black-monday-market-crash-2025-5#:~:text=For%20some%2C%20this%20economic%20instability,Dow%20Jones%20plummeted%20by%2022.6%25.

Cascade Strategy. (n.d.). Delta Air Lines strategy study. Cascade. https://www.cascade.app/studies/delta-strategy-study

CBS News. (2019a, May 9). Uber IPO: Will Uber drivers profit from tech company's initial public offering? https://www.cbsnews.com/news/uber-ipo-will-uber-drivers-profit-from-tech-companys-initial-public-offering/#:~:text=U.S.%2Dbased%20drivers%20will%20have,Wedbush%20stock%20analyst%20Daniel%20Ives.

CBS News. (2019b, May 9). Uber IPO promises riches for a handful of investors — and risks galore. https://www.cbsnews.com/news/uber-ipo-promises-riches-for-a-handful-of-investors-and-risks-galore/

CNBC. (2019, May 9). Uber IPO pricing: Company prices shares amid Lyft rivalry. https://www.cnbc.com/2019/05/09/uber-ipo-pricing.html#:~:text=Kalanick's%20ouster%20was%20preceded%20by,Picker%20contributed%20to%20this%20article.&text=Clarification:%20Uber%20priced%20its%20IPO,earlier%20version%20of%20this%20article.

Columbia University Press. (n.d.). The world's first stock exchange. https://cup.columbia.edu/book/the-worlds-first-stock-exchange/9780231163781/#:~:text=The%20launch%20of%20the%20Dutch,had%20begun%20to%20trade%20them.

Crunchbase News. (2024, December 31). Venture-backed U.S. startups IPOs. https://news.crunchbase.com/public/venture-backed-us-startups-ipos/

Fool.com. (2025, April 27). Prediction: Nvidia stock will soar after May 1. The Motley Fool. https://www.fool.com/investing/2025/04/27/prediction-nvidia-stock-will-soar-after-may-1/#:~:text=Nvidia%20just%20wrote%20off%20$5.5,coming%20up%20on%20May%201.

Historic UK. (n.d.). The South Sea Bubble. https://www.historic-uk.com/HistoryUK/HistoryofEngland/South-Sea-Bubble/#:~:text=Then%20in%20September%20of%201720,to%20his%20rise%20to%20power.

Hobson, N. (2019, August 15). 25 years ago, Steve Jobs saved Apple from collapse — It's a lesson for every tech CEO today. Inc.com. https://www.inc.com/nick-hobson/25-years-ago-steve-jobs-saved-apple-from-collapse-its-a-lesson-for-every-tech-ceo-today.html

Investopedia. (2016, August 17). Understanding Apple's capital structure (AAPL). https://www.investopedia.com/articles/investing/081716/understanding-apples-capital-structure-aapl.asp#:~:text=the%20foreseeable%20future.-,Tying%20It%20All%20Together,main%20and%20wall%20street%20investors.

Investopedia. (2016, August 26). How the stock market works. https://www.investopedia.com/articles/investing/082614/how-stock-market-works.asp#toc-why-does-the-stock-market-go-up-and-down

Investopedia. (2012, October 4). The history of Apple stock increases. https://www.investopedia.com/articles/stocks/12/history-apple-stock-increases.asp

Investopedia. (2015, February 24). How Pinterest makes money. https://www.investopedia.com/articles/personal-finance/022415/how-pinterest-makes-money.asp#:~:text=Opportunities%20for%20increasing%20revenue%20that,12

Investopedia. (n.d.). What is an institutional investor? https://www.investopedia.com/ask/answers/06/institutionalinvestor.asp

Law, University of Tennessee, Knoxville. (n.d.). Case study: Six Flags bankruptcy. https://ir.law.utk.edu/cgi/viewcontent.cgi?article=1035&context=utk_studlawbankruptcy

MarketWatch. (2025, March 11). The dot-com bubble peaked 25 years ago this week: Are investors falling into the same trap? https://www.marketwatch.com/story/the-dot-com-bubble-peaked-25-years-ago-this-week-are-investors-today-falling-into-the-same-trap-4f0cf81a#:~:text=reached%20its%20dot%2Dcom%2Dera,investors%27%20confidence%20in%20the%20market.

Nasdaq. (n.d.). Daily market summary. Nasdaq Trader. https://www.nasdaqtrader.com/Trader.aspx?id=DailyMarketSummary

New York Fed. (2016, February 5). Crisis chronicles: The long depression and the panic of 1873. Liberty Street Economics. https://libertystreeteconomics.newyorkfed.org/2016/02/crisis-chronicles-the-long-depression-and-the-panic-of-1873/#:~:text=The%20panic%20led%20to%20bank,The%20Real%20Great%20Depression%E2%80%9D%29

Pinterest IPO. (n.d.). Pinterest IPO overview. Stash. https://www.stash.com/learn/pinterest-ipo/

StartupWize. (2020, December 15). Revisiting Airbnb IPO. https://startupwize.com/revisiting-airbnb-ipo/#:~:text=This%20gave%20Airbnb%20a%20valuation,and%20its%20asset%2Dlight%20platform.

TD Direct Investing. (n.d.). What is the stock market? https://www.td.com/ca/en/investing/direct-investing/articles/what-is-stock-market#:~:text=Share%20prices%20are%20determined%20by,new%20prices%20with%20each%20other.

World's First Stock Exchange. (2020, September 1). About this blog. https://www.worldsfirststockexchange.com/2020/09/01/about-this-blog/

Yahoo Finance. (2025, April). Nvidia stock just did something for the first time. https://finance.yahoo.com/news/nvidia-stock-just-did-first-080500351.html

Yahoo Finance. (2025, April). Analyst explains Nvidia's tricky position. https://finance.yahoo.com/news/analyst-explains-nvidia-nvda-tricky-201536617.html

Bankrate. (2025, March). Elon Musk may now be the biggest risk to Tesla's stock — here's why. https://www.bankrate.com/investing/elon-musk-may-now-be-the-biggest-risk-to-teslas-stock-heres-why/#:~:text=Tesla%20(TSLA)%20has%20been%20making,become%20shareholders'%20problem%2C%20too.

Diabetic Retinopathy Classification Using CNNs: Analysis Of Ordinal Loss Functions And Explainability By Ayaan Gupta

Abstract

Diabetic Retinopathy is a leading cause of vision loss worldwide, and early detection of the disease is crucial in preventing irreversible damage to eyesight. Manual screening of retinal fundus images is time consuming and expensive, making it difficult to obtain care in many regions around the world. The paper presents a deep learning-based approach to automating diabetic retinopathy detection and classification using a model built upon a pre-trained EfficientNet-B0 base and a custom classifier head. The objective was to explore the effect of different loss functions on predictions and implement Gradient-weighted Class Activation Mapping (Grad-CAM) to visualize the regions that influence model predictions. Several loss functions were systematically evaluated: cross-entropy loss, quadratic weighted kappa loss, class distance weighted cross-entropy loss, and a novel hybrid loss function combining standard cross-entropy loss with quadratic weighted kappa loss. Results show that the hybrid loss function achieved the greatest overall performance with a validation accuracy of 76.4% and a weighted F1-score of .7668, exhibiting superior behavior by reducing misclassifications across ordinally distant classes. Overall, this work demonstrates that hybridizing traditional loss functions with ordinal-aware loss functions can offer promising results in the task of DR classification while tools such as Grad-CAM offer enhanced explainability.

Keywords

Medical and Health Sciences; Biomedical Imaging; Diabetic retinopathy; Deep learning; Ordinal loss functions

Introduction

Diabetes is a global medical crisis that affected 14% of adults over the age of 18 in 2022 (World Health Organization). Diabetes is a chronic disease that occurs when the body cannot produce enough insulin, leading to a dangerous increase in the amount of glucose in the blood. It affects the eyes, kidneys, feet, nerves, and heart. Modern statistical reports reveal that 830 million people will have diabetes in 2022, and almost half of this number will live in developing countries without adequate treatment. Specifically, the Lancet study demonstrates that in 2014, 24.4% adults with diabetes lived in China, 15.3% lived in India, and 11.7% lived in Indonesia (NCD Risk Factor Collaboration).

One of the complications that arises alongside diabetes is Diabetic Retinopathy (DR), which is the leading cause of vision loss in adults of working age in the world and is expected to affect 191.0 million by 2030 (Zheng et al.). DR occurs when chronic hyperglycemia damages the small blood vessels in the retina. To supplement the consequential reduced oxygen supply, new fragile blood vessels proliferate (neovascularization), which can leak or rupture, causing progressive retinal damage (Sayin et al.).

The severity of DR is determined by the presence and extent of retinal abnormalities (Figure 1), allowing DR to be classified into five stages: no DR, mild DR, moderate DR, severe DR, and proliferative DR (Fyra.io; Tymchenko et al.). The key pathological markers for classification include microaneurysms, hemorrhages, venous beading, and hard exudates (Jenkins et al.). Microaneurysms are generally the first manifestation of DR that presents itself as small red bulges (smaller than 125 μm) in the blood vessels of the retina that appear due to weakening of the vessel walls (Triwijoyo et al.). They can leak fluid or blood, potentially causing vision problems if left untreated. Hemorrhages appear as larger spots (larger than 125 μm) and refer to bleeding within the retina (Murugesan et al.). In addition to dot-shaped hemorrhages, larger flame-typed hemorrhages can appear, signifying DR progression. Hard exudates appear as bright-yellow, lipid-rich deposits in the retina caused by leakage from damaged blood vessels (Joshi and Karule). Venous beading is an indicator of severe DR and refers to localized areas of intense swelling and constriction of retinal veins.

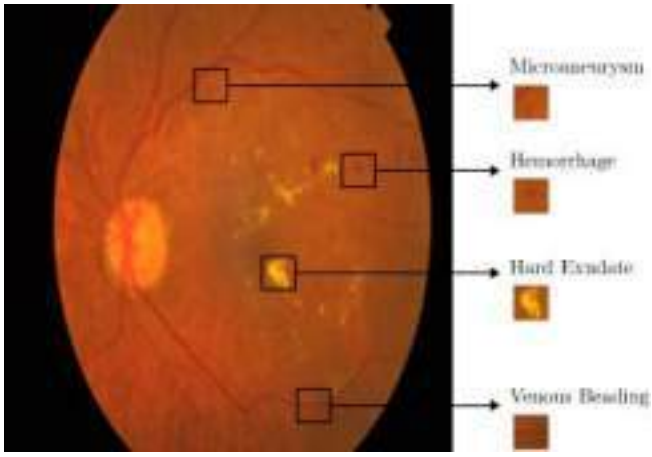


Figure 1. Diabetic Retinopathy.

Consistent retinal screening is crucial in order to detect and treat DR at an early stage and prevent further retinal deterioration and irreversible vision loss (American Diabetes Association; Yadav et al.). However, traditional screening requires trained ophthalmologists to manually examine retinal fundus images, which is time-consuming and expensive, making it inaccessible in many regions around the world. Thus, the development of new forms of automated screening reduces costs and increases accessibility (Wolf et al.; Tahir et al.; Bhaskaranand et al.). In this context, deep learning-based methods, particularly convolutional neural networks (CNNs) prove to be promising tools for automated DR detection from fundus images. Explainability techniques such as Gradient-weighted Class Activation Mapping (Grad-CAM) help visualize the process of deep models, improving transparency and trust in diagnosis by pointing towards abnormalities (Selvaraju et al.). The paper focuses on the development of a CNN-based model for the classification of diabetic retinopathy. The approach integrates modern deep learning techniques including Grad-CAM to visualize and interpret the retinal regions influencing model predictions and provide insight on how the model generates predictions. Additionally, the paper explores the

effect of different loss functions such as ordinal-aware loss functions in comparison to conventional categorical cross-entropy loss, aiming to investigate the potential improvement in performance when using ordinal loss functions on inherently ordinal classes. Therefore, the key contributions of this work are as follows:

- We build and evaluate a CNN-based classifier for diabetic retinopathy detection trained on a combined Eye-PACS (Kaggle "Diabetic Retinopathy Detection Dataset") and APTOS (Kaggle "APTOS 2019 Blindness Detection Dataset") dataset with a collapsed 3-class labeling scheme.
- We compare the performance of different loss functions, including categorical cross-entropy, quadratic weighted kappa loss (Chivinge et al.), and class-distance weighted cross-entropy (Polat et al.), to assess the impact of ordinal-aware objectives on DR classification.
- We integrate Grad-CAM visualizations to provide insights into the learned decision process and highlight clinically relevant retinal regions influencing predictions.

Dataset and Preprocessing

The dataset used in this study was comprised of a combination of two publicly available datasets: the EyePACS dataset and the APTOS 2019 Blindness Detection dataset. Together, these datasets contain over 35,000 images with annotated labels corresponding to the severity of the DR. The dataset was obtained from Kaggle and is freely available on the website. Many of the images are lower quality or contain a large amount of noise, so proper preprocessing is essential to create a preferable dataset. For this study, around 6000 images were extracted from the dataset and the original 5-class labels were remapped into 3 broader classes:

- Class 0: No DR (original class 0)
- Class 1: Mild/Moderate DR (original classes 1 and 2)
- Class 2: Severe/Proliferative DR (original classes 2 and 4)

The class remapping and extraction of the 6321 images were performed to address severe class imbalance issues and simplify the task to better compare the different loss functions while retaining clinically meaningful distinctions in presence and size of retinal abnormalities. The distribution of the original dataset is shown in Figure 2, exhibiting the substantial predominance of class 0 compared to the other classes. In total, the final dataset for training and validation consisted of 6321 images with the following distribution (also shown in Figure 3):

- Class 0 (no DR): 2154 images
- Class 1 (mild/moderate): 2308 images
- Class 2 (severe/proliferative): 1889 images

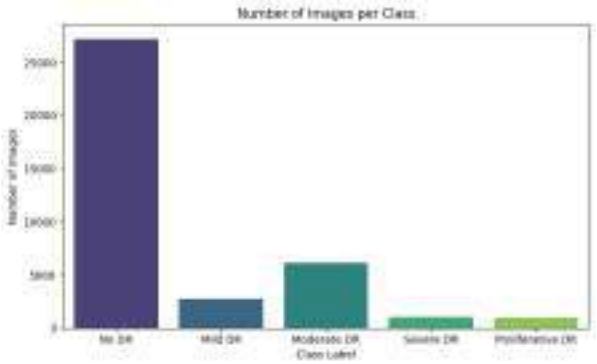


Figure 2. Original distribution of data across five classes.

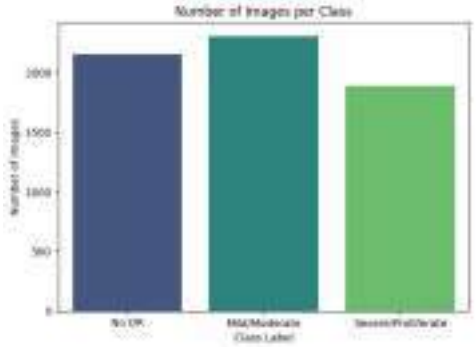


Figure 3. Distribution of data across three classes.

To prepare the images for model training, a consistent preprocessing pipeline was applied with various data augmentation techniques, as illustrated in Figure 4:

- Resizing: All images were resized to 224x224 pixels to match the resolution that is expected by EfficientNet-B0 (pre-trained CNN) (Tan and Le)
- Data Augmentation: Techniques for data augmentation include RandomHorizontalFlip, RandomRotation, and ColorJitter
- Normalization: All pixel values were normalized using the mean and standard deviation of the ImageNet dataset to allow compatibility with EfficientNet-B0 (Corley et al.)
- Format Handling: The two datasets contained both .jpeg and .png images, which were unified into a consistent input pipeline without conversion issues
- Dataset Splitting: The dataset was split into training and validation subsets at a 70/30 split using stratified sampling (Sadaiyandi et al.) to further ensure class balance across splits

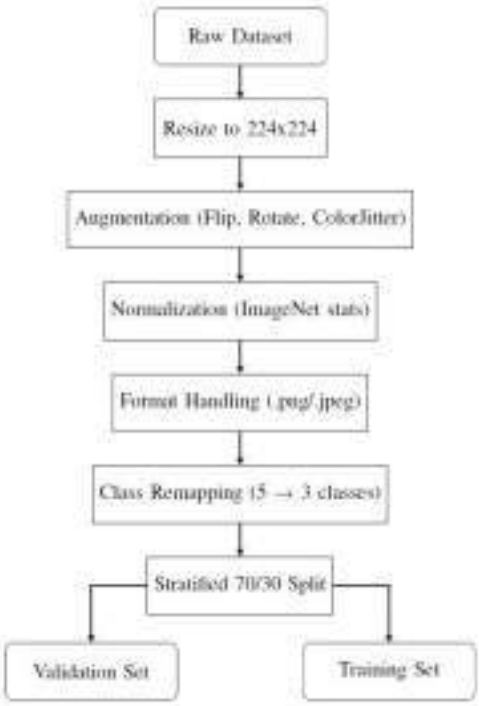


Figure 4. Preprocessing pipeline showing the sequence of transformations applied to the dataset prior to training/validation splitting.

Methods

This section provides a detailed description of the model architecture, loss functions, training pipeline, and explainability techniques used in this study. The approach leverages transfer learning by utilizing a pre-trained EfficientNet-B0 model (Tan and Le) as a feature extractor, combined with a custom classifier head. This strategy enables the model to benefit from the powerful feature extraction learned from the large-scale ImageNet dataset while allowing further fine-tuning on the diabetic retinopathy classification task.

Therefore, the complete model consists of the EfficientNet-B0 convolutional base followed by a lightweight custom classifier.

Model Architecture

The base architecture used for multi-class classification is EfficientNet-B0, a CNN known for attaining high accuracy with high parameter efficiency on visual recognition tasks. The original fully connected classifier head of EfficientNet-B0 was replaced with a custom fully connected layer consisting of a dense layer with 512 neurons and a Rectified Linear Unit (ReLU) activation function. This dense layer is followed by a final dense layer projecting to 3 output neurons that correspond to the 3 target classes. A diagram illustrating the referenced architecture is shown in Figure 5.

More specifically, the EfficientNet-B0 model employs Mobile Inverted Bottleneck Convolutions (MBConv) that offer significant benefits by increasing representational power

while maintaining computational efficiency. In each MBConv block, input channels are first expanded using a 1×1 pointwise convolution that allows the model to capture a richer set of features early on by increasing channel dimensionality early on. This is followed by a depthwise convolution (Chollet) which is computationally lightweight as it operates on each channel independently but does not sacrifice detail due to the expanded feature space. Finally, the dimensionality is reduced back to a compact form using an additional 1×1 convolution.

Many MBConv blocks also implement Squeeze-and-Excitation (SE) modules, which adaptively learn and recalibrate the relative importance of individual channels using mini neural modules to emphasize important features and suppress less relevant ones (Hu et al.). The network progressively reduces spatial resolution while increasing the number of channels, permitting the model to extract finer details, which is critical for detecting small, localized abnormalities in fundus images.

Training Procedure

The dataset was split into training 70% and validation (30%) subsets using stratified sampling to further ensure class balance. Training was performed for up to 75 epochs with early stopping applied based on validation F1-score with a patience of 5 epochs. Specifically, if the increment in F1 score was larger than the assigned minimum delta, training was stopped and the best model was selected as the final model. The F1 evaluation metric was calculated as follows:

$$F1 = \frac{TP}{TP + \frac{1}{2}(FP + FN)}$$

where TP represents the number of true positives (correct predictions of DR), FP the number of false positives (incorrect predictions of non-DR cases), and FN the number of false negatives (incorrect predictions of DR).

The optimizer used was Adam with an initial learning rate of 0.001, which was dynamically adjusted using a learning rate scheduler to encourage more precise adjustment and smoother convergence. To reduce overfitting, standard regularization techniques were incorporated via data augmentation as referenced in *Dataset and Preprocessing*. All training was performed on a single NVIDIA GPU.

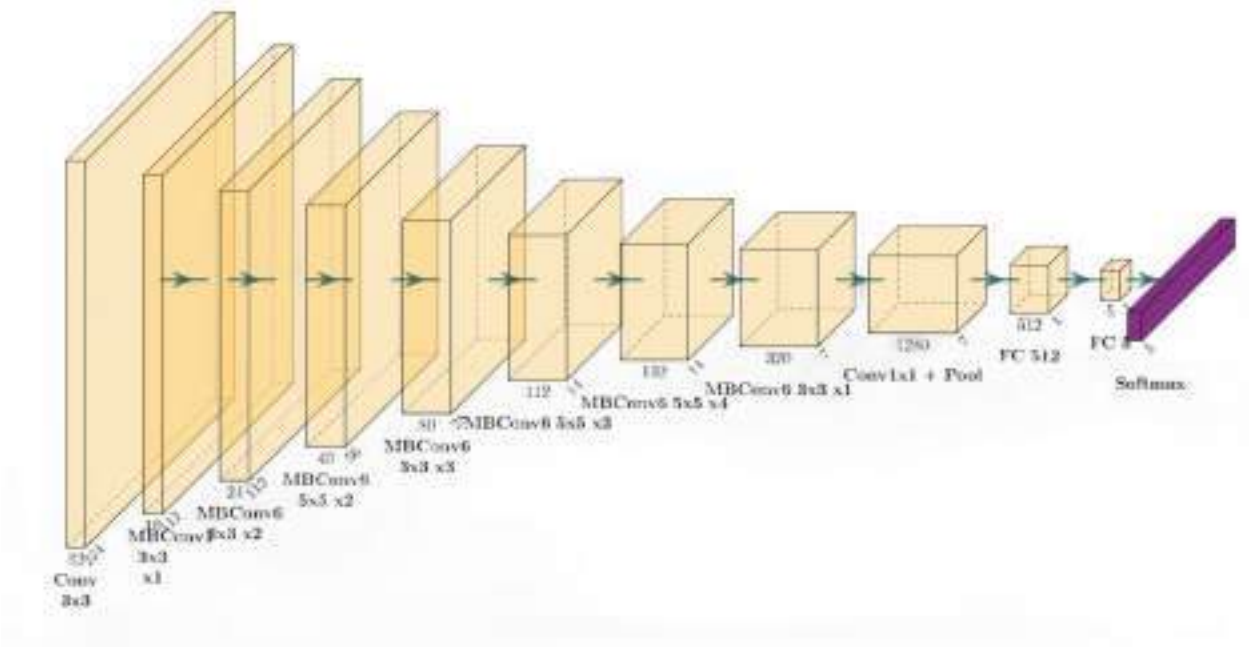


Figure 5. Modified EfficientNet-B0 architecture with custom classifier head for 3-class diabetic retinopathy classification

Loss Functions

One of the core goals of the paper is to investigate the impact of different loss functions on performance. Specifically, three loss functions were tested, including both traditional loss functions and ordinal loss functions:

1) Categorical Cross-Entropy Loss (CE): The standard loss function for multi-class classification tasks is defined by the following formula:

$$L_{CE} = -\sum_{k=1}^{K} y_k \log(p_k)$$

where y_i is the ground-truth label (one-hot encoded) and p_i is the predicted probability for class i.

2) Quadratic Weighted Kappa Loss (QWK): An ordinal-aware loss function that penalizes incorrect classification based on their distance from the true label. QWK extends Cohen's Kappa by applying quadratic weighting to penalize larger discrepancies much more heavily. It is defined as follows:

$$k = 1 - \frac{\sum_{i,j} W_{ij} O_{ij}}{\sum_{i,j} W_{ij} E_{ij}}, L_{QWK} = 1 - k$$

where $W_{ij} = (i - j)^2$ is the quadratic weighting matrix, *O* is the observed agreement matrix, and *E* is the expected agreement matrix under random agreement.

3) Class Distance Weighted Cross-Entropy Loss (CDWCE): A variant of cross-entropy loss that incorporates ordinal distances into the loss to also penalize classifications more based on their distance from the true label.

$$L_{CDWCE} = -\frac{1}{N}\sum_{n=1}^{N}\sum_{c=1}^{C} d(y_n, c)\log(p_n^c)$$

where $d(y_n, c)$ represents the ordinal distance between ground-truth class y_n and predicted class *c*.

4) In addition to testing the standard and ordinal-aware loss functions individually, a hybrid loss function combined both the standard cross-entropy loss function with Quadratic Weighted Kappa loss function to combine the reliability of cross-entropy loss with the ordinal sensitivity of QWK. Specifically, the hybrid loss L_{hybrid}, was constructed as a weighted sum of the two functions:

$$L_{hybrid} = 0.7 * L_{CE} + 0.3 * L_{QWK}$$

where L_{CE} represents the cross-entropy loss and L_{QWK} is the quadratic weighted kappa loss.

Explainability with Grad-CAM

Grad-CAM was implemented to provide visualization of which regions provided the greatest influence on model predictions. Grad-CAM generates heatmaps by computing the gradients of predicted classes with respect to feature maps.

An example of Grad-CAM visualization for each class is shown in Figure 6.

Results

The model was trained using different loss functions on the 3-class diabetic retinopathy classification task. The results are reported using both validation accuracy and F1-score, as these metrics reflect overall correctness of predictions and factor in recall.

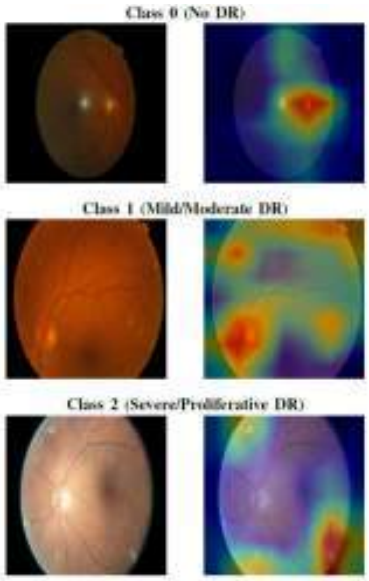


Figure 6. Example original fundus images and corresponding Grad-CAM visualizations for each DR severity class. Heatmaps highlight regions contributing most to model predictions.

The baseline model trained using standard cross-entropy loss achieved a validation accuracy of 73.3% and a weighted F1 score of 0.7329. This demonstrates that a traditional, straightforward loss function can perform reasonably well on a task like this.

The model trained using Quadratic Weighted Kappa loss exhibited improved performance in recognizing ordinal relationships and demonstrated a slightly worse accuracy and F1-score. The model displayed results with an accuracy of 69.7% and an F1-score of 0.6770. The key improvement in the model using QWK is its improved sensitivity to classes farther from the true label, leading to fewer false positives and fewer false negatives.
The Class Distance Weighted Cross-Entropy loss also yielded similar results, achieving a validation accuracy of 70.9% and a weighted F1-score of 0.7115. CDWCE produced a more balanced prediction distribution with reduced overconfidence and incorrect positive predictions.

To further test the effect of using ordinal-aware loss functions, a hybrid loss function approach combining categorical cross-entropy loss and Quadratic Weighted Kappa loss was evaluated. The hybrid model achieved a peak with a validation accuracy of 76.4% and an F1-score of 0.7668, emphasizing the superiority of the hybrid function.

A comparison of the performance of each loss function is presented in Figure 7, and the confusion matrix of the hybrid function is shown in Figure 8. Specifically, the misclassifications of the hybrid model predominantly occurred adjacent to the true label while misclassifications that predicted distant ordinal classes (e.g., between Class 0 and 2) were very rare. This indicates that the hybrid model benefited from the incorporation of an ordinal-aware loss function.

Finally, Grad-CAM explainability analysis supported the reliability of trained models. Heatmaps were produced using the best model (using the hybrid loss function) and revealed that the model focused attention on pathological markers for DR relatively consistently. The

visualization provided by Grad-CAM-- shown in Figure 6--provided key insight into what influences the model's predictions as well as increasing trustworthiness in predictions.

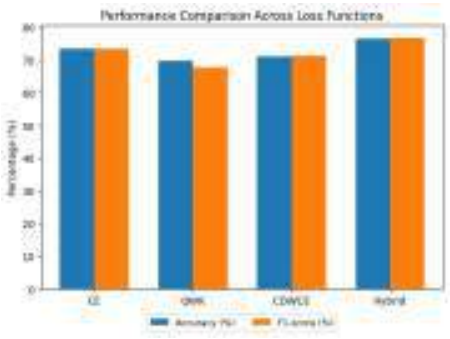


Figure 7. Validation accuracy and F1-score comparison across loss functions

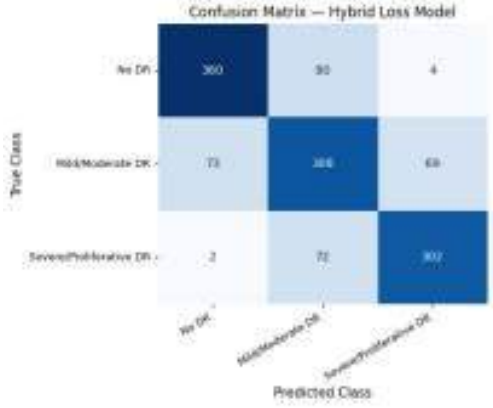


Figure 8. Confusion matrix for hybrid loss model on validation set

Discussion

The experimental results demonstrate that tailored loss function design can significantly impact the performance of deep learning models for DR classification. While standard cross-entropy loss produced the best results from individual loss functions, the ordinal-aware loss functions including QWK and CDWCE improved the distribution of predictions to favor classes closer to the true label, an outcome that could be considered valuable despite slightly lower accuracy.

The hybrid loss function, combining both CE and QWK using a weighted sum, was able to achieve the highest validation accuracy and F1-score, outperforming all the individual loss functions. These findings suggest that blending traditional loss functions with those that exhibit ordinal sensitivity can achieve better performance for tasks with data of an inherently ordinal nature such as DR severity classification. Furthermore, incorporating an ordinal-aware loss function reduced misclassifications across more distant severity stages, which could prove beneficial in a clinical setting where the cost of incorrect predictions are asymmetric.

An important factor to consider is that even though overall accuracy improvement between loss functions may appear moderate, even minor jumps in accuracy were significant given the nature of the data. The dataset proved to be a major limitation due to the fact that many images were

low quality or likely mislabeled, making it difficult for the model to maintain its understanding of complex patterns. This led to a situation where improvements in predictions for one class often came at the expense of accuracy on others, making even moderate improvements into important leaps.

Grad-CAM visualizations confirmed that all models consistently focused on relevant regions in the images, highlighting relevant retinal regions containing abnormalities that served as markers for DR. This confirms that the model succeeded at learning to detect clinically meaningful features instead of making random guesses.

Despite these results, there were some key limitations. The dataset used, although preprocessed to improve balance, was relatively small after balancing, being reduced to 6321 images from over 35,000 due to class imbalance. Additionally, although the hybrid model demonstrated the best results, its weighting was empirically chosen and not finely tuned, leaving room for improvement.

Future work could focus on testing on larger, more uniform datasets and exploring additional ordinal aware loss functions that could boost performance when incorporated into the hybrid loss function. Integrating better preprocessing pipelines to mitigate noise and inconsistent quality could enhance model performance.

Overall, the paper reinforces that certain loss functions tailored to the ordinal nature of DR classification can significantly enhance the performance of automated classification systems, and explainability through tools such as Grad-CAM can provide insight into the regions that influenced predictions.

Conclusion

The paper presented a deep learning approach to the automated classification of diabetic retinopathy and explored the impact of loss function design and model explainability. The proposed hybrid loss function, which blends standard cross-entropy loss with QWK, achieved the best overall performance and demonstrated the benefits of incorporating ordinal-aware loss functions into a model when the data exhibits an inherently ordinal nature. Grad-CAM visualizations further reinforced the ideas presented in the paper by displaying what specifically influences predictions, enhancing model interpretability and trustworthiness. Overall, this work contributes to the development of more accurate and trustworthy automated screening systems for diabetic retinopathy that could improve early detection of the disease globally.

Acknowledgements

The author thanks the creators of the EyePACS and APTOS datasets for providing open access data used in this study.

Works Cited

World Health Organization. "Diabetes Fact Sheet." World Health Organization, 2024, www.who.int/news-room/fact-sheets/detail/diabetes. Accessed 2025.

NCD Risk Factor Collaboration. "Worldwide Trends in Diabetes Since 1980: A Pooled Analysis of 751 Population-Based Studies." Lancet, vol. 387, no. 10027, 2016, pp. 1513-30.

Zheng, Y., et al. "The Worldwide Epidemic of Diabetic Retinopathy." Current Opinion in Ophthalmology, vol. 23, 2012, pp. 87-95.

Sayin, N., et al. "Ocular Complications of Diabetes Mellitus." World Journal of Diabetes, vol. 6, no. 1, 2015, pp. 92-108.

Fyra.io. "The Four Stages of Diabetic Retinopathy." 2019, modernod.com/articles/2019-june/the-four-stages-of-diabeticretinopathy. Accessed 2025.

Tymchenko, B., et al. "Deep Learning Approach to Diabetic Retinopathy Detection." arXiv, 2020, arxiv.org/abs/2003.02261. Accessed 2025.

Jenkins, A. J., et al. "Biomarkers in Diabetic Retinopathy." Review of Diabetic Studies, vol. 12, no. 1-2, 2015, pp. 159-95.

Triwijoyo, B. K., et al. "Deep Learning Approach for Classification of Eye Diseases Based on Color Fundus Images." Advances in Computer Vision and Pattern Recognition, Academic Press, 2020, pp. 25-57.

Murugesan, N., et al. "Thrombosis and Hemorrhage in Diabetic Retinopathy: An Inflammatory Perspective." Seminars in Thrombosis and Hemostasis, vol. 41, no. 6, 2015, pp. 659-64.

Joshi, S., and P. Karule. "A Review on Exudates Detection Methods for Diabetic Retinopathy." Biomedicine & Pharmacotherapy, vol. 97, 2018, pp. 1454-60.

American Diabetes Association. "Microvascular Complications and Foot Care: Standards of Medical Care in Diabetes—2021." Diabetes Care, vol. 44, supplement 1, 2020, pp. S151-67.

Yadav, P., et al. "Impact of Severity of Diabetic Retinopathy on Quality of Life in Type 2 Indian Diabetic Patients." International Journal of Community Medicine and Public Health, vol. 8, no. 1, 2020, p. 207.

Wolf, R. M., et al. "Autonomous Artificial Intelligence Increases Screening and Follow-Up for Diabetic Retinopathy in Youth: The ACCESS Randomized Control Trial." Nature Communications, vol. 15, 2024, p. 421.

Tahir, H. N., et al. "Artificial Intelligence versus Manual Screening for the Detection of Diabetic Retinopathy: A Comparative Systematic Review and Meta-Analysis." Frontiers in Medicine, vol. 12, 2025.

Bhaskaranand, M., et al. "Automated Diabetic Retinopathy Screening with the EyeArt System: More Than 100,000 Encounters." Diabetes Technology & Therapeutics, vol. 21, no. 11, 2019, pp. 635-43.

Selvaraju, R. R., et al. "Grad-CAM: Visual Explanations from Deep Networks via Gradient-Based Localization." Proceedings of the IEEE International Conference on Computer Vision, 2017.

Kaggle. "Diabetic Retinopathy Detection Dataset." 2015, www.kaggle.com/competitions/diabetic-retinopathy-detection. Accessed 2025.
Kaggle. "APTOS 2019 Blindness Detection Dataset." 2019, www.kaggle.com/competitions/aptos2019-blindness-detection. Accessed 2025.
Chivinge, L., et al. "Quadratic Weighted Kappa Score Exploration in Diabetic Retinopathy Severity Classification Using EfficientNet." 1st Zimbabwe Conference of Information and Communication Technologies (ZCICT), IEEE, 2022, pp. 1-9.
Polat, G., et al. "Class Distance Weighted Cross Entropy Loss for Classification of Disease Severity." Expert Systems with Applications, vol. 269, 2025, p. 126372.
Tan, M., and Q. Le. "EfficientNet: Rethinking Model Scaling for Convolutional Neural Networks." Proceedings of the International Conference on Machine Learning, 2019.
Corley, I., et al. "Revisiting Pre-Trained Remote Sensing Model Benchmarks: Resizing and Normalization Matters." arXiv, 2023, arxiv.org/abs/2305.13456. Accessed 2025.
Sadaiyandi, J., et al. "Stratified Sampling-Based Deep Learning Approach for Unbalanced Data." Electronics, vol. 12, no. 21, 2023, p. 4423.
Chollet, F. "Xception: Deep Learning with Depthwise Separable Convolutions." arXiv, 2016, arxiv.org/abs/1610.02357. Accessed 2025.
Hu, J., et al. "Squeeze-and-Excitation Networks." arXiv, 2019, arxiv.org/abs/1709.01507. Accessed 2025.

Advancing Aortic Morphology Analysis: LCPC Transform Technique Application for Shape-Based Acute Aortic Dissection Characterization By Srianshi Samantaray

INTRODUCTION

Acute Aortic Dissection (AAD) is an acute cardiovascular crisis characterized by a tear in the intima layer of the aorta, the largest artery of the body and primary vessel for the distribution of blood from the heart to the remainder of the body. As this tear occurs, blood enters the aortic wall, which splits its layers and forms an artificial lumen that can compress the real lumen, restrict blood flow, or form blood clots known as thrombi that will subsequently stiffen the vessel wall. When the dissection begins to rupture, it can cause internal hemorrhage and harm in its enormity. Patients typically experience sudden and severe chest or back pain that is described as "tearing" or "ripping" in nature, and can be felt in the neck, jaw, abdomen, or back. Other presenting symptoms are shortness of breath, syncope, weakness, and stroke-like presentations.

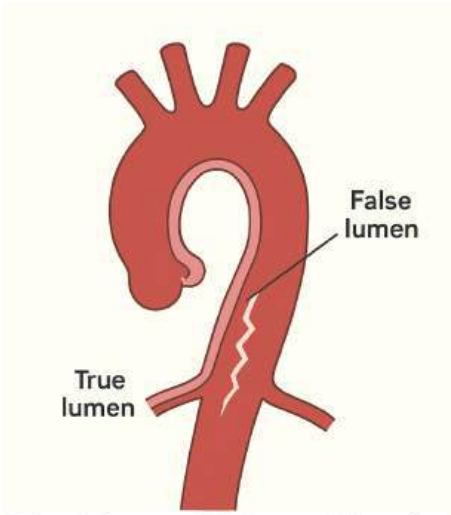


Figure 1. Structure of the Aorta and Formation of True and False Lumens. Acute Aortic Dissection (AAD) occurs when a tear in the intimal layer allows blood to enter the medial layer, creating a false lumen that separates it from the true lumen. The true lumen represents the normal blood flow channel, while the false lumen forms an abnormal passage within the vessel wall.

Traditionally, research has focused mainly on diameter measurement, centerline analysis, and volume calculation to describe the morphology of aortic dissection. Most research has examined plain two-dimensional and three-dimensional geometry, but these approaches lack the subtlety to identify differences in shape that can distinguish subtypes. There is not yet a conventional shape-based method to transform dissection geometry to mathematical function. This research study explores that gap by utilizing the The Linearized Compressed Polar Coordinate (LCPC) Transform, which provides the ability to measure morphology in a new way, beyond diameter-based measurement. Such an approach can help clinicians and researchers identify shape cues, and accelerate classification by automating it. Moreover, the ability to properly describe morphology would open new doors for targeted treatments, customized surgical modifications, and research into how some dissection shapes relate to genetics, disease development, and outcomes.

ACADEMIC CONTEXT

AAD is most common in older adults with a maximum age of 60-80 years, but it can also present in younger individuals with connective tissue disorders such as Marfan syndrome or Ehlers-Danlos syndrome. Epidemiologic studies have also suggested population differences: men are more frequently affected, and women present in later and with more severe complications.

African American patients have been reported to have higher incidence and poorer outcomes, presumed related to higher rates of uncontrolled hypertension. Indeed, hypertension is the most important single risk factor for AAD. Other major risk factors include congenital aortic abnormalities such as bicuspid aortic valve, connective tissue disorders, hemodynamic changes in pregnancy, atherosclerosis, chest trauma, pre-existing aneurysm of the aorta, and aortic disease in family history. It is diagnosed on the basis of clinical presentation and advanced imaging modalities. CT angiography is the gold standard, although MRI and TEE are employed to a large extent in the monitoring of aortic shape and hemodynamics. Other symptoms include differential blood pressure between the limbs and increased mediastinum on chest X-ray.

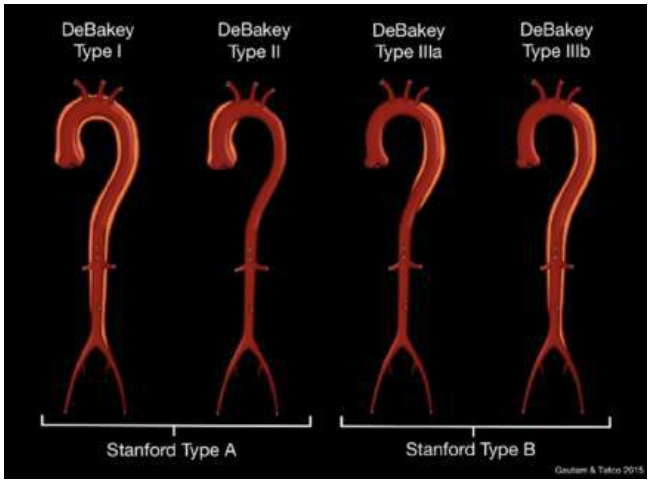


Figure 2. Classification of Aortic Dissections by DeBakey and Stanford Systems. Aortic dissections are categorized by the site and extent of the intimal tears. *DeBakey Type I* involves the ascending and descending aorta, *Type II* is confined to the ascending aorta, *Type IIIa* is limited to the thoracic aorta, and *Type IIIb* extends below the diaphragm. *Stanford Type A* includes DeBakey I–II, while *Stanford Type B* includes DeBakey IIIa–IIIb.

AAD classification is important for the guidance of treatment. The most widely employed is the Stanford system, which makes a distinction between Type A and Type B dissections. Type A dissections involve the ascending aorta, and require emergency operation to repair. Type B dissections involve the descending aorta, and are typically managed medically unless there are major complications, in which case surgery is necessary.

DeBakey's system adds additional specificity: Type I dissections are caused in the ascending aorta and extend into the arch and descending aorta, Type II are confined to the ascending aorta, and Type III begin in the descending aorta and can extend to the abdominal aorta. Treatment is varied accordingly, with surgical interventions like open-heart repair or endovascular stenting for more serious cases, and medical therapy, usually beta-blocker therapy, aimed at strict blood pressure control for less serious cases.

Apart from clinical management, recent studies have also placed a high priority on morphology and hemodynamics in the explanation and prediction of AAD. Various landmark studies have reinforced this perception. First, statistical shape analysis demonstrated that three-dimensional aortic features were closely related to dissection risk and matching hemodynamic stress patterns. Second, morphologic predictors, namely geometric features of the

thoracic aorta were put forward as predictors of high-risk patients. Third, advanced imaging and computational modeling have enabled noninvasive determination of morphologic and hemodynamic parameters, particularly in Type B dissections. These findings collectively highlight the significance of aortic shape and hemodynamic blood flow in determining risk and clinical outcome.

METHODS

The dataset used in this study was downloaded from Figshare (aortic Vessel Tree [AVT] CTA Datasets and Segmentations) as an open-access material for thoracic CT angiography scans with segmented aortic structures (Figshare, 2021). The dataset includes various scan views and annotations for differentiating healthy and diseased aortas to enable comparisons by conditions. Since this project is being done as a pilot study to test feasibility, analysis of only a small subset of the entire dataset will be done. Even though the dataset is multicenter, which means some geographic diversity is implied, it is not large. With small numbers of aneurysm or aortic dissections and its representativeness by race, sec, or global populations cannot be determined.



Figure 3. Original CT Scan of the Aorta. Three-dimensional reconstruction of the thoracic and abdominal aorta showing the full vascular structure prior to image processing.

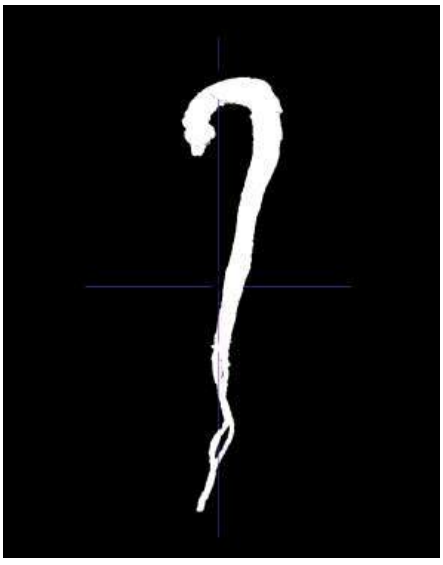


Figure 4. Processed Aortic Structure in ImageJ. The aortic lumen is isolated and enhanced in contrast to visualize the vessel boundaries for quantitative analysis.

IMAGE PROCESSING.

The primary software for processing and visualizing CT scans will be ITK-SNAP (version 4.0) and FIJI (ImageJ, version 2.14/1.54). The public domain 3D medical image viewer ITK-SNAP will be used to import the CT scans and visualize the aorta in three dimensions for the identification of both normal and pathological morphologies and patterns in the location of dissections. FIJI, with a set of plugins facilitating sophisticated image analysis, will be used to convert CT slices to 2D images and trace the boundaries of the aortic wall. Accurate shape contours for quantitative subsequent processing will be produced by this procedure.

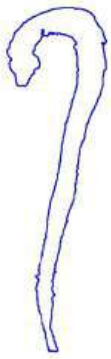


Figure 5. LCPC Transform Outline of the Aorta. The extracted contour of the aortic structure following application of The LCPC Transform, representing the vessel's geometric profile for computational analysis.

APPLICATION OF THE LCPC TRANSFORM.

The aortic outlines obtained will be processed with the Linearized Compressed Polar Coordinate (LCPC) Transform (version 2.0). The LCPC Transform converts body contours into quantitative frequency data, operationally converting complex forms into numbers. More than large diameter, area, or circumference measurement, the LCPC Transform provides a more sensitive analysis of form that enables the detection of subtle differences that would define new subtypes of AAD. The goal in applying this method is to determine if new morphological subtypes can be recognized and if these patterns will have prognostic significance for treatment and diagnosis planning.

This study requires experience with a range of technical software. Image thresholding and segmentation techniques will be applied in ITK-SNAP and FIJI to separate out the aorta, with radiological conventions for accurately labeling anatomical orientations being familiar. Python programming, done in Jupyter Notebook, will apply the LCPC Transform and regulate data output. Some elementary familiarity with the Fourier Transform will also be necessary as it is the foundation of some elements of the LCPC Transform algorithm. Comparisons between healthy and diseased aortas based on findings in the Transform will be made to determine whether morphological differences are identifiable in a reliable way. Analysis will determine specifically whether such differences can be identified well enough to suggest that there are new existing subtypes of AAD. Results will be presented in relation to dataset limitations and demographic variability.

The aim of this study is to establish whether the LCPC Transform can be used to differentiate normal and dissected aortas and to identify AAD-specific morphological patterns. The goals of this research on the other hand can be quantified into three main concepts. Firstly, this study aims to demonstrate how the LCPC Transform outperforms traditional measurement methods. Secondly, it focuses on detailing and comparing the shape characteristics of normal and dissected aortas. Lastly, this research has an objective to present early evidence favoring the construction of future shape based classification systems for enhanced diagnosis, risk stratification, and personalized treatment in AAD.

To achieve this, I will use the LCPC Transform on three-dimensional CT scans of the aorta, examine the generated quantitative data, and compare patterns between control and dissected cases to determine differentiating morphological signatures.

RESULTS

OVERVIEW OF THE PCA APPLICATION.

To provide an overview on the PCA application, it's important to note what exactly it is and what it did in the context of this research. Principal Component Analysis (PCA) was applied to the LCPC Transform output to reduce high-dimensional frequency data to principal components (PCs) that capture the greatest sources of variation in aortic shape. PC1 (x) captures the direction of maximal variance within the dataset, while PC2 (y) and PC3 (z) capture the next orthogonal axes of reducing variance. Collectively, the first three components captured most of the geometric variability and thereby provided an informative space in which normal and dissected aortas could be compared.

CONDITIONS OF THE STUDY.

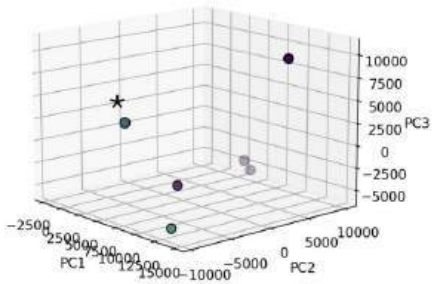
Next, it's also crucial to note that this study was done by observing the morphology of the entire aorta. When the entire length of the aorta was taken into consideration, samples projected into PC1–PC3 space exhibited significant overlap between AAD and normal groups. Normal specimens were dispersed across a wide range of PC1 values, and some overlapped with dissected aortas. This implies that whole-aorta measurements, while reflecting global shape differences, do not have the differentiating power. Aneurysm cases also overlapped partially with the two groups, reflecting their intermediate morphological signatures. The conclusion from this phase of analysis is that whole-aorta geometry alone is not reliable in the discrimination of AAD from normal anatomy

Not all normal aortas followed the expected clustering pattern. A subset of morphologically "normal" aortas had PCA signatures closely resembling those of AAD cases. These outliers suggest the presence of AAD-like normal subtypes, which may be anatomical predispositions to dissection, transitional geometries, or limitations of the dataset. Their presence highlights the sensitivity of LCPC-derived data: while traditional diameter or area measurements would likely classify these cases as normal, the frequency-based approach picks up on underlying shape similarities to pathological cases.

By inspection of the principal directions, PC1 captured largely large-scale geometric variation, including overall curvature and vessel elongation. PC2 appeared to capture mid-scale irregularities along the aortic wall, while PC3 accounted for finer variations in contour. The ability to separate cases in this reduced-dimensionality space confirms that PCA, when paired with LCPC, can capture clinically meaningful features of morphology beyond gross measurements.

To summarize the information presented above:

1. Whole-aorta PCA: Normal and AAD cases overlapped significantly; diameter-based morphology remains insufficient for discrimination.



2. Normal subtypes: One group of normals was morphologically similar to AAD, raising questions of prognostic significance and confirming the greater sensitivity of LCPC.
3. Interpretation of PCs: PC1–PC3 encapsulate global-to-local morphological variability, highlighting their effectiveness at capturing the range of aortic shapes.

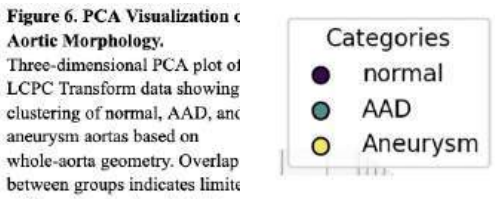


Figure 6. PCA Visualization o Aortic Morphology. Three-dimensional PCA plot of LCPC Transform data showing clustering of normal, AAD, and aneurysm aortas based on whole-aorta geometry. Overlap between groups indicates limite differentiation using global shape features.

These results together imply that PCA of LCPC Transform data can detect subtle morphological trends, distinguish diseased from normal aortas more clearly when considered regionally, and possibly identify at-risk subtypes of overall normal morphology.

DISCUSSION

The present study sought to evaluate the potential of the Linearized Compressed Polar Coordinate (LCPC) Transform, in conjunction with principal component analysis (PCA), as a novel methodology for the description of intact and dissected aorta morphology. Traditional morphometric descriptors, such as maximum diameter, circumference, or cross-sectional area, have been utilized for decades as standard in clinical evaluation of aortic disease. However, such parameters provide only crude worldwide data and are not ideally suited to chart the fine-grained, localized morphological alterations that dictate the pathophysiology of acute aortic dissection (AAD). Results of this pilot study suggest that frequency-based descriptors generated by the LCPC Transform provide better discriminatory power and may be the basis for a more nuanced morphological classification system.

Whole-length aortic analysis according to LCPC-derived frequency data and following PCA revealed extensive overlap between the normal and dissected groups. The finding is consistent with the earlier findings that global morphological markers such as whole-aorta diameter or length cannot effectively differentiate between healthy and diseased individuals (Nienaber & Clough, 2015; Erbel et al., 2014). The extensive spread of run-of-the-mill cases with respect to PC1 values and the overlap with AAD cases emphasize the limitation of a whole-vessel perspective. Regional division of the thoracic aorta, however, resulted in far superior discrimination between groups. Four of five AAD cases clustered within a definable region of principal component space, largely distinct from normal specimens. This is in accord with the theory that local geometric irregularities, rather than global expansion in itself, are the determinants of dissection risk morphologically. These results corroborate earlier shape analysis studies, which have emphasized the roles of localized curvature, wall asymmetry, and geometric irregularity in destabilizing the vessel wall and producing dissection events (Bollache et al., 2019; Pasta et al., 2012).

An additional important finding was the detection of "outlier" normal aortas with frequency-based signatures comparable to those in AAD cases. Several explanations are

possible. These aortas could be transitional or preclinical morphologies conferring increased susceptibility to subsequent dissection and could therefore serve as markers of cryptic risk. They could also be normal anatomical variation not clinically significant but detectable nonetheless using this sensitive method. However, the existence of such overlap strengthens the validity of the LCPC Transform's power to detect morphology that is not defined by threshold-based diameter. Subsequent longitudinal analyses will need to determine if such outliers actually develop to pathology or represent benign variability throughout the population.

Principal components interpretation again highlights the strength of this methodology. PC1 preserved large-scale vessel curvature and extension, PC2 preserved intermediate-scale wall irregularities, and PC3 preserved finer contour details. The ability to decompose shape variation by scale is particularly valuable in the case of AAD, where small wall irregularities can contribute disproportionately large amounts to biomechanical stress distribution. Linking these morphological axes to computational fluid dynamics and wall stress modeling holds particular promise for future work. Such integration would make mechanistic relationships between hemodynamic forces, morphology, and outcome possible, enhance risk prediction and pathophysiological understanding.

It also notes some methodological advantages. The LCPC Transform provides mathematically valid, automated ways of converting challenging vascular contours into quantitative descriptors, reducing observer variability and enhancing reproducibility. When used in conjunction with dimensionality reduction algorithms such as PCA, the method facilitates visualization and clustering of specimens beyond what is attainable by typical morphometric analysis. In addition, the regional paradigm of segmentation is clinically relevant in that risk of dissection is generally localized within some anatomical zones, e.g., the ascending thoracic aorta.

Important limitations should, however, be mentioned. First, the present analysis was constrained by the small sample size and the limited demographic representation of the Figshare dataset. While the multicenter derivation of the data implies some heterogeneity, the representativeness of the dataset to sex, race, and age distributions is uncertain. Second, as a pilot analysis, statistical power was insufficient to make definitive conclusions about classification accuracy or predictive value. Third, the use of segmentation accuracy as an anchor introduces a source of variability, particularly under changing image quality. Manual thresholding and tracing, while unavoidable here, can potentially introduce variability that can affect LCPC results. Fourth, the study's cross-sectional design precludes analysis of longitudinal progression, limiting the ability to formulate causal associations between morphology and clinical outcomes.

Despite these limitations, findings provide proof-of-concept validation for the LCPC Transform as a useful tool for morphological description of AAD. By identifying concealed geometric variability that leaks to traditional measures, the method is not only viable for retrospective analysis but also has future potential in risk stratification. If validated in larger cohorts, LCPC-based morphology could potentially find application in the construction of shape-based classification schemes that supplement or even obviate diameter-based thresholds in clinical practice today. Such schemes could enhance diagnostic precision, identify at-risk

subgroups earlier, and guide individualization of therapeutic strategies, including timing of surgery and form of repair modality.

Guidelines for future research should therefore include extension of this method to larger, heterogeneous, and longitudinally followed cohorts, integration with biomechanics modeling to link shape descriptors to wall stress, and examination of correlations of LCPC-based morphology with genetic, demographic, and clinical variables. Ultimately, integration of shape-based analytics with hemodynamic modeling and molecular profiling can enable an integrated, multimodal strategy to aortic dissection understanding and management.

CONCLUSION

This pilot study demonstrates that the Linearized Compressed Polar Coordinate (LCPC) Transform, coupled with principal component analysis, is a novel and sensitive approach to the assessment of aortic morphology in acute aortic dissection. Whereas conventional diameter or perimeter measures are of modest discriminatory utility, LCPC-derived descriptors quantified regional shape differences that discriminated between dissected and normal aortas and characterized outlier morphologies of potential clinical significance. In spite of the constraints of a small and heterogeneous dataset, these findings offer proof of concept that frequency-based morphological analysis can manifest outside of classical geometric measurements. Validation in larger and longitudinal cohorts could see the LCPC Transform form the basis of new shape-based classification systems, improve diagnostic precision, stratify risk more accurately, and ultimately guide more individualized therapeutic approaches for patients with aortic disease.

Works Cited

1.Baman, J. R., & Malaisrie, S. C. (2023). What is aortic dissection? JAMA, 330(2), 198. https://doi.org/10.1001/jama.2023.5592

2.Gautam, R. (2016). CT imaging of non traumatic aortic emergencies: Acute aortic syndrome and beyond. European Congress of Radiology. https://doi.org/10.1594/ECR2016/C-1286

3.Murillo, H., Molvin, L., Chin, A. S., & Fleischmann, D. (2021). Aortic dissection and other acute aortic syndromes: Diagnostic imaging findings from acute to chronic longitudinal progression. RadioGraphics, 41(2), 425-446. https://doi.org/10.1148/rg.2021200138

4.Thrumurthy, S. G., Karthikesalingam, A., Patterson, B. O., Holt, P. J. E., & Thompson, M. M. (2011). The diagnosis and management of aortic dissection. BMJ, 344(jan11 1), d8290. https://doi.org/10.1136/bmj.d8290

Market Power in K–12 Textbooks: Price Discrimination, Procurement Risks, and Policy Remedies By Alonzo Estrada

Abstract

The K–12 textbook and curriculum market in the United States is dominated by a few large publishers, and a small group of powerful adoption states – especially Texas, California, and Florida – heavily influences what gets taught. Their statewide review processes and purchasing power help set national expectations for both content and price (Schmidt).

Centralized adoptions and bulk deals are meant to save money and improve quality, but in a concentrated market they often enable price discrimination and weak procurement. Smaller districts may pay more than large ones for the same materials; bundled add-ons and short-term digital licenses drive up long-run costs; and frequent new editions push districts to replace books that are still instructionally usable.

This paper explains how the K–12 curriculum market is structured, how adoption cycles work, and where pricing and procurement break down. It shows that these failures hit small and under-resourced districts hardest, with consequences for equity, budgets, and classroom instruction. It then evaluates policy options such as enforcing lowest-price rules, increasing transparency around adoption criteria and contracts, expanding regional buying consortia, and widening access to high-quality open educational resources (OER). Stronger oversight, combined with robust OER, can curb publisher market power, protect taxpayers, and ensure that teachers and students have materials that are effective, affordable, and usable.

Introduction

In most public schools, textbooks and curriculum platforms feel like neutral background tools, but they sit at the center of a multi-billion-dollar marketplace shaped by a small group of publishers and a few powerful states. When this market works well, states and districts can secure standards-aligned materials at fair prices. When it does not, systems overpay for products they cannot fully use or get locked into contracts that drain funds from other priorities.

This paper asks: How does market concentration in the K–12 textbook sector enable price discrimination and risky procurement practices, and what policy tools can mitigate those harms? I argue that enforcing lowest-price statutes, increasing price and contract transparency, aggregating purchasing power for small districts, and investing in state-supported OER can blunt publisher market power and improve equity for under-resourced systems.

Research has documented rising textbook prices, the role of bundled “enhanced offerings,” and automatic or “inclusive access” billing models that turn one-time purchases into recurring fees (U.S. Government Accountability Office; U.S. PIRG Education Fund). Studies of OER find that open materials can generate major cost savings while maintaining or improving learning outcomes (Wiley et al., “A Preliminary Examination”; SPARC). Policy work and journalism on adoption show how a few states can shape content and offerings nationwide (Schmidt; EdReports, “Our Process”).

Methods and scope. This paper draws on state statutes and administrative rules from Texas and Florida that define publisher obligations (Texas Education Code §31.151; Florida Statutes; Florida Administrative Code); state and district documents on instructional materials funding and adoption (Texas Education Agency; Tennessee Department of Education); investigative reporting on the Los Angeles Unified iPad initiative and Tennessee's textbook commission disputes (Edwards; Lapowsky; Torres and Watanabe; Chalkbeat Tennessee Staff; Stockard); and research on pricing, automatic billing, and OER (U.S. Government Accountability Office; U.S. PIRG Education Fund; Wiley et al., "A Preliminary Examination"; SPARC). Case studies from Florida, Los Angeles, and Tennessee show how market power appears in pricing, vendor lock-in, and politicized adoption.

The sections that follow explain how the K–12 market is structured, analyze pricing tactics and edition cycles, examine key controversies, trace consequences for equity and classrooms, and present a set of policy reforms.

Background: How the K–12 Market Works

Textbook publishing for K–12 education in the United States is highly concentrated. After decades of mergers, three or four big firms – especially McGraw Hill, Savvas Learning Company (formerly Pearson's K–12 arm), and Houghton Mifflin Harcourt (HMH) – control much of the market. HMH reports that its programs, including core texts and supplements, are used in roughly 90 percent of U.S. K–12 schools, showing how widely a single company's materials can reach (Houghton Mifflin Harcourt).

Selection procedures differ by state. Nineteen states plus Washington, D.C. use statewide adoption systems: a state agency or board vets materials for standards alignment and suitability, then publishes an approved list and, in some cases, price contracts that districts can use to access funding (Schmidt). The remaining states rely on local adoption, but many districts still look to state guidance or independent reviewers such as EdReports, which publishes public ratings of instructional materials (EdReports, "Our Process").

Because of their size and centralized processes, Texas, California, and Florida have outsized influence on what gets published. From March 2020 to March 2021, California, Florida, and Texas spent about 3.9 million, 8.5 million, and 2.3 million dollars, respectively, on instructional materials; together, their purchases accounted for about one quarter of pre-K–12 resource revenue for publishers (Schmidt). Publishers often tailor content to meet these states' requirements, since winning one of these adoptions can determine a product's success.

Adoptions typically follow multiyear subject cycles, creating predictable windows for districts to update materials and for publishers to release new editions. Texas and Florida largely use statewide lists for most grades, while California centrally adopts K–8 materials and allows district-level choice in high school (Schmidt; Center for Education Market Dynamics). Texas has recently moved toward "homegrown" Bluebonnet-branded textbooks to exert more direct control over content, illustrating how politics and market structure intersect (Simmons).

Even in local-adoption states, districts may form consortia or piggyback on state-negotiated prices to improve leverage. Recent reforms emphasize transparency and participation, including open meetings, posted evaluation reports, and formal opportunities for teacher and parent input; California, for example, requires fair representation of diverse groups in social studies texts (Schmidt). Yet despite these safeguards, market concentration still shapes both costs and options. With only a few dominant providers, states and districts face limited real choice, and without strong oversight and clear purchasing rules, they are vulnerable to higher prices, faster edition churn, and uneven access to high-quality materials.

Pricing Mechanics: Discounts, Bundles, and Subscriptions

In theory, bulk purchasing by states or large districts should lower per-unit prices, and many states have statutes meant to guarantee that outcome. In practice, publishers still have strong incentives to maximize profit and may use tactics that undercut the spirit or letter of those rules, especially for smaller buyers.

Several states use "most-favored" or lowest-price clauses that require publishers to charge no more than the lowest price offered anywhere else in the country. Texas, for example, requires publishers to furnish materials at a price that does not exceed the lowest price offered to any state, public school, or district, and to extend later price reductions and free ancillary items automatically (Texas Education Code §31.151). Florida has nearly identical obligations written into its education code and administrative rules (Florida Statutes; "Florida Statutes §1006.38"; Florida Administrative Code).

Recent events in Florida suggest that these protections are not always honored. In August 2025, the state attorney general sued McGraw Hill and Savvas, alleging that they violated Florida's lowest-price statute by overcharging districts in at least 5,900 transactions (WLRN News; WFLX; Badillo). According to local reporting, some titles were heavily discounted for large systems such as Miami-Dade but sold at higher prices to other districts, which collectively overpaid by hundreds of thousands of dollars; Osceola County alone is alleged to have overpaid more than 279,000 dollars on a single adoption (Badillo). State officials have described this pattern as corporate greed that penalizes smaller or less wealthy districts and are seeking reimbursement and substantial penalties (WLRN News; WFLX).

Bundling further complicates compliance with lowest-price rules. Publishers often package teacher editions, workbooks, digital tools, or platform licenses as "free" add-ons when districts purchase class sets. If the cost of these extras is baked into the bundle price, or if only some buyers receive them at no charge, the result can conflict with lowest-price requirements. Florida's position is that any materials provided free to one eligible buyer should be free to all, but enforcing that standard requires visibility into deals across many states and districts (Florida Statutes; Florida Administrative Code). Bundles can also push districts to pay for components they do not need, and time-limited digital pieces eventually expire, adding renewal fees that increase long-run costs.

Frequent edition churn amplifies these concerns. New K–12 editions are often justified as aligning to updated standards, but teachers report that some "new" versions mainly reshuffle chapters, refresh graphics, or make cosmetic layout changes. Even superficial updates can render older books administratively obsolete. Where districts once used a core text for seven to ten years, they may now feel pressure to replace materials in half that time.

Economic incentives encourage this pattern. The U.S. Government Accountability Office found that bundled "enhanced offerings" drive price increases in the college textbook market and that frequent new editions undermine the used-book market and push students toward buying new (U.S. Government Accountability Office). While that work focuses on higher education, the incentives are similar in K–12: when districts reuse texts longer or turn to used copies, publishers lose revenue, and one response is to accelerate edition cycles and raise list prices.

The shift to digital and subscription models multiplies these pressures. Instead of one-time purchases, districts increasingly face per-student annual licenses for platforms and e-texts. These arrangements guarantee recurring revenue and eliminate the used-book market, but they can also lock schools into proprietary ecosystems, erode traditional ownership, and raise total cost of ownership. In higher education, "automatic textbook billing" or "inclusive access" models, where textbook charges are bundled into tuition or fees, have triggered transparency concerns and led to recommendations for clear student opt-out rights (U.S. PIRG Education Fund). K–12 analogs appear when adaptive software, homework systems, or assessments are tied to expiring access codes and annual renewals.

In a genuinely competitive market, districts could solicit multiple bids and choose among several high-quality options at the best price. With only a few dominant vendors and uneven enforcement, publishers can rely on opaque bundles, selective discounts for large clients, and premature obsolescence to drive new sales. Public funds that could hire teachers, reduce class sizes, or expand student supports are instead absorbed by inflated curriculum costs and repeated purchases.

Case Studies: Investigations and Disputes

Real-world controversies make these dynamics concrete and show what is at stake for schools and taxpayers.

Florida's lowest-price lawsuit:

Florida's 2025 lawsuit against McGraw Hill and Savvas is a direct test of lowest-price statutes. According to press releases and news coverage, the state alleges that the publishers systematically failed to give all districts the same lowest available price, in violation of Florida law (WLRN News; WFLX; Badillo). Investigators claim that in thousands of transactions, some districts paid more per unit than others for identical materials; in one example, nine districts allegedly overpaid a combined 250,000 dollars for a single title, and Osceola County is said to have overpaid nearly 280,000 dollars on one adoption (Badillo). Florida is seeking reimbursement, treble damages, and civil penalties under anti-fraud statutes (WLRN News; WFLX). The scale of the alleged overbilling, potentially in the tens of millions statewide,

suggests a business practice rather than an isolated mistake. Most districts would not have detected these discrepancies on their own, underscoring the importance of state-level auditing and the likely influence of this case on pricing in other states with similar rules.

Los Angeles Unified's iPad initiative:

The Los Angeles Unified School District's iPad initiative illustrates the risks of vendor lock-in, unfinished digital products, and weak competition. In 2013, LAUSD launched an approximately 1.3 billion dollar plan to provide every student with an iPad preloaded with Pearson's digital curriculum, pairing Apple as the exclusive device provider with Pearson as the content vendor (Edwards; Lapowsky). The contract bundled a three-year license for Pearson's curriculum into the per-device cost, adding about 200 dollars to each iPad (Lapowsky).

Soon after rollout, teachers reported receiving only sample lessons rather than the full curriculum, students quickly learned to bypass device restrictions, and the district struggled with technical issues and limited professional development (Torres and Watanabe; Edwards; Lapowsky). Emails later revealed pre-award communications between district officials, Apple, and Pearson that raised concerns about whether the companies had an unfair advantage, prompting FBI scrutiny and federal investigations, though no charges were filed (Torres and Watanabe).

By 2015, LAUSD had canceled the program and negotiated a 6.4 million dollar settlement related to the Pearson curriculum, a small recovery relative to the initiative's overall scale (Torres and Watanabe; Lapowsky). The district had paid roughly 768 dollars per iPad, including the Pearson license, yet the promised curriculum never fully materialized during the license period (Edwards; Lapowsky). The episode is now a cautionary tale about sole-source mega contracts, the need to pilot before full deployment, and the importance of tying technology purchases to ready-to-use, high-quality content.

Tennessee's adoption controversy:

Tennessee's textbook process shows how favoritism and conflicts of interest can distort selection even when price is not the central issue. After Commissioner Penny Schwinn took office in 2019, district leaders and at least one major publisher alleged interference in the state's adoption process. Houghton Mifflin Harcourt filed a lawsuit claiming that improper actions by the education department kept its materials off the approved list while competitors advanced (Stockard). Although the case was dismissed, it heightened concerns that political officials could shape outcomes behind the scenes.

In response, Tennessee lawmakers enacted changes meant to insulate the process from politics. In 2020, the legislature removed the commissioner as a voting member of the Textbook and Instructional Materials Quality Commission and eliminated unilateral waiver authority, which had allowed the commissioner to approve nonlisted materials for some districts but not others (Chalkbeat Tennessee Staff; Tennessee Department of Education). These reforms aimed to reinforce independence and ensure that waivers and approvals rest on consistent, transparent criteria rather than personal discretion.

Taken together, these case studies reveal a pattern: when oversight is weak, vendors can inflate prices or push unproven products, and political actors can exercise informal influence. In each instance, the costs fall on students, teachers, and taxpayers.

Consequences for Equity, Small Districts, and Classrooms

Pricing and procurement decisions ripple outward through K–12 systems because public school finance is essentially zero-sum. When districts overspend on textbooks or are pushed into premature replacements, they have less money for teachers, tutors, technology, and student support. In Texas, for example, districts rely on an Instructional Materials and Technology Allotment that must cover books, digital content, and devices (Texas Education Agency). If a district with 10,000 students pays even twenty percent more than necessary for a reading program because it misses a discount or accepts an overpriced bundle, the lost funds can easily reach hundreds of thousands of dollars that could have staffed reading specialists, expanded tutoring, or modernized labs.

Equity between districts: Market concentration magnifies gaps between large and small buyers. Big urban systems can secure volume discounts, extended pilots, and complimentary add-ons. Small and rural districts often lack both bargaining power and staff capacity to negotiate complex contracts or audit invoices. Two districts can end up paying different prices for the same book, with smaller systems paying more per student. As this pattern repeats across subjects and grades, resource gaps grow: larger or wealthier districts refresh materials on schedule and add full digital components, while poorer or smaller ones delay purchases or accept stripped-down packages.

Equity within classrooms: Cost pressure also widens gaps inside classrooms. When materials are too expensive, districts may buy fewer copies, forcing students to share books or leaving them without materials at home. Delayed adoptions can keep teachers using outdated editions that no longer align with current standards or assessments, pushing them to assemble updates from the internet or handouts, which increases workload and can reduce coherence. Digital subscriptions intensify these divides because they require recurring payments and reliable devices and connectivity. Schools that cannot sustain license fees or maintain enough devices lose access to interactive tools, while students in better-resourced districts continue to use full platforms.

Instructional continuity and trust: Frequent edition changes create instructional friction. Each new version forces teachers to rework pacing guides, assessments, and assignments. If updates are mostly cosmetic or if professional development and ancillary materials are underfunded, the instructional value of an expensive adoption is never fully realized. Skipping updates for budget reasons, however, leaves teachers with misaligned materials and leads to improvisation that can produce inconsistent experiences across classrooms. Weak procurement controls also erode public trust and staff morale. News about cozy vendor relationships, sole-source deals, or expensive tools that teachers do not use can trigger backlash and leadership turnover. States with strong oversight and transparent statewide price lists can negotiate lower

ceilings, while those without such systems may routinely overpay. Lowest-price clauses only protect buyers when they are audited and enforced; without that visibility, smaller districts and less assertive states can end up subsidizing better deals elsewhere.

Cross-Mechanism Analysis: How Market Power Shows Up in Schools

Across these examples, four patterns recur.

Equity effects: Discriminatory pricing and high switching costs push smaller and rural districts to pay more per student for the same materials. Without specialized procurement staff to unpack complex bundles or verify invoices against state price lists, these districts gradually fall behind, creating systematic resource gaps between communities.

Budget effects: Compressed edition cycles and digital subscriptions turn what used to be occasional, capital-style book purchases into ongoing operating costs. Money that could support tutoring, teacher training, or special education services instead gets locked into continuous materials refreshes and platform licenses. When districts receive a fixed allotment for instructional materials and technology, higher per-student curriculum costs directly crowd out other investments (Texas Education Agency).

Instructional effects: Constant product changes disrupt pacing, assessments, and collaboration. Teachers have to relearn new platforms and rebuild materials, while rationed purchases or delayed adoptions leave students with outdated content, fewer take-home resources, or only partial access to digital tools. Homework and study equity suffer most for students whose families cannot fill the gaps with private purchases.

Governance effects: Closed-door negotiations, nonpublic pricing terms, and murky adoption decisions erode trust. Allegations of favoritism, conflicts of interest, or mismanaged initiatives — such as the LAUSD iPad program — can trigger leadership turnover and make educators skeptical of future adoptions (Edwards; Lapowsky; Torres and Watanabe). That distrust then becomes another barrier to implementing even genuinely strong materials.

These mechanisms reinforce one another. A district locked into an expensive digital platform, for example, may not be able to afford enough devices or licenses for all students, worsening both equity and instructional problems. Seeing how these links fit together is crucial for designing effective policy responses.

Policy Solutions and Reforms: Transparency, Oversight, and Open Resources

Addressing problems in the K–12 curriculum market requires action on several fronts. The tools mostly exist already; the real challenge is using them consistently.

Enforcing lowest-price rules and strengthening auditing is a first step. Many states already have statutes similar to those in Texas and Florida, but they only work when backed by regular audits and real consequences. Education agencies and attorneys general should require annual sworn price disclosures from publishers affirming that no eligible buyer is paying above the lowest national price, conduct periodic audits of contracts and invoices to identify discrepancies, and recover overcharges while imposing penalties large enough to deter repeat

behavior (WLRN News; WFLX; Badillo). Whistleblower mechanisms, including qui tam provisions where appropriate, can further expose hidden price discrimination by rewarding individuals who bring credible evidence forward.

Price and contract terms must also be transparent. States can make price transparency the norm by publishing full price lists for all approved materials – including student and teacher editions, bundles, and digital license options – in a searchable public portal. Districts can be encouraged or required to share key contract terms, such as license duration, renewal clauses, and service levels, in standardized formats. This visibility helps small districts negotiate more confidently, allows journalists, teachers, and parents to hold vendors and officials accountable, and leaves less room for favoritism or quiet exceptions.

At the same time, states can aggregate purchasing power without locking in a single vendor. They can use nonexclusive master agreements that set ceiling prices and standard terms while leaving districts free to choose among programs or to opt out entirely. Regional consortia can play a similar role where state authority is limited. Effective agreements clearly define ceiling prices rather than one fixed price, standardize license and renewal terms that any district may adopt, and preserve local choice through opt-in participation. This approach lets even the smallest districts benefit from volume discounts while retaining discretion.

Adoption processes themselves should be open and evidence-based. States and districts can hold adoption committee deliberations in public or post recordings, publish rubrics, evaluation reports, and scoring summaries, and disclose conflicts of interest for commission members, reviewers, and key administrators. They should also apply consistent criteria to requests for waivers or the use of nonlisted materials and provide written rationales for approvals and denials (Chalkbeat Tennessee Staff; Tennessee Department of Education; EdReports, “Our Process”). Legislatures can reinforce independence by separating political offices from voting roles on textbook commissions and by setting clear rules on gifts, outside employment, and vendor contact during active adoptions.

Contract design can be used to reduce churn and protect classrooms. States and large districts can negotiate terms that require minimum edition lifespans, with only minor updates allowed unless standards change significantly, and guarantee rights to low-cost or free minor content updates, such as new problem sets or supplemental lessons, during the contract period. For digital platforms, they can favor shorter base terms with renewal options, clear service-level agreements, and termination clauses for nonperformance. Midterm reviews tied to actual classroom usage and teacher feedback can trigger adjustments before multiple years of funding are locked in – a step that might have prevented some of the problems seen in LAUSD (Edwards; Lapowsky; Torres and Watanabe).

Investment in Open Educational Resources offers a structural way to reduce dependence on a few vendors. OER are freely available, openly licensed materials that schools can adopt and adapt legally. Research in K–12 science classes finds that open textbooks can generate large cost savings while producing learning outcomes at least comparable to traditional texts (Wiley et al., “A Preliminary Examination”), and advocacy groups estimate that OER have already saved

students more than a billion dollars, mainly in higher education (SPARC). States can extend this model to K–12 by funding the development of standards-aligned OER for core subjects, creating quality review hubs that mirror or partner with organizations like EdReports, providing professional learning so teachers can adopt and adapt OER responsibly, and ensuring that ecosystems include not only student texts but also teacher guides, assessments, and ancillary materials. When high-quality OER are maintained as living resources, districts can localize and update content without waiting for new commercial editions, and vendor power is naturally constrained.

Finally, governance must match the complexity of the instructional materials market. States and districts should avoid very long, inflexible contracts that assume one product will remain ideal for a decade, require periodic performance reviews and implementation dashboards for major adoptions, and track real classroom use to distinguish widely used products from those that sit unused. They should also train board members and administrators in procurement law, ethics, and instructional materials research (U.S. Government Accountability Office; U.S. PIRG Education Fund). Independent oversight committees at the state or district level can monitor large purchases and act as early warning systems for emerging problems.

Conclusion

The K–12 textbook and curriculum market will always have a commercial side, because creating high-quality materials is labor-intensive and publishers should be paid for products that work. The core problem is not profit-seeking itself, but what happens when a small group of firms, reinforced by adoption processes in a few large states, gain enough market power to set high prices, push districts into repeated repurchases, and use information gaps to disadvantage smaller or less sophisticated buyers.

The Florida lawsuit, the LAUSD iPad initiative, and Tennessee's adoption disputes show how pricing practices, vendor lock-in, and politicized governance can undermine instructional quality and erode public trust. At the same time, research on textbook pricing, automatic billing, and OER demonstrates that there are realistic alternatives to business as usual (U.S. Government Accountability Office; U.S. PIRG Education Fund; Wiley et al., "A Preliminary Examination"; SPARC).

With policies that enforce fair pricing, mandate transparency, aggregate purchasing power for small systems, expand open alternatives, and uphold ethical procurement, states and districts can reclaim control over the curriculum marketplace. The goal is straightforward: direct funds toward materials that genuinely enhance teaching and learning rather than toward unnecessary churn or opaque bundles. Every dollar saved through better procurement or OER can be redirected to academic priorities, and every abuse prevented helps rebuild trust. By learning from recent failures and implementing these reforms, policymakers can move toward a more equitable and sustainable model that delivers the textbooks and tools students and teachers need without shortchanging the public interest.

Works Cited

Blume, Howard. “The Epic Failure of LA’s $1.3-Billion iPad Program.” Time, 17 Nov. 2014, https://time.com/3581755/los-angeles-ipad/.

Brown, Aarian, and Dominic M. Garcia. “LAUSD’s iPad Scandal Was a Multimillion-Dollar Disaster.” Wired, 30 Aug. 2015, https://www.wired.com/2015/08/lausd-ipad-scandal/.

Chalkbeat Tennessee Staff. “Tennessee Textbook Panel Changes Aim to Reduce Politics in Classroom Materials.” Chalkbeat Tennessee, 30 June 2020, https://tn.chalkbeat.org/2020/6/30/21308498/tennessee-textbook-panel-changes-aim-to-reduce-politics-in-classroom-materials.

“Florida Sues McGraw Hill and Savvas for Overcharging School Districts.” WLRN, 6 Aug. 2025, https://www.wlrn.org/education/2025-08-06/florida-sues-textbook-publishers-mcgraw-hill-and-savvas-over-overcharging-allegations.

Houghton Mifflin Harcourt. “About HMH.” HMHCo.com, https://www.hmhco.com/about-us.

Texas Education Agency. “To the Administrator Addressed: Instructional Materials and Technology Allotment (IMTA) and HB 1605 Implementation.” Texas Education Agency, 3 Apr. 2024, https://tea.texas.gov/academics/instructional-materials/texas-resource-review/taa-letters.

Texas Education Code. “§31.151. Publisher or Manufacturer Obligations.” Texas Statutes, https://statutes.capitol.texas.gov/Docs/ED/htm/ED.31.htm#31.151.

Tennessee. “Textbook and Instructional Materials Quality Commission.” TN.gov, https://www.tn.gov/education/textbook-services.html.

Wiley, David, John Hilton III, Jeff Ellington, and Tiffany Hall. “A Preliminary Examination of the Cost Savings and Learning Impacts of Using Open Textbooks in Middle and High School Science Classes.” International Review of Research in Open and Distributed Learning, vol. 13, no. 3, 2012, https://www.irrodl.org/index.php/irrodl/article/view/1153.

SPARC. “OER Has Already Saved Students More Than a Billion Dollars.” SPARC, 2018, https://sparcopen.org/wp-content/uploads/2018/08/SPARC-OPP1154.pdf.

EdReports. “Our Process.” EdReports.org, https://www.edreports.org/about/our-process.

Schmidt, Emily. “Required Reading: How Textbook Adoption in 3 States Influences the Nation’s K–12 Population.” APM Research Lab, 2022, https://www.apmresearchlab.org/10x-textbook-adoption.

Center for Education Market Dynamics. “State Market Map.” CEMD, https://www.cemd.org/state-market-map.

EdReports. “Our Process.” EdReports, https://www.edreports.org/about/our-process.

WLRN News. “Florida Sues Textbook Publishers McGraw Hill and Savvas Over Overcharging Allegations.” WLRN, 6 Aug. 2025, https://www.wlrn.org/education/2025-08-06/florida-sues-textbook-publishers-mcgraw-hill-and-savvas-over-overcharging-allegations.

WFLX (FOX 29). “Florida Sues Textbook Publishers McGraw Hill and Savvas, Calling Them ‘Deceitful Profiteers.’” WFLX, 6 Aug. 2025, https://www.wflx.com/2025/08/06/florida-sues-textbook-publishers-mcgraw-hill-savvas/.

Florida Statutes. “Title XLVIII, K–20 Education Code, Chapter 1006: Support for Learning.” Online Sunshine, Florida Legislature, https://www.flsenate.gov/Laws/Statutes/2024/Chapter1006.

“Florida Statutes §1006.38 — Duties, Responsibilities, and Requirements of Instructional Materials Publishers and Manufacturers.” Justia US Law, https://law.justia.com/codes/florida/2024/title-xlviii/chapter-1006/section-1006-38.

Florida Administrative Code. “Rule 6A-7.0710 — Publishing Specifications and Adoption Procedures for Instructional Materials.” Florida Administrative Code & Florida Administrative Register, https://www.flrules.org/gateway/ruleNo.asp?id=6A-7.0710.

Badillo, Andrew. “Florida AG Suing K–12 Publishers for Alleged Overcharging.” First Coast News, 6 Aug. 2025, https://www.firstcoastnews.com/article/news/education/florida-ashley-moody-attorney-general-lawsuit-textbooks-overcharging-k-12/77-3a7e5116-59cc-47f8-a0f1-1a1f7738870a.

Torres, Zahira, and Teresa Watanabe. “Feds Have Ended Criminal Investigation of iPads-for-All Plan in L.A. Schools.” Los Angeles Times, 8 May 2015, https://www.latimes.com/local/education/la-me-ipads-lausd-20150509-story.html.

Lapowsky, Issie. “LAUSD’s iPad Scandal Was a Multimillion-Dollar Disaster.” Wired, 30 Aug. 2015, https://www.wired.com/2015/08/lausd-ipad-scandal/.

Edwards, Haley Sweetland. “The Epic Failure of LA’s $1.3-Billion iPad Program.” Time, 17 Nov. 2014, https://time.com/3581755/los-angeles-ipad/.

Stockard, Sam. “School Textbook Company Sought Legal Action Against Schwinn’s Department Over Alleged Interference.” Tennessee Lookout, 2021, https://tennesseelookout.com/2021/05/03/school-textbook-company-sought-legal-action-against-schwinns-department-over-alleged-interference/.

Tennessee Department of Education. “Textbook and Instructional Materials Quality Commission.” TN.gov, https://www.tn.gov/education/textbook-services.html.

Simmons, Ryan. “Texas Public Schools Will Use New Homegrown ‘Bluebonnet’ Textbooks Next Year.” Houston Chronicle, 18 June 2024, https://www.houstonchronicle.com/news/houston-texas/education/article/texas-bluebonnet-textbooks-19445350.php.

U.S. PIRG Education Fund. “Automatic Textbook Billing: An Offer Students Can’t Refuse.” U.S. PIRG, 2020, https://uspirg.org/feature/usp/automatic-textbook-billing.

U.S. Government Accountability Office. “College Textbooks: Enhanced Offerings Appear to Drive Recent Price Increases.” GAO-05-806, 2005, https://www.gao.gov/products/gao-05-806.

Wiley, David, John Hilton III, Jeff Ellington, and Tiffany Hall. “A Preliminary Examination of the Cost Savings and Learning Impacts of Using Open Textbooks in Middle and High School Science Classes.” The International Review of Research in Open and Distributed Learning, vol. 13, no. 3, 2012, https://www.irrodl.org/index.php/irrodl/article/view/1153.

The Relationship Between Creativity Motivation and Agreeableness in the Context of Plurilingualism By Teresa Chen

Abstract

Previous research has defined creativity motivation as the drive that compels individuals to engage in original and creative acts, particularly in the pursuit of new ideas. Subsequent research has found this concept, measured by the Creativity Motivation Scale (CMS), to be linked with personality factors, namely the Big Five personality traits (openness, conscientiousness, extraversion, agreeableness, and neuroticism). Although relevant links have been found between creativity motivation, conscientiousness, and neuroticism, there has been limited research on the relationship between agreeableness and creativity motivation. The present study aimed to explore the relationship between agreeableness, creativity motivation, and plurilingualism. We hypothesized that there would be a positive correlation between agreeableness and creativity motivation, as well as a positive correlation between plurilingualism and both of those previous factors. The data we analyzed was publicly sourced, and using that dataset, we examined plurilingual individuals to whom the Big Five personality scale and the Creativity Motivation scale were administered. Our analyses revealed that agreeableness was statistically significantly positively correlated with creativity motivation. Additionally, we concluded that higher levels of plurilingualism in individuals were associated with a statistically significant increase in creativity. Our research demonstrated that the development of plurilingualism strengthens creativity motivation, which is also influenced by agreeableness, implying that further research on personality and creativity may need to consider the significance of other factors such as plurilingualism.

Keywords plurilingualism, creativity motivation, Big Five, personality, divergent thinking

Introduction

Previous studies have defined agreeableness as "individual differences in being likeable, pleasant, and harmonious in relations with others" (Graziano and Tobin). It is perceived as a beneficial trait, for since "ancient times, writers have commented on the value of agreeableness in social relationships." The term 'agreeableness' is commonly known as a key part of the Big Five personality scale, with the other four personality traits being openness, conscientiousness, extraversion, and neuroticism. The Big Five scale, also known as the Five-Factor Model (John et al.), conceptualizes personality as defined by five traits. Common measures of personality, like the NEO-PI-R, are composed of a large number of Likert-type items to determine the traits that individuals possess. Recent studies have simplified this scale into a shortened ten-item questionnaire, with a 7-point Likert system (Gosling et al.).

Researchers disagree on many aspects of agreeableness. According to the research of Bergeman et al., there is little evidence for the heritability of agreeableness. The environment in which one is raised appears to play a more substantial role in individuals' levels of

agreeableness. In contrast, Tellegen et al. have found that traits associated with agreeableness are heritable. Research suggests that an individual's level of agreeableness is positively correlated with their mental health (Lamers et al.) and also mental health treatment outcomes (Bucher et al.). Recent studies have found that higher levels of agreeableness have a substantial positive effect on educational performance as well (Ahadi and Narimani).

In addition, agreeableness appears to be a moderating variable in the relationship between strong emotions, specifically anger, on creativity. Within the context of emotion induction, higher levels of agreeableness were found to be related to higher creative performance (Kao and Chiou). However, using the HEXACO (Honesty-Humility, Emotionality, Extraversion, Agreeableness, Conscientiousness, and Openness to Experience) personality model, no relationship was found between agreeableness and creativity (Silvia, Kaufman, et al.). In the workplace context, it was found that a subscale of agreeableness, such as quality agreement, had a positive relationship with creative work (Hoseinifar et al.). When comparing self-reported creativity to externally rated creativity, agreeableness was more strongly related to self-reported creativity, but this effect was still minor (Puryear et al.). Furthermore, in their 2016 literature review, Abdullah et al. write that studies regarding the relationship between agreeableness and creativity have contradicting results. Overall, studies agree that agreeableness and divergent thinking have a positive relationship, and divergent thinking leads to creativity (Abdullah et al.; Nusbaum and Silvia; Silvia, Winterstein, et al.; Silvia, Nusbaum, et al.). However, some assert that agreeableness cannot predict creativity (Abdullah et al.; Feist; King et al.), while others state that high levels of creativity result in high levels of everyday creativity (Abdullah et al.; Batey and Furnham). What's more, King et al. (1996) concluded in an experiment that agreeableness had no correlation with creativity and, in fact, possessed a negative correlation with creative endeavors.

Past research has proven creativity to be beneficial in both psychopathology (Slayton et al.) and day-to-day health (Richards). A meta-analysis conducted by Acar et al. (2021) highlights the correlation between higher levels of creativity and higher well-being across multiple studies and contexts, such as mood and problem-solving. Furthermore, an enterprise education study by Lourenço & Jayawarna (2011) reveals that individuals' perceptions of their creativity significantly impact their motivation to learn. If an individual believes they are more creative, they will have a higher tendency to continue to develop entrepreneurship skills and take risks. Creativity motivation has been defined as "the force (high-quality experience, instrumental purpose, and value) which drives individuals into creativity-related behaviors shown so as to do, learn, and accomplish new things" (Zhang et al., 2018, Abstract). According to this definition, the Creativity Motivation Scale (CMS) was developed. Recent studies have found that creativity motivation is positively correlated with a growth mindset (He and Chiang). In addition, creativity motivation contributes to the negative relationship between a fixed mindset and creative thinking. Furthermore, creativity motivation is correlated with language learning, such as in a study on English-as-a-second-language learners' ability to create unique metaphors (Wang and Cheng). The data revealed that creativity motivation has a positive correlation with the language

learners' ability to create metaphors. Still, creativity motivation was limited in its ability to predict this metaphoric ability.

In previous research, multilingualism has been defined as the ability to speak more than one language, in addition to an individual's primary language. This definition leads to the concept of bilingualism, where "languages are seen as separate knowledge systems that exist side by side" (Kharkhurin et al., 2023, p. 2). However, the present study emphasizes a transition to the plurilingualism perspective, which emphasizes how the individual functions within a new cultural context when using a foreign language. Plurilingualism is defined as not just proficiency in more than one language, but also as an individual's ability to mediate between the different cultural contexts that come with those languages, immersing themselves in the multiple aspects of a new culture. Research has been done on the relationship between language and the Big Five personality traits. (Dylman and Zakrisson) found significant differences in bilingual participants' responses to personality inventories when the inventories were presented in Swedish compared to English. For instance, participants viewed themselves as more agreeable when the questionnaire was presented in Swedish instead of English. This information reveals the influence of language on personality, especially when personality traits are self-reported. Furthermore, outside of the Big Five Personality Inventory, multilingual individuals score higher on personality traits such as flexibility, social initiative, and open-mindedness (Dewaele and Botes).

Kharkhurin et al. conducted a study on the overall mediating role that personality traits play in plurilingualism/pluriculturalism and divergent thinking, which revealed that individuals who were more resilient (less neurotic) were able to develop fluency in a foreign language better, and therefore had higher levels of cognitive flexibility. Also, more extraverted individuals were found to better immerse themselves in multicultural experiences, as well as come up with creative and unique ideas more quickly. Forthmann et al. found that the Big Five factor of openness significantly predicted a participant's level of divergent thinking. In the case of culture shock, low levels of openness to experience could lead to lower levels of divergent thinking, even if there was increased multicultural experience. Kharkhurin, Koncha, et al. connected plurilingualism to tolerance of ambiguity by outlining how plurilingual individuals develop tolerance of ambiguity by navigating different cultures, which fosters divergent thinking and, in turn, creativity. Piccardo supports this idea by asserting that plurilingual individuals thrive in diverse cultures and have a better grasp of creating original ideas. However, relatively little research has been done specifically on the relationship between personality and creativity motivation as measured by the Creativity Motivation Scale.

The trait of agreeableness has been overlooked when it is very likely that it has a significant connection with individuals' creativity motivation. The relationship between agreeableness and creativity is unclear, and it is unknown whether plurilingualism serves as an additional factor. The present study's goal is to explore the relationship between agreeableness and creativity motivation, and how plurilingualism is a moderating factor in this relationship. We hypothesize that there will be a positive correlation between agreeableness and creativity

motivation, and that plurilingualism will play a significant role in the moderation of the relationship between agreeableness and creativity motivation.

Materials and Methods

We used a publicly available survey dataset (Kharkhurin, Koncha, et al.; Koncha and Kharkhurin) through a data collection platform (1KA). In total, 261 participants were involved in the data collection, 47 males and 214 females, between the ages of 17 and 66. Although the assessments were given in Russian, the participants resided in 15 countries: Russia, Kazakhstan, the USA, Israel, Ukraine, Moldova, the UAE, Belarus, Germany, Canada, Mongolia, the Netherlands, Latvia, Belgium, and Tajikistan. Relevant assessments presented in the data collection include: a shortened version of the Multilingual and Multicultural Experience Questionnaire in Russian as a language assessment, the Integrative Intercultural Competence Survey, the Ten-Item Personality Inventory as a measure of Big Five personality traits, and the Creativity Motivation Questionnaire. Ethical measures taken in collecting this data include informed consent from the participants through a form approved by the Ethical Committee of the HSE University (Russia).

Multilingual and Multicultural Experience Questionnaire in Russian

The language assessment used was a shortened version of the Multilingual and Multicultural Experience Questionnaire in Russian (Kharkhurin). This self-administered questionnaire measured the number of languages participants spoke and their proficiency in listening, reading, writing, and speaking skills using a Likert-type 5-point scale. The proficiency score for each language was calculated by the average of the participants' scores in each of the four skills for that language. The overall proficiency score is the sum of all of a participant's proficiency scores across all languages. In Kharkhurin's 2023 study, participants self-reported the number of languages they spoke. The researchers then filtered the data to create the 'Number Counted' category. Those who spoke only one language were omitted from the 'Number Lang' category, which was used in the study's analysis of language proficiency and plurilingualism.

Integrative Intercultural Competence Survey

Intercultural competence was measured using the self-administered Integrative Intercultural Competence Survey (Хухлаев et al.), which is in the Russian language and uses eighteen five-point Likert-type items. A higher score of total points indicates more intercultural competence. The survey included four subscales: Intercultural Stability (traits of an individual that help them be less stressed when engaging in intercultural communication), Intercultural Interest (an individual's willingness to interact with those of different cultures), Lack of Ethnocentrism (open-mindedness and acceptance of those different than oneself), and Management of Intercultural interaction (communication skills necessary for intercultural interaction). These are all designed to assess how well an individual would do when engaging with those in other cultures.

Ten-Item Personality Inventory: Big Five Personality Traits Questionnaire

The Big Five personality traits of openness, conscientiousness, extraversion, agreeableness, and neuroticism were measured using a Russian language version of the Ten-Item Personality Inventory (Erzhanova et al.; Gosling et al.) and contained questions designed to help individuals quickly and efficiently self-report their personality traits. For example, a question from the inventory is "I see myself as: Extraverted, enthusiastic," and participants would have to rate themselves on a scale from one to seven, one being 'disagree strongly' and seven being 'agree strongly.'

Creativity Motivation Scale

The Creativity Motivation Scale (Zhang et al., 2018) consists of nine six-point Likert-type items ranging from one, 'strongly disagree,' to six, 'strongly agree.' According to the CMS theory, there are two dimensions of creativity motivation: Dimension 1 is creativity-related behaviors (do, learn, and accomplish new things), and Dimension 2 is the three types of forces (high-quality experience, value, and instrumental purpose) behind it. As a result, each item in the Creativity Motivation Scale aims to combine one force and one creativity-related behavior. An example item from the survey is "I experience pleasure when I discover new things that I have never seen before." This item combined 'high-quality experience' (Dimension 1) and 'learn new things' (Dimension 2). Participants were asked to rate their agreement with the statement on a scale of 1-6, from strongly disagree to strongly agree. In our examination of the original researchers' data (Koncha and Kharkhurin), we concluded that the data regarding CMS was likely switched to a 7-point scale from a 6-point scale, similar to the Big Five questionnaire from Gosling et al. referenced earlier.

Statistical Analyses

To conduct the statistical analyses, the statistical program JASP (Version 0.19.3) was used (JASP Team). To evaluate the relationship between agreeableness and creativity motivation, the correlation between the agreeableness variable and the Creativity Motivation variable, as well as between agreeableness and each of the variables included in Dimension 1 of the Creativity Motivation Scale, was examined. Similarly, the correlations between agreeableness and each variable included in Dimension 2 of the CMS were also examined.

ANOVA was used to determine if there were significant differences in levels of agreeableness between each language group. Based on the number of languages each participant spoke, they were part of a group, and the mean agreeableness scores between those groups were examined for substantial differences. Likewise, ANOVA was used to determine if there were significant differences in creativity motivation scores between each language group. The mean creativity motivation scores of each language group were analyzed for this purpose. To determine group differences in agreeableness and creativity motivation, a post-hoc test was used for pairwise comparisons when the overall model was significant. ANCOVA was utilized to examine the relationships between creativity motivation and the number of languages

participants spoke, with agreeableness as a covariate. A post-hoc test was used for pairwise comparisons when the overall model was significant.

In addition, linear regression was used to compare creativity motivation (dependent variable) and the 'NumberLang' variable (factor), with agreeableness as a covariate. The purpose of this analysis was to determine if plurilingualism and agreeableness predict creativity motivation. To determine the moderating role of plurilingualism and intercultural competence on the relationship between agreeableness and creativity motivation, we conducted a moderation analysis with plurilingualism and intercultural interest as moderating variables for the relationship between agreeableness and creativity motivation.

Results

Agreeableness and Creativity Motivation

We used a correlational model to analyze the relationship between agreeableness and creativity motivation, as well as between agreeableness and each of the elements involved in Dimension 1 of the CMS (the motivation to learn, do, and accomplish new things, or the CMS Learn subscale, CMS Do subscale, and CMS Accomplish subscale, respectively). We found a statistically significant positive correlation between agreeableness and creativity motivation (r = 0.150, p = 0.015), with agreeableness accounting for approximately 2.3% of the variance in creativity motivation (R^2 = 0.0225). In addition, there is a slight positive correlation between agreeableness and the subscale CMS Learn (r = 0.129, p = 0.038), with agreeableness accounting for approximately 1.7% of the variance in CMS Learn ($R^2 \approx 0.017$). There is also a statistically significant relationship between agreeableness and the subscale CMS Accomplish (r = 0.127, p = 0.041). Agreeableness accounted for approximately 1.6% of the variance in CMS Accomplish ($R^2 \approx 0.016$). We found there to be no relationship between agreeableness and the subscale CMS Do.

Table 1

Correlation Matrix for Agreeableness and Dimension 1 of the Creativity Motivation Scale

Variable	Agreeableness	Creativity Motivation	CMS Learn	CMS Do	CMS Accomplish
Agreeableness	__				
Creativity Motivation	0.150*	__			
CMS Learn	0.129*	0.847***	__		
CMS Do	0.018	0.873***	0.599***	__	
CMS Accomplish	0.127*	0.891***	0.642***	0.670***	__

Note. * indicates p < .05, ** indicates p < .01, *** indicates p < .001

Table 1: Correlation matrix between agreeableness, creativity motivation, CMS Learn, CMS Do, and CMS Accomplish. In this table, CMS stands for Creativity Motivation Scale, and Learn, Do, and Accomplish represent the creativity-related behaviors of learning, doing, and accomplishing new things (respectively).

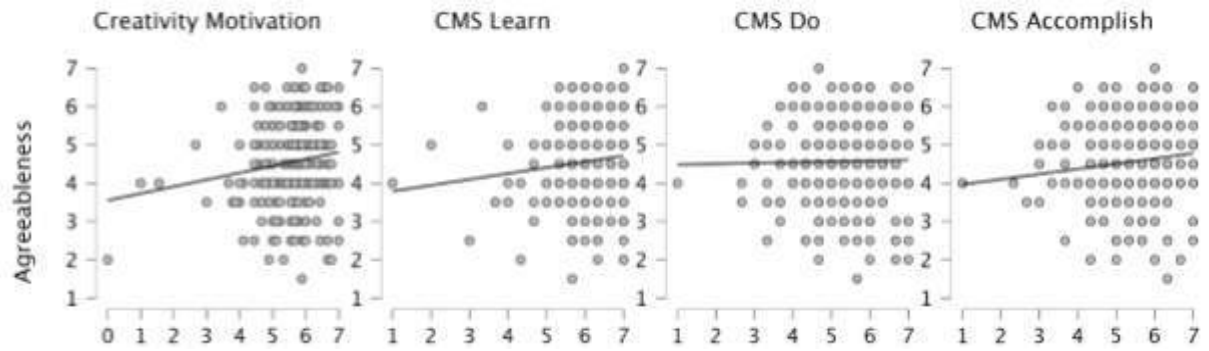


Figure 1: Correlation plots for the relationships between agreeableness and creativity motivation, and its Dimension 1 subscales.

Another correlational model was used to examine the relationship between agreeableness and each of the elements involved in Dimension 2 of the CMS, represented by the subscales CMS Value, CMS Experience, and CMS Instrumental. These variables represent the creativity-related forces of value, high-quality experience, and instrumental purpose (respectively). Pearson's correlation showed a statistically significant positive correlation between agreeableness and the CMS Experience subscale ($r = 0.124$, $p = 0.046$), with agreeableness accounting for 1.5% of the variance in CMS Experience ($R^2 \approx 0.015$). We found there to be no significant correlation between agreeableness and the CMS Value subscale. Similarly, there is no significant correlation between agreeableness and the subscale CMS Instrumental.

Table 2

Correlation Matrix for Agreeableness and Dimension 2 of the Creativity Motivation Scale

Variable	Agreeableness	CMS Value	CMS Experience	CMS Instrumental
Agreeableness	—			
CMS Value	0.080	—		
CMS Experience	0.124*	0.657***	—	
CMS Instrumental	0.064	0.567***	0.584***	—

Note. * indicates p < .05, ** p < .01, *** p < .001

Table 2: Correlation matrix between agreeableness, CMS Value, CMS Experience, and CMS Instrumental. In this table, CMS stands for Creativity Motivation Scale, and Value, Experience, and Instrumental represent the creativity-related forces of value, high-quality experience, and instrumental purpose (respectively).

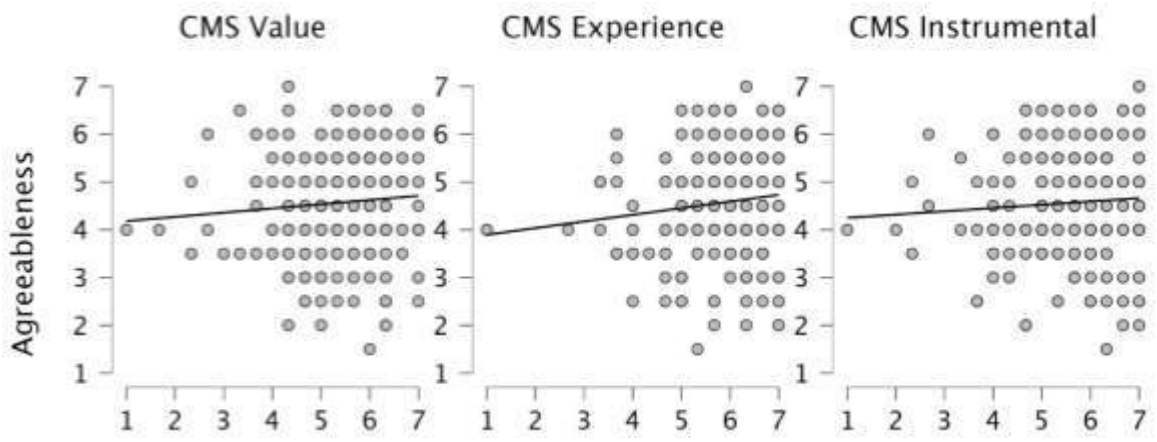


Figure 2: Correlation plots between the variables listed in Table 2.

In the original study (Kharkhurin, Koncha, et al.), the dataset (Koncha and Kharkhurin) reported the same values for the subscales CMS Behavioral, CMS Force, and CMS Average. These variables likely represent the overall categories of creativity-related behaviors, creativity-related forces, and the average of the prior two categories (respectively). We did not focus on these values in our analysis, but instead on the more specific variables within those categories.

Plurilingualism and Agreeableness

We used an analysis of variance (ANOVA) model to examine the relationship between the number of languages participants spoke and agreeableness. We aimed to determine if speaking more languages would increase participants' level of agreeableness. An independent one-way ANOVA showed no significant effect of the number of languages spoken on the level of agreeableness.

Plurilingualism and Creativity Motivation

The Brown-Forsythe test was used to investigate whether speaking more languages would be associated with participants' level of creativity motivation, since Levene's test showed unequal variances. Games-Howell post-hoc tests were used for pairwise comparison. Therefore, we examined the relationship between the number of languages spoken and creativity motivation. The Brown-Forsythe test showed no significant effect of the number of languages spoken on creativity motivation ($F = 1.187$, $p = 0.396$). The effect size of the test was small ($w^2 = 0.029$). Post hoc testing with Tukey's correction revealed that there was no significant difference in levels of creativity motivation between participants in each of the language groups.

Intercultural Competence and Agreeableness

Furthermore, we used a correlation model to analyze the relationship between the variable 'Agreeableness' and the subscales of the Integrative Intercultural Competence Survey, namely intercultural stability, intercultural interest, lack of ethnocentrism, and management of

intercultural interaction. Pearson's correlation showed a positive correlation between agreeableness and intercultural stability ($r = 0.192$, $p = 0.002$), with agreeableness accounting for 3.7% of the variance in intercultural stability ($R^2 \approx 0.037$). In addition, we found a positive correlation between agreeableness and intercultural interest ($r = 0.306$, $p < 0.001$). Agreeableness accounted for 9.4% of the variance in intercultural interest ($R^2 \approx 0.094$). Furthermore, we found a positive correlation between agreeableness and lack of ethnocentrism ($r = 0.278$, $p < 0.001$), with agreeableness accounting for 7.7% of the variance in lack of ethnocentrism ($R^2 \approx 0.077$). There is a positive correlation between agreeableness and management of intercultural interaction ($r = 0.229$, $p < 0.001$), with agreeableness accounting for 5.2% of the variance in management of intercultural interaction ($R^2 \approx 0.052$).

Table 3

Correlation Matrix for Agreeableness and Subscales of Integrative Intercultural Competence Survey

Variable	Agreeableness	Intercultural Stability	Intercultural Interest	Lack of Ethnocentrism	Management of Intercultural Interaction
Agreeableness	—				
IICS Stability	0.192**	—			
IICS Interest	0.306***	0.273***	—		
IICS Ethnocentrism	0.278***	0.515***	0.440***	—	
IICS Interaction	0.229***	0.192**	0.507***	0.282***	—

Note. * indicates p < .05, ** indicates p < .01, *** indicates p < .001

Table 3: Correlation matrix between agreeableness, IICS Stability, IICS Interest, IICS Ethnocentrism, and IICS Interaction. In this table, IICS stands for Integrative Intercultural Competence Survey, and Stability represents intercultural stability, Interest represents intercultural interest, Ethnocentrism represents lack of ethnocentrism, and Interaction represents management of intercultural interaction.

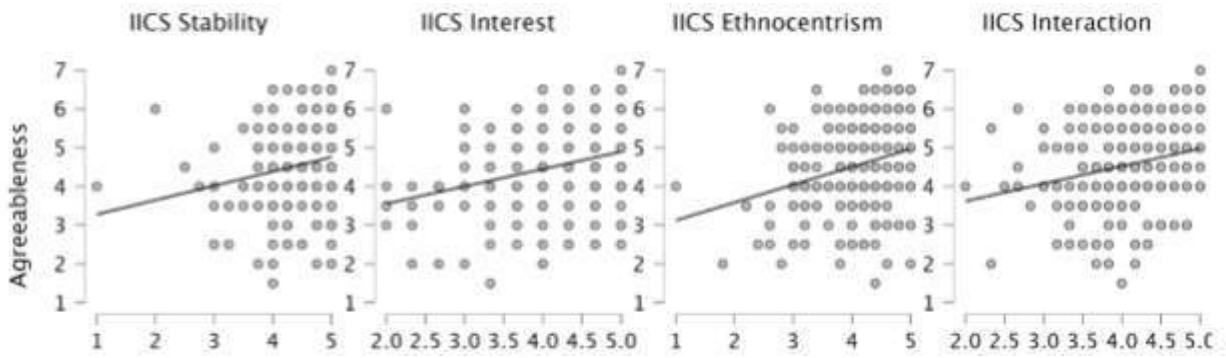


Figure 3: Correlation plots between the variables listed in Table 3.

Plurilingualism and Agreeableness as Predictors of Creativity Motivation

A simple linear regression was used to predict creativity motivation from plurilingualism (represented by the NumberLang variable) and agreeableness. NumberLang and agreeableness were shown to explain a significant amount of the variance in creativity motivation ($F(5, 255) = 3.297$, $p = 0.007$, $R^2 = 0.061$).

Plurilingualism as a Moderating Factor for the Relationship Between Agreeableness and Creativity Motivation

A moderation analysis was performed to determine whether plurilingualism moderated the relationship between agreeableness and creativity motivation. Plurilingualism was defined by the number of languages each participant spoke. The moderation analysis included the dependent variable creativity motivation and the independent variable agreeableness, with plurilingualism included as a covariate to assess its moderating effect. We found that the overall model was significant ($F(9, 251) = 4.180$, $p < 0.001$, $R^2 = 0.130$). Specifically, the interaction between agreeableness and speakers of six languages was significant ($p < 0.001$).

Intercultural Competence as a Moderator Between Agreeableness and Creativity Motivation

Four separate moderation analyses were performed to determine whether components of intercultural competence moderated the relationship between agreeableness and creativity motivation. The components measured by the subscales of the Integrative Intercultural Competence Survey include intercultural stability, intercultural interest, lack of ethnocentrism, and management of intercultural interaction. Each moderation analysis included the dependent variable creativity motivation and the independent variable agreeableness, with one of the components included as a covariate to assess its moderating effect. We found that agreeableness ($p = 0.005$), intercultural stability ($p < 0.001$), and the interaction between agreeableness and intercultural stability ($p = 0.008$) are all statistically significant. Also, agreeableness ($p = 0.042$) and intercultural interest ($p = 0.006$) are statistically significant, but the interaction between agreeableness and intercultural interest is not ($p = 0.067$). In addition, agreeableness ($p = 0.006$), lack of ethnocentrism ($p < 0.001$), and the interaction between agreeableness and lack of ethnocentrism ($p = 0.011$) are statistically significant. Similarly, agreeableness ($p = 0.005$), management of intercultural interaction ($p < 0.001$), and the interaction between agreeableness and management of intercultural interaction ($p = 0.008$) are statistically significant.

Discussion

The purpose of this study was to gain a better understanding of the relationship between the Big Five personality factors of agreeableness and creativity motivation as defined by the Creativity Motivation Scale (CMS). In addition, plurilingualism and pluriculturalism were examined as moderating factors of this relationship. The results of the present study support the hypothesis that there is a statistically significant but weak relationship between agreeableness

and dimension one of creativity motivation (the creativity-related behaviors of learning, doing, and accomplishing new things), where both plurilingualism and pluriculturalism may act as moderating factors.

There are three key findings of the present research. First, the relationship between agreeableness and creativity motivation takes place within dimension one of creativity motivation, not dimension two. This finding may be explained by the idea that dimension one of the CMS addresses creativity-related behaviors, while dimension two addresses creativity-related forces, "which drives individuals into creativity-related behaviors shown so as to do, learn, and accomplish new things" (Zhang et al.). These creativity-related forces are high-quality experience, instrumental purpose, and value. According to the data, agreeableness appears to have a more direct influence on creativity-related behavior than creativity-related forces. This may be because creativity-related forces like instrumental purpose have greater variations between individuals, regardless of personality, while creativity-related behaviors are more universal. For example, one individual may try painting to bond with a friend who is a passionate painter, while another individual may paint to reduce stress and achieve peace. In both scenarios, individuals are not doing the creativity-related behavior simply because they want to try it; there is an end goal that the creativity-related behavior helps them reach. However, the reasons behind each individual's instrumental purpose for painting are vastly different. This example demonstrates how it may be more difficult for agreeableness to influence creativity-related forces than creativity-related behaviors.

Second, plurilingualism serves as a moderating factor of this relationship when an individual speaks more languages (ex. six languages). The most compelling explanation for this finding is likely that someone who speaks six languages has a more diverse set of cultural experiences. Plurilingualism involves not only being fluent in multiple languages but also being able to adapt to the culture associated with each of those languages (Kharkhurin, Koncha, et al.). This may result in a more open mindset than someone who only speaks one language and is more limited in their perspective of the world. In fact, Acar, Balayar, et al. noted that "bilingual environments [are] highly complex and uncertain…enabl[ing bilingual individuals] to explore and learn from their environment differently and more broadly compared to monolinguals. This connects to creativity because bilingualism, as a source of environmental diversity, allows individuals to attend to novelty" (Singh et al.). An open mindset can lead to higher levels of creativity because an individual will be able to generate more unique ideas that diverge from a traditional point of view. Since a plurilingual individual has interacted with many languages and cultures, they may be more motivated to come up with original ideas since they are familiar with adapting to new situations. Further tests that are more focused on plurilingualism may find more concrete conclusions regarding this topic.

Third, the subscales of the Integrative Intercultural Competence Survey that we examined to represent pluriculturalism were found to be statistically significant moderators in the relationship between agreeableness and creativity motivation, except for intercultural interest. This idea is further supported by the finding of positive correlations between agreeableness and

each of the subscales of the Integrative Intercultural Competence Survey (IICS). As mentioned before, a pluricultural individual is more flexible and willing to adapt to customs different from their native culture (Kharkhurin, Koncha, et al.). For example, one of the subscales of the IICS is lack of ethnocentrism. If an individual is less ethnocentric, they could be more open to different perspectives of the world. This may broaden their capability for creativity and foster a willingness to learn in new ways, even if there might be a risk of discomfort or failure.

Previous findings state that there is a statistically significant relationship between agreeableness and creativity. For example, Kao and Chiou found that, regarding emotion induction, higher levels of agreeableness are related to higher creative performance. Overall, studies appear to agree on the positive relationship between agreeableness and divergent thinking and that divergent thinking leads to creativity (Abdullah et al.; Nusbaum and Silvia; Silvia, Winterstein, et al.; Silvia, Nusbaum, et al.). Our findings support these past studies, strengthening their validity. However, some assert that agreeableness cannot predict creativity (Abdullah et al.; Feist; King et al.), while others state that high levels of creativity result in high levels of everyday creativity (Abdullah et al.; Batey and Furnham). Researchers have also found that there is little to no relationship between agreeableness and creativity (King et al.; Silvia, Kaufman, et al.), but the present study opposes those findings through the discovery of a positive relationship between the two variables. Nevertheless, this correlation is weak, and like previous research, more studies will need to be done in order for this to be a confirmed claim. It is also important to distinguish between creativity motivation, which Zhang et al. defined as "the force (high-quality experience, instrumental purpose, and value) which drives individuals into creativity-related behaviors shown so as to do, learn, and accomplish new things," and creativity itself.

Limitations

A limitation of this study is that some variables lacked clarity, and inferences were made for the purpose of data analysis. Since we did not personally conduct the experiment and the data were from a publicly-sourced data set, it was unclear what certain abbreviations meant since the definitions were not mentioned in the paper that reported the original data set (Kharkhurin, Koncha, et al.). For example, we were not sure if the variable 'NumberLang' represented the number of languages participants reported they spoke or the number of languages that were actually counted in the experiment. It was necessary to examine other papers by the same author and the scales for different variables to deduce what that variable meant. Furthermore, in the original data set (Koncha and Kharkhurin), the Creativity Motivation Scale was scaled differently than it was when created by Zhang et al. In our examination of the data, we concluded that the data regarding CMS was likely switched to a 7-point scale from a 6-point scale, similar to the Big Five questionnaire from Gosling et al., referenced earlier.

Another limitation of this study is that there were only five individuals in the language group who spoke six languages. There are 98 individuals in the two-language group, 103 in the three-language group, 35 in the four-language group, and 17 in the five-language group. There is

an imbalance in sample size, as the number of individuals in the language group decreases as the number of languages spoken increases. Therefore, the finding that plurilingualism is a stronger moderator in the relationship between agreeableness and creativity motivation for those who speak six languages may be unreliable. Due to the small sample size, the results could have been due to coincidental variations, and multiple studies with other samples may yield contrasting findings. Larger sample sizes for more languages spoken (ex. five or six) would increase the validity of these results.

Further research could be done to increase the evidence for these conclusions, so that the conclusions could be generalizable to a broader range of audiences. It might be beneficial to explore whether being plurilingual but speaking fewer languages can still benefit creativity motivation, and if there are facets of agreeableness that have the greatest influence on creativity motivation. As mentioned previously, a similar study with a larger sample size may yield more reliable and valid results.

Conclusion

This study expanded on previous research on creativity and the Big Five personality trait of agreeableness. Specifically, our research focused on the relationship between creativity motivation (as measured by the Creativity Motivation Scale) since it has not been explored as thoroughly. In addition, we examined the role of plurilingualism and pluriculturalism as moderating factors in this relationship. We found that there was a statistically significant positive correlation between creativity motivation and agreeableness, and that plurilingualism and pluriculturalism were significant moderating factors. These findings suggest that agreeableness, plurilingualism, and pluriculturalism are all contributing factors to creativity motivation, which may help in research investigating why some individuals may be 'more creative' than others. In addition, our results could be beneficial for further research on the relationship between creativity and motivation, especially agreeableness, because it is a more overlooked trait compared to extraversion and neuroticism.

Works Cited

Abdullah, Iqra, et al. A Literature Review on Personality, Creativity and Innovative Behavior. vol. 6, no. 1, 2016. Zotero.

Acar, Selcuk, Bhoj Balayar, et al. "Are Bilinguals More Creative Than Monolinguals? A Meta-Analysis." The Journal of Creative Behavior, vol. 58, no. 4, 2024, pp. 755–76. Wiley Online Library, https://doi.org/10.1002/jocb.1521.

Acar, Selcuk, Harun Tadik, et al. "Creativity and Well‐being: A Meta‐analysis." The Journal of Creative Behavior, vol. 55, no. 3, Sept. 2021, pp. 738–51. DOI.org (Crossref), https://doi.org/10.1002/jocb.485.

Ahadi, B, and M Narimani. “STUDY OF RELATIONSHIPS BETWEEN PERSONALITY TRAITS AND EDUCATION.” Trakia Journal of Sciences, vol. 8, no. 3, 2010. Zotero.

Batey, Mark, and Adrian Furnham. Creativity, Intelligence, and Personality: A Critical Review of the Scattered Literature. 2006.

Bergeman, C. S., et al. “Genetic and Environmental Effects on Openness to Experience, Agreeableness, and Conscientiousness: An Adoption/Twin Study.” Journal of Personality, vol. 61, no. 2, June 1993, pp. 159–79. DOI.org (Crossref), https://doi.org/10.1111/j.1467-6494.1993.tb01030.x.

Bucher, Meredith A., et al. “A Meta-Analytic Review of Personality Traits and Their Associations with Mental Health Treatment Outcomes.” Clinical Psychology Review, vol. 70, June 2019, pp. 51–63. DOI.org (Crossref), https://doi.org/10.1016/j.cpr.2019.04.002.

Dewaele, Jean-Marc, and Elouise Botes. “Does Multilingualism Shape Personality? An Exploratory Investigation.” International Journal of Bilingualism, vol. 24, no. 4, Aug. 2020, pp. 811–23. DOI.org (Crossref), https://doi.org/10.1177/1367006919888581.

Dylman, Alexandra S., and Ingrid Zakrisson. “The Effect of Language and Cultural Context on the BIG-5 Personality Inventory in Bilinguals.” Journal of Multilingual and Multicultural Development, Mar. 2023, pp. 1–14. DOI.org (Crossref), https://doi.org/10.1080/01434632.2023.2186414.

Erzhanova, Asiia, et al. “The Influence of Big Five Personality Traits on Foreign Language Classroom Anxiety.” Psychology. Journal of the Higher School of Economics, vol. 21, no. 1, 2024, pp. 184–201. DOI.org (Crossref), https://doi.org/10.17323/1813-8918-2024-1-184-201.

Feist, Gregory J. A Meta-Analysis of Personality in Scientific and Artistic Creativity. 1998.

Forthmann, Boris, et al. “Revisiting the Interactive Effect of Multicultural Experience and Openness to Experience on Divergent Thinking.” International Journal of Intercultural Relations, vol. 63, Mar. 2018, pp. 135–43. DOI.org (Crossref), https://doi.org/10.1016/j.ijintrel.2017.10.002.

Gosling, Samuel D, et al. “A Very Brief Measure of the Big-Five Personality Domains.” Journal of Research in Personality, vol. 37, no. 6, Dec. 2003, pp. 504–28. DOI.org (Crossref), https://doi.org/10.1016/S0092-6566(03)00046-1.

Graziano, William G., and Renée M. Tobin. “Agreeableness.” Handbook of Individual Differences in Social Behavior, The Guilford Press, 2009, pp. 46–61. APA PsycNet.

He, Wu-jing, and Tin-wai Chiang. “From Growth and Fixed Creative Mindsets to Creative Thinking: An Investigation of the Mediating Role of Creativity Motivation.” Frontiers in Psychology, vol. 15, June 2024. Frontiers, https://doi.org/10.3389/fpsyg.2024.1353271.

Hoseinifar, Jafar, et al. An Investigation of the Relation between Creativity and Five Factors of Personality in Students. 2011.

JASP Team. JASP (Version 0.19.3)[Computer Software]. 2025, https://jasp-stats.org/.

Kao, Chien-Che, and Wen-Bin Chiou. The Moderating Role of Agreeableness in the Relationship between Experiencing Anger and Creative Performance. Aug. 2019.

Kharkhurin, Anatoliy V., Valeriya Koncha, et al. “Effects of Plurilingualism and Pluriculturalism on Creativity: Testing the Mediating Role of Tolerance and Intolerance of Ambiguity.” International Journal of Multilingualism, vol. 0, no. 0, Aug. 2023, pp. 1–24. Taylor and Francis+NEJM, https://doi.org/10.1080/14790718.2023.2242373.

Kharkhurin, Anatoliy V. “Language Mediated Concept Activation in Bilingual Memory Facilitates Cognitive Flexibility.” Frontiers in Psychology, vol. 8, June 2017. Frontiers, https://doi.org/10.3389/fpsyg.2017.01067.

Kharkhurin, Anatoliy V., Koncha ,Valeriya, et al. “The Effects of Plurilingualism and Pluriculturalism on Divergent Thinking: Testing the Moderating Role of Personality Traits.” International Journal of Bilingual Education and Bilingualism, vol. 27, no. 6, July 2024, pp. 772–92. Taylor and Francis+NEJM, https://doi.org/10.1080/13670050.2023.2232521.

King, Laura A., et al. “Creativity and the Five-Factor Model.” Journal of Research in Personality, vol. 30, no. 2, June 1996, pp. 189–203. DOI.org (Crossref), https://doi.org/10.1006/jrpe.1996.0013.

Koncha, Valeriya, and Anatoliy Kharkhurin. “Dataset.” 2024, https://doi.org/10.6084/m9.figshare.25967515.v1.

Lamers, Sanne M.A., et al. “Differential Relationships in the Association of the Big Five Personality Traits with Positive Mental Health and Psychopathology.” Journal of Research in Personality, vol. 46, no. 5, Oct. 2012, pp. 517–24. DOI.org (Crossref), https://doi.org/10.1016/j.jrp.2012.05.012.

Lourenço, Fernando, and Dilani Jayawarna. “Enterprise Education: The Effect of Creativity on Training Outcomes.” International Journal of Entrepreneurial Behavior & Research, vol. 17, no. 3, May 2011, pp. 224–44. DOI.org (Crossref), https://doi.org/10.1108/13552551111130691.

Nusbaum, Emily C., and Paul J. Silvia. “Are Intelligence and Creativity Really so Different?☆Fluid Intelligence, Executive Processes, and Strategy Use in Divergent Thinking.” Intelligence, vol. 39, no. 1, Jan. 2011, pp. 36–45. DOI.org (Crossref), https://doi.org/10.1016/j.intell.2010.11.002.

Piccardo, Enrica. “Plurilingualism as a Catalyst for Creativity in Superdiverse Societies: A Systemic Analysis.” Frontiers in Psychology, vol. 8, Dec. 2017, p. 2169. DOI.org (Crossref), https://doi.org/10.3389/fpsyg.2017.02169.

Puryear, Jeb S., et al. “Relationships of Personality to Differential Conceptions of Creativity: A Systematic Review.” Psychology of Aesthetics, Creativity, and the Arts, vol. 11, no. 1, Feb. 2017, pp. 59–68. DOI.org (Crossref), https://doi.org/10.1037/aca0000079.

Richards, Ruth. “Everyday Creativity: Our Hidden Potential.” Everyday Creativity and New Views of Human Nature: Psychological, Social, and Spiritual Perspectives, American

Psychological Association, 2007, pp. 25–53. APA PsycNet, https://doi.org/10.1037/11595-001.
Silvia, Paul J., Beate P. Winterstein, et al. “Assessing Creativity with Divergent Thinking Tasks: Exploring the Reliability and Validity of New Subjective Scoring Methods.” Psychology of Aesthetics, Creativity, and the Arts, vol. 2, no. 2, May 2008, pp. 68–85. DOI.org (Crossref), https://doi.org/10.1037/1931-3896.2.2.68.
Silvia, Paul J., James C. Kaufman, et al. “Cantankerous Creativity: Honesty–Humility, Agreeableness, and the HEXACO Structure of Creative Achievement.” Personality and Individual Differences, vol. 51, no. 5, Oct. 2011, pp. 687–89. DOI.org (Crossref), https://doi.org/10.1016/j.paid.2011.06.011.
Silvia, Paul J., Emily C. Nusbaum, et al. “Openness to Experience, Plasticity, and Creativity: Exploring Lower-Order, High-Order, and Interactive Effects.” Journal of Research in Personality, vol. 43, no. 6, Dec. 2009, pp. 1087–90. DOI.org (Crossref), https://doi.org/10.1016/j.jrp.2009.04.015.
Singh, Leher, et al. “Effects of Environmental Diversity on Exploration and Learning: The Case of Bilingualism.” Journal of Experimental Psychology: General [US], vol. 153, no. 11, 2024, pp. 2879–98. APA PsycNet, https://doi.org/10.1037/xge0001562.
Slayton, Sarah C., et al. “Outcome Studies on the Efficacy of Art Therapy: A Review of Findings.” Art Therapy, vol. 27, no. 3, Jan. 2010, pp. 108–18. Taylor and Francis+NEJM, https://doi.org/10.1080/07421656.2010.10129660.
Tellegen, Auke, et al. Personality Similarity in Twins Reared Apart and Together. 1988. Zotero.
Wang, Hung-chun, and Yuh-show Cheng. “Dissecting Language Creativity: English Proficiency, Creativity, and Creativity Motivation as Predictors in EFL Learners’ Metaphoric Creativity.” Psychology of Aesthetics, Creativity, and the Arts, vol. 10, no. 2, May 2016, pp. 205–13. DOI.org (Crossref), https://doi.org/10.1037/aca0000060.
Zhang, Zhitian, et al. Creativity Motivation Construct Development and Cross-Cultural Validation. 2018. Zotero.
Хухлаев, О.Е., et al. “Разработка и адаптация методики «Интегративный опросник межкультурной компетентности».” Психология. Журнал Высшей школы экономики, vol. 18, no. 1, Mar. 2021, pp. 71–91. DOI.org (Crossref), https://doi.org/10.17323/1813-8918-2021-1-71-91.

The Impacts of AI Integration on the Engineering Problem Solving Process By Katie Hu

Abstract

Using data and research from articles related to the integration of Artificial Intelligence(AI) in organizations, this literature review analyzes the impacts that AI has brought to the various stages of the design process for both software and hardware engineering. Generative designs and AI automation tools are analyzed alongside computational technologies such as digital twins and topology optimization. Moreover, this review consists of surveys,

comparative studies, and simulation studies to visualize AI's current influence and potential contribution in the future. Besides that, feasibility from a business perspective and long-term consequences of AI (AI bias, unemployment, critical thinking, etc.) are offered as a different perspective. Finally, key trends indicate a positive correlation between productivity gains and utilization of AI despite the uncertainties pointed out.

Introduction

Artificial Intelligence has been becoming significantly popular, gaining attention worldwide in the past few years. Driven by the surge of generative AI and transformer models, it has proved itself to be very useful from simple daily tasks to complex problems in research and industries. The most common AI models currently used in engineering industries consist of machine learning models, deep learning models, generative models, and computer vision models.

A survey in 2020 including faculties, technical staffs, research assistants, and PhD students working across various fields of engineering was conducted to gather perspectives of AI during the time. Many respondents believe that in the next 2 decades, there will be a 45.55% increase in engineering productivity by AI . In addition, 50.54% responded that in the future, the possible risks and uncertainty of AI will be exceeded by its benefits (Blake et al. 1732). The purpose of this article is to determine whether the assumption is valid after 5 years of rapid growth in Artificial intelligence by focusing on existing research and studies.

To begin, the engineering design process is a systematic process to identify problems and to design and implement solutions. The method includes the following stages:

1. Define the problem
2. Conduct background research to recognize and understand the issue
3. Brainstorm all possible solutions and formulate a design
4. Prototype, evaluate, and optimize design
5. Communicate/present to others for inspiration

The topics to be investigated in this review consists of, how has generative AI contributed to creativity and innovation on the design stages #2 and #3? How has AI aided system optimization, digital twins creation, and computational model generation and transformed evaluation stage #4?

Role of generative AI in improving creativity and innovation

As a subset of generative AI, generative design is enhanced from machine learning by recognizing patterns from data and producing striking results. This methodology, implemented through algorithmic software, provides an extensive range of solutions from user specified criterias. It is commonly combined with a design space such as Computer Aided Design(CAD) to create various 3D models. Generative AI is not restricted to 3D modeling and can be applied in media, healthcare, logistics, and across other industries. For instance, in hospitals, generative AI is used to produce new personalized treatment plans based on patients' individual data

(Bhuyan et al.). Back to engineering design, with the use of this generative design tool, engineers can be quickly provided with numerous available ideas that may not have been thought of manually by engineers themselves. Another generative AI driven tool besides generative design is topology optimization (TO). TO, first introduced in the late 1980s, removes unnecessary materials in a structure using physics and mathematical representation. The combination of AI in topology optimization (AITO) resolves challenges often faced by engineers such as the need for lightweight components and high functionality ("Generative Design 101). Several studies (Chatterjee et al.; Halle et al.) converge in using AI to find advancements for the performance of structural development. These results were specifically illustrated in detecting wind turbine flaws, where a generative model (Generative Adversarial Network) proposes fault data that are crucial to predictive maintenance and improving overall reliability of wind turbines (Chatterjee et al.). Similarly, a study conducted by Halle et al. also demonstrated productivity gains. In their research, they proposed a method called predictor evaluator network(PEN) to produce ideal geometric structures. In this method, artificial neural networks(ANN) are applied and trained by about 7.6 million randomly generated data points. Compared with conventional TO, PEN was able to complete the same task 259 times faster. Based on the results, it can be concluded that generative AI empowers engineers to explore solutions beyond individual human intellect limits, boosts creativity in engineering fields, and thus fosters optimism.

To further understand generative AI tools in the engineering design stage, comparative studies "Performance-Driven Engineering Design Approaches…" and "A multi-case study of traditional, parametric and generative design…" provide results from different perspectives.

Firstly, Loris Barbieri and Maurizio Muzzupappa conducted a study analyzing the performances of computer aided technologies in CAD (computer aided design), comparing AI assisted generative design (AIGD) with conventional topology optimizations (TO) without AI assistance. CAD is a fundamental tool for modelling, translating user's needs into geometric forms which will be analyzed by CAE (computer aided engineering) through simulation and by CAM (computer aided manufacturing) for manufacturability. In this study, two mechanical components in Formula Student race cars built by University of Calabria were designed, a rocker arm and a brake pedal. In the rocker arm design, aluminum alloy was the material used for comparison between the traditional approach, AIGD and TO. Before presenting the data, it is important to understand the criteria and goals of this study. Displacement (mm) is often seen in the methodology to represent the distance the material moves under a stress or force. Larger displacement usually means a flexible but unstable component, while smaller displacement usually means a component that is stiff but resistant to deformation. Consequently, the target maximum displacement should be low, but not at zero, indicating both its durability and elasticity. Another criteria commonly appeared is Factor of Safety (FoS). FoS is defined as the amount of strength a structure can withstand without deforming. For instance, FoS 2.4 means that the rocker arm can tolerate 2.4 times the load until it breaks. Thus, FoS, similar to displacement, shouldn't be too high or too low, to balance its weight versus safety. Using the TO method, engineers had to first create an initial design space, then iteratively remove the

unnecessary components until the model meets the target objective - maximum stiffness, mass reduction, and FoS. The results for aluminum rocker using TO is demonstrated in Fig 1. b), with a 2.2% mass reduction and 46% reduction for maximum displacement compared to the traditional method in a) while keeping the same FoS 2.4. On the other hand, the solutions from AIGD are not affected by setup conditions from designers as it can produce several different designs. The optimal solutions from AIGD are illustrated in c) and d). Keeping the same FoS 2.4, the AIGD design in c) displayed a 38% mass reduction and 42% reduction for maximum displacement. The last design d) demonstrates the best design by AIGD, balancing approximately equal benefits between the three factors: 35% mass reduction, 30% reduction for maximum displacement, and 25% increase in FoS. Similar conclusions were reached with the rocket arm made from titanium and for the brake pedal. These observations indicate that AIGD tools are most productive in creating high-performance designs, with TO being second, and traditional methods being the least productive.

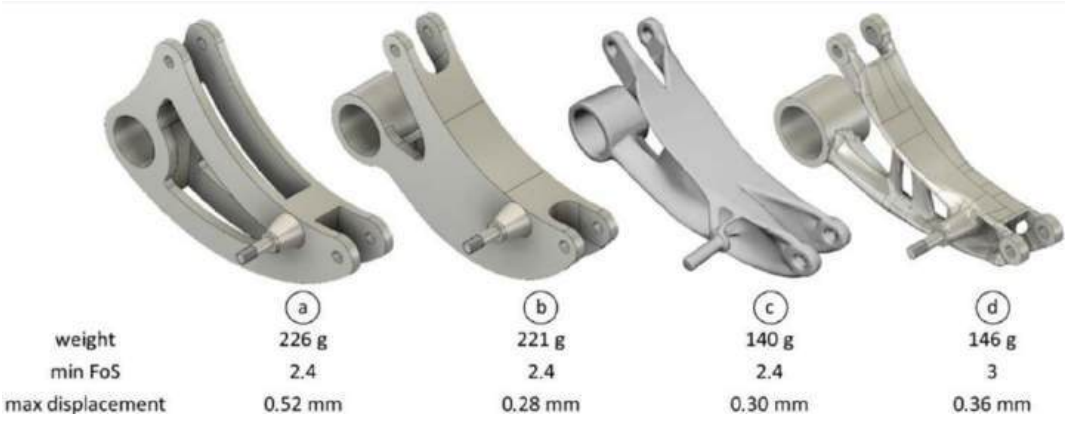


Fig 1. Aluminum rocker designed from a) traditional approach, b) TO tools, c/d) AIGD tools (Barbieri and Muzzupappa)

As mentioned earlier, GD tools, unlike TO tools, do not face limitations on starting parameters, and are therefore allowed to determine the global optimum for prototypes such as the rocker arm in this case. TO tools are considered to be time consuming and difficult to incorporate in the translation and redesign stages because TO is mainly mesh-based and composed of small tessellated components, making it difficult to incorporate with CAD for evaluations. On the contrary, GD tools were developed based on the CAD system, meaning that it can be better combined with CAD. In general, because TO and GD are different types of tools that operate differently, AI assisted GD (AIGD) should be directly compared with non AI assisted GD to ascertain AI's positive impact. Furthermore, the experiment was performed around 3 years ago. During these past few years, AI experienced rapid changes and dramatic advancements, thus the current AIGD could result in higher performances than that illustrated in this study. In addition, this study lacks consideration of TO and GD's original intention for their usage in engineering fields. Specifically, the methodology, allowing the two software tools to create their own structure/shape of the rocket arm, is inherently biased towards GD. GD is more profound at early

design innovations as it explores a broader range of solutions and selects the most ideal design to continue on later stages. Conversely, TO is programmed to optimize an existing design to improve structural integrity and minimize weight (Choudhury et al.). This means that by allowing TO to generate designs, something that it originally wasn't programmed for, makes it more probable to expose its weaknesses.

Although merging AI into generative design together makes a powerful tool, human oversight is necessary for personalization and comprehension. The second case study on the research question of how engineering students think and behave in the generative design (GD) versus traditional design (TD) and parametric design (PD), offers a different perspective. These are three separate methods that fall into the category of computational design. Firstly, TD is when engineers follow methodological steps, essentially depending on 2D drawings and a physical model. Secondly, PD is when designers use parameters, constraints, and algorithms to manipulate and modify only a single model. The last method GD is primarily focused on exploring new and optimum solutions with machine learning. Although GD and PD both are an AI computational model, the core component of PD is determined by its designers while the core component of GD is from AI. In this study, Sabrina and Suyash found traditional design to be very laborious as it contains too much manual input. In addition, TD is highly dependent on individual skills and experiences, resulting in challenges for some designers. On the contrary, all of the students believed that GD is competent, but simultaneously unpredictable and incomprehensible as it is hard to trace back the steps of AI. Consequently, none of the cautious students chose GD by itself and preferred a middle ground for future projects (Fig. 2). This indicates that people do acknowledge AI's potential for projects and that AI in computational modeling does indeed create a larger variety of designs but do not have the confidence to solely rely on its decisions. In terms of data sampling, there is a population gap in the study because this survey only reflects opinions upon undergraduate students and only three students were thoroughly analyzed. Therefore, professionals with more experience were under-represented and the result may not accurately represent the whole population.

Table 2 Comparison of TD, PD, GD discussion for three case studies

Discussion	Sabrina	Suyash	Ricky
TD	(1) Found TD tedious, (2) Explored broadly, (3) Considered environmental factors	(1) Found TD tedious, (2) Power output objective, (3) Considered environmental factors	(1) Cost output objective, (2) Power output objective, (3) Considered environmental factors
PD	(1) Visual objective, (2) Energy output objective	(1) Defined variable ratios, (2) Cost objective	(1) Defined variable ratios, (2) Visual objective, (3) Cost objective, (4) Energy output objective
GD	(1) Expected identical designs generated by the same objective, (2) Defined variable ranges, (3) Variable ranges based on PD	(1) Expected identical designs generated by the same objective, (2) Defined variable ranges, (3) Variable ranges based on PD	(1) Realized the same objective gave different designs, (2) Defined variable ranges, (3) GD expectations based on PD
TD vs. PD vs. GD	PD is more hands-on than GD	(1) PD is more challenging than TD, (2) GD is the most modern	PD is a "sweet spot" between TD and GD
Preference	GD mixed with PD	GD with TD and PD as secondary options	PD

Fig. 2 (Koolman et al. 121)

Likewise, in Kuhail et al.'s study, a space haptic boot case study demonstrates the necessity of human oversight for the usage of AI. Haptic boots are futuristic boots that include sensors and motors intending to enhance space navigation for astronauts by the use of sensors and motors. It is currently still in its research and development stage and is not yet used. The study is to test how a design of space haptic boots would be with the use of generative AI. To begin, they started with a large language model aided zero-shot prompt, then inputted super specific content and details to refine and generate a use case that would be more complex and accurate to their goal. Next, they utilized chatGTP for their evaluation process, testing for the reliability of radiation hardened electronics, comfort levels, and other minor adjustments. Finally, they will use chatGTP to analyze the safety requirements of their design and send it to the validation stage. After going through the entire process, they observed the results of this experiment. The foremost finding is that the specifications generated by AI lack traceability, thus do not meet the standard guideline for software requirements (IEEE). Another flaw of using AI to produce the whole design, including the parts necessary to build it, is that the components do not truly exist and is a completely imaginary material the AI model (LLM) created. Since Artificial intelligence is unable to distinguish what is real and what is fictional, they do not have the capability to create practical designs that could be implemented in the real world. Due to AI's inconsistency and unreliability, the space haptic boot design proved some of the main dangers of AI created solutions. While AI is able to generate vast amounts of use cases and purposes of the space haptic boot, hallucinations on necessary components may disintegrate the entire project. This example demonstrates that AI possesses a higher level of creativity due to analyzing vast amounts of data that cannot be done by humans, but people must use AI with even more caution, making sure to set all necessary parameters, checking for design requirements, and ensuring its

viability. However, this case study also has data limitations because the whole process is solely conducted with chatGTP and does not include other types of generative AI. As a result, their conclusions may not be completely accurate unless it uses a variety of AI models to prove whether or not they will still have hallucinations. The data they collected with chatGTP could possibly be an exception compared to other AI models.

Role of AI automation in design evaluation and optimization

With the new adaptive capabilities of AI, it can now automate detail oriented tasks by recognizing patterns, interpret deeper meaning, and analyze vast amounts of both quantitative and qualitative data. By doing so, it reduces the unnecessary repetitive labor for humans, allowing humans to work on assignments more worthwhile and essential. Quantitative data illustrate that AI-assisted testing takes on an average 67.3% of the original time and increases coverage 43.8% higher than traditional approaches (Patel 340). Based on a workflow analysis, automation engineers, prior to AI, spent 42.7% of their time preserving and maintaining the current code functionality, 23.8% debugging failure, 18.5% designing new testing frameworks, and 15% analyzing results. After utilizing AI, the arrangement changed to 14.3% managing, 8.7% debugging, 46.3% designing new test platforms, and 30.7% on analytical modeling. As demonstrated in this redistribution, it shows that AI is able to exceed humans in terms of the capability to supervise code and debug errors, but human involvement is more necessary in areas such as to produce content validation tests and to identify unexpected patterns from results. While AI may be able to generate an innovative testing system, it is difficult to ensure its reliability to meet the objectives in the required scope, and difficult to draft an original prototype due to its dependability on training data it has seen before.

Characteristics of traditional methods in software coding consist of sequential development, extensive use of documentation, manual coding, and minimal flexibility. Although the traditional sequential method has been used for several decades due to its predictability and transparency, it is considered to be resource-heavy and time-consuming. There are multiple studies where AI tools are applied in coding programs and resolve some of the challenges faced in software development life cycle. For instance, Bilgin proposed an AI technique named Code2Image in which coding sources are automatically converted into images that can be analyzed using computer vision and neural networks (CNNs). The Code2Image method was proved to outperform Ast2Vec (vector embeddings) in terms of predicting vulnerabilities in code, thus was able to improve the process of analyzing code. Detecting security weaknesses in source codes is crucial because it ensures practicality and reliability, ultimately reducing risks such as unauthorized access that could lead to significant damage to companies. Nevertheless, the Code2Image approach has its weaknesses too, which needs to be further addressed. Due to AI's tendency to display bias towards the frequently seen classes, Code2Image's performance significantly dropped when tested in CWE-469 method where there is an imbalance in dataset, causing the AI model to overfit. Moreover, the preprocessing stages combined together adds to the amount of computational overhead, which may be detrimental when applied to large datasets.

The preprocessing phases include converting the source code into AST(Abstract Syntax Tree) for conversion into images, constructing a visual representation by converting tokens into coordinate points and colors, and finally removing any unnecessary sections within the pixelated image. Particularly in substantial amounts of input, these distinctive steps lead to increased time consumption, hence reducing its efficiency.

Another example of an AI automation tool is GitHub copilot, which is an AI coding assistant that can generate code and provide feedback on code snippets. In the experimental study that evaluated the quality of GitHub's code, the authors selected 164 programming problems among the HumanEval dataset and inserted prompts to each of the problems as input (Yetistiren et al.). Afterwards, they evaluated the code's validity, correctness, and efficiency. The results were a 91.5% success for GitHub copilot to generate valid code that ran without error according to programming rules, 28.7% success to generate correct code that performed as intended, 20.1% failure rate for correctness, and 51.2% to generate code partially correct which means it only passes one test. The large percentage for validity indicates the potential for AI to automate code generation but its ability to comply as demanded should be improved. In terms of efficiency, their evaluation was split into two categories, time complexity which measures the amount of time it takes for an algorithm to function as the size of input grows and space complexity which measures the amount of memory required as input space increases. According to their data, 87.2% of the correctly generated code had equivalent time complexity as human written code, while 12.8% ran relatively fast despite larger inputs, indicating greater efficiency. In addition to the similar ratios of equivalent and greater efficiency, 3.6% of the partially correctly generated code had a lower level of efficiency. For space complexity, 89.4% of the accurately generated code had the same space complexity, 4.2% used lower memory with larger datasets, and 6.4% performed worse, or required more memory.

Because of its value proposition that goes beyond evaluation metrics, both Code2Image and GitHub Copilot are undoubtedly convenient automation tools for programmers and engineers. For instance, as of July 2025, GitHub Copilot has achieved a record of more than 20 million users (Zeff). Nonetheless, its potential to be fully automated is still far from reach as demonstrated from Code2Image's high computational cost and GitHub Copilot's small likelihood of achieving correct code, requiring human supervision.

On the contrary, Donglian Chen and Zhihan Lv offer a more positive outlook on the future applications of AI automation, suggesting that it can contribute beyond common complexities in the software development process. Their experimental study revolves around how AI powered digital twins, a form of AI automation, can improve network security and traffic safety. Digital twins (DTs) integrate a wide variety of AI models for virtual simulation that reflect real world scenarios, analyzing a system's behavior and flaws. Similar to topology optimization, digital twin has been used for decades before AI intervention, but is enhanced by AI to provide better precision and reliability. In this case, network load balancing and spatial-temporal graph convolution network (STGCN) is used for traffic prediction, hence securing operational safety and identifying nonlinear variables. AI automation plays a crucial

role in autonomous cars as it is the control center which includes perception, prediction, planning, and controlling. Through its information network that uses a combination of sensors, autonomous cars are able to comprehend the current driving conditions. After input is transferred into the data center, the spatiotemporal convolution layer extracts in-depth features via filtration, and is then used to make a final classification layer for output or quantifiable decisions. In order to train the proposed AI model, the researchers firstly constructed an autonomous car simulation using DTs which can generate spatiotemporal data as input. Next, mathematical formulas are applied in data scheduling, data processing, understanding underlying patterns in traffic flow, and finding correlations for each node in a graph. To evaluate its efficiency, STGCN is compared with other models such as AlexNet, DenseNet, IGCNet, VGGNet, and ResNet algorithms. Fig 3 a) shows a ROC curve, representing the sensitivity (true positive) vs specificity (false positive). With higher specificity meaning fewer false values and higher sensitivity meaning more true values, STGCN always had the highest sensitivity, with the largest ROC value of 0.9379. Similarly, in the AUC vs iterations graph, STGCN had the best performance overall, learning quickly initially from the steep increase and flattening out later to illustrate that the model has reached convergence from the training data.

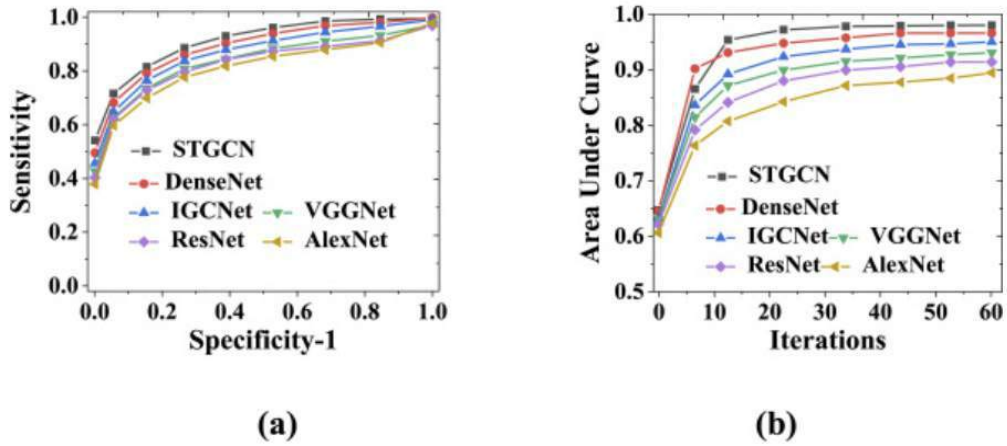


Fig 3 (Chen et. al)

Furthermore, STGCN displays the highest value in graphs of accuracy, precision, recall, and F1 vs iterations too. For accuracy vs iterations, STGCN reached 92.7% which is 2.94% greater than the second highest, DenseNet algorithm. Hence, STGCN, as an example of a model that benefits from DT training, proves how DTs can refine prediction, reaction, and safety in autonomous cars. Since STGCN is a specialized model within the prediction component of an automation system, its excellency can reflect the overall behavior of autonomous cars. On the other hand, AI automation enables data collection, decision-making, and self-optimization (Viquez et al.) which provide realistic interactions and quantifiable results for digital twins, thus creating a mutual benefit relationship. Besides analyzing its proficiency in traffic management, the scholars also emphasize its role in cybersecurity. In particular, the independent variables of

vehicle quantity plotted in graphs against dependent variables of average delivery rate, average leakage rate, and average delay. As observed in fig 4 a), when the number of experimental vehicles are increased, STGCN shows the highest delivery rate which is never less than 80%. In graph b), STGCN's vulnerability for potential cyberattacks never surpasses 10%, indicating its reliability when it comes to cybertheft. Graph c) offers an inverse relationship of graph a), thus having the lowest average delay. As regards to the speed of a vehicle, STGCN continues to be the most outperforming from the other algorithms. In general, all the graphs presented in this study implies how STGCN, as a part of the AI automation system, streamlines validation and eases maintenance in the latter part of the engineering design process.

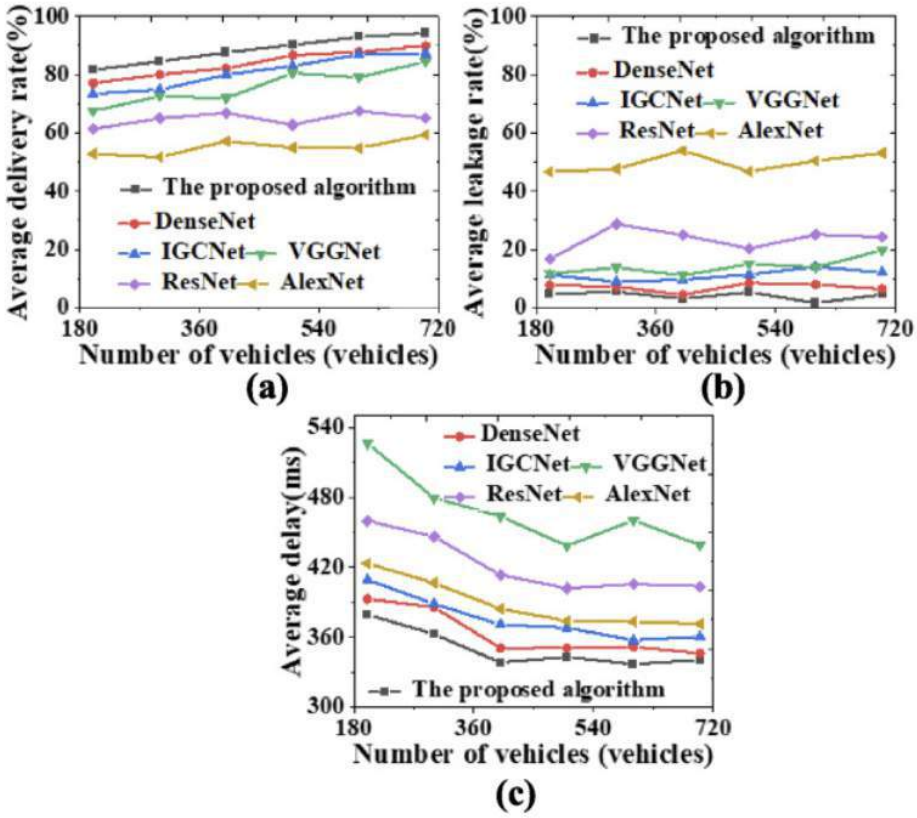


Fig 4 (Chen et al.)

This STGCN method appears effective because of its exemplary proximity sensing analysis and information technology security, but its existence has only been tested in simulations and may not reflect real world scenarios where factors such as weather conditions and road conditions are involved. Additionally, traffic safety is dependent upon the entire AI automation system consisting of perception, to detect and recognize the surrounding environment; localization, to determine the car's precise location; prediction, to forecast and decide how the car should react; and control, to execute the plan (Cohen). Although STGCN represents mastery from DT in the prediction section, improved decision-making is only one

aspect of an autonomous vehicle, with perception and execution also taking a key part in the whole process. Therefore DT should also be tested with sensors, SLAM algorithms, steering, and reinforcement learning models for a comprehensive visualization on DT's impact. Overall, AI automation allows DTs to automatically run vast amounts of scenarios, reducing manual testing, and producing accurate models like the one presented in this study, STGCN. While DTs are efficiently used in autonomous vehicles, large scale implementation continues to be an area of difficulty due to data quality issues that require maintenance cost and due to operational complexity (O'Sullivan et al. 1526). Similar to the Code2Image model, STGCN is an innovative idea where active academic research is still being conducted. Despite promising observations, they are not yet assessed for viability and scalability as a business model.

Challenges and limitations

Besides reviewing gaps from numerical data and results, ethical issues are also crucial to visualize the full scope of AI's impact in the engineering design process. As mentioned throughout the several studies presented, AI provides desirable results from generating creative solutions by generative AI to enhancing optimization through AI automation. Yet every action comes with consequences and responsibilities whether it is short term or long term. Immediate effects include AI transparency, bias, and accountability issues. Specifically, autonomous cars function through the AI automation system built by software developers which makes it hard to determine whose fault it belongs to when accidents occur. Currently, only state regulation efforts exist, demonstrating its inaptness for it to be utilized in wide markets. The complexity of deep learning causes unexplainable outputs in what is known as "AI Black box", making it difficult to identify dependability. Bias is also another major challenge that can lead to technical issues or even societal concerns. Learning from training data, AI models have a high risk of overfitting and require to be fed with quality data. As a result, AI becomes prone to exhibit sampling error and even turn into what is known as self fulfilling AI models, which reflects stereotyping and distorts information. According to a study, a healthcare allocation algorithm that was used in many U.S. hospitals allocated a higher risk score to white Americans compared to black Americans who were in worse conditions (D'Antonoli). This discriminatory action illustrates how AI may negatively impact marginalized people. Environmental concern is an example of AI's long term effect that could possibly reverse climate change efforts to countries seeking mitigation and adaptation strategies. In the research paper that examines energy consumption and regulations regarding natural language processing (NLP), training NLP through neural architecture search method releases approximately 626,000 pounds of CO_2 into the atmosphere which is ~315 round trips flights from New York to San Francisco (Strubell et al.). With about 78% of organizations worldwide using AI and this percentage rising each year, greenhouse gas emissions will become more difficult to control in the future (Maslej et al.). Employment is also noteworthy to mention as people have both optimistic and pessimistic views regarding this issue. Generally, researchers agree that AI investment will for sure displace jobs and change the labor market with remaining jobs for those that can manage or work alongside AI. This results in

fluctuations of income especially within lower paid employees which are easily replaced by AI (Okur et al.).

Only a few studies have investigated AI related setbacks to human intellect, where excess usage of AI may hinder cognitive ability development and usage including critical analysis and memory retention skills (Gerlinch). In particular, Michael Gerlinch conducted an experiment where he collected data from 666 participants of diverse age groups and professions hoping to understand AI's impact on people's critical thinking. Using the ANOVA statistical method, Gerlinch found that there is a strong correlation between high usage of AI tools and increased cognitive offloading. The result ultimately suggests that the availability of AI has lowered the need for human analytical reasoning, thus potentially diminishing human's ability to generate innovative output and deep imagination. Its impacts on children who are in a critical phase of intellect development could be even more profound. For that reason, more investigation and research needs to be performed.

Conclusion

Through the literature reviews and summaries presented in this review, it is apparent that the integration of AI has significantly impacted the engineering design process by effectively providing a variety of prompts through generative AI tools and validating its performance through AI automation. In the initial and final stages of the engineering design process, humans are still the ones who lead the problem definition, make decisions on final design, and communicate to others. While, in the second (research to understand issue) and third (propose possible solutions and formulate design) stages, generative AI greatly surpassed topology optimization and other traditional approaches. In the case studies presented, it was able to minimize the weight and maximize the factor of safety while keeping deformation relatively small in both the rocket arm and brake pedal. Generative design's contribution to brainstorming possible solutions indicates its creativity that improves initial prototypes. AI automation tools also work well on formulating designs by allowing repetitive and complex tasks to be quickly handled without human intervention. Copilot GitHub is one example, whose main purpose is to assist developers in coding and allow programmers to focus more on strategic areas, hence streamlining the process of creating prototypes. In the fourth stage (evaluation and optimization), AI automation can be used with simulations to predict and evaluate performances. As demonstrated by an inquiry into the correlation between the deep learning model, STGCN, and digital twins, AI automation strengthened cybersecurity defenses and enhanced the prediction portion of autonomous systems in self-driving cars. However, in reference to the limitations section, several concerns on AI are pointed out and AI should therefore be used with caution. Further investigations and protection measures need to be done before AI can be safely used for our societies.

Works Cited

Alam, Md Ferdous, et al. “From Automation to Augmentation: Redefining Engineering Design and Manufacturing in the Age of NextGen-AI.” An MIT Exploration of Generative AI, Mar. 2024, https://doi.org/10.21428/e4baedd9.e39b392d. Accessed 22 Oct. 2025.

Alfaro-Viquez, David, et al. “A Comprehensive Review of AI-Based Digital Twin Applications in Manufacturing: Integration across Operator, Product, and Process Dimensions.” Electronics, vol. 14, no. 4, Multidisciplinary Digital Publishing Institute, Feb. 2025, pp. 646–46, https://doi.org/10.3390/electronics14040646. Accessed 10 Nov. 2025.

Barbieri, Loris, and Maurizio Muzzupappa. “Performance-Driven Engineering Design Approaches Based on Generative Design and Topology Optimization Tools: A Comparative Study.” Applied Sciences, vol. 12, no. 4, Jan. 2022, p. 2106, https://doi.org/10.3390/app12042106. Accessed 19 Oct. 2025.

Bhuyan, Soumitra S., et al. “Generative Artificial Intelligence Use in Healthcare: Opportunities for Clinical Excellence and Administrative Efficiency.” Journal of Medical Systems, vol. 49, no. 1, Springer Science and Business Media LLC, Jan. 2025, https://doi.org/10.1007/s10916-024-02136-1. Accessed 23 Nov. 2025.

Bilgin, Zeki. “Code2Image: Intelligent Code Analysis by Computer Vision Techniques and Application to Vulnerability Prediction.” ArXiv.org, 2021, arxiv.org/abs/2105.03131. Accessed 26 Oct. 2025.

Blake, Robert W., et al. “Impact of Artificial Intelligence on Engineering: Past, Present and Future.” Procedia CIRP, vol. 104, Jan. 2021, pp. 1728–33, https://doi.org/10.1016/j.procir.2021.11.291. Accessed 10 Oct. 2025.

Chatterjee, Subhajit, and Yung-Cheol Byun. “Leveraging Generative Adversarial Networks for Data Augmentation to Improve Fault Detection in Wind Turbines with Imbalanced Data.” Results in Engineering, vol. 25, Jan. 2025, p. 103991, https://doi.org/10.1016/j.rineng.2025.103991. Accessed 30 Oct. 2025.

Chen, Dongliang, and Zhihan Lv. “Artificial Intelligence Enabled Digital Twins for Training Autonomous Cars.” Internet of Things and Cyber-Physical Systems, vol. 2, May 2022, https://doi.org/10.1016/j.iotcps.2022.05.001. Accessed 4 Nov. 2025.

Choudhury, Mohammad Mohiuddin, et al. “Artificial Intelligence (AI) in the Design Process – a Review and Analysis on Generative AI Perspectives.” Proceedings of the Design Society, vol. 5, Cambridge University Press, Aug. 2025, pp. 631–40, https://doi.org/10.1017/pds.2025.10077. Accessed 21 Oct. 2025.

Cohen, Jeremy. “4 Pillars vs End to End: How to Pick an Autonomous Vehicle Architecture.” Welcome to the Library!, Welcome to The Library!, 21 July 2023, www.thinkautonomous.ai/blog/autonomous-vehicle-architecture/. Accessed 11 Nov. 2025.

D’Antonoli, Tugba Akinci. “Ethical Considerations for Artificial Intelligence: An Overview of the Current Radiology Landscape.” Diagnostic and Interventional Radiology, vol. 26, no. 5, July 2020, https://doi.org/10.5152/dir.2020.19279. Accessed 22 Nov. 2025.

GeeksforGeeks. “Common AI Models and When to Use Them?” GeeksforGeeks, 24 Apr. 2024, www.geeksforgeeks.org/artificial-intelligence/common-ai-models-and-when-to-use-them/. Accessed 10 Oct. 2025.

Generative Design 101. “Generative Design 101.” Formlabs, 2015, formlabs.com/blog/generative-design/?srsltid=AfmBOopzmTIzX6P9bQyqmrjLIiSrPpxMnsjrnDlLc0JB23ctX0HqMsja. Accessed 12 Oct. 2025.

Gerlich, Michael. “AI Tools in Society: Impacts on Cognitive Offloading and the Future of Critical Thinking.” Societies, vol. 15, no. 1, MDPI AG, Jan. 2025, p. 6, https://doi.org/10.3390/soc15010006. Accessed 30 Oct. 2025.

Halle, Alex, et al. “An Artificial Intelligence–Assisted Design Method for Topology Optimization without Pre-Optimized Training Data.” Applied Sciences, vol. 11, no. 19, Sept. 2021, p. 9041, https://doi.org/10.3390/app11199041. Accessed 21 Oct. 2025.

Khogali, Hisham O., and Samir Mekid. “The Blended Future of Automation and AI: Examining Some Long-Term Societal and Ethical Impact Features.” Technology in Society, vol. 73, no. 1, Mar. 2023, https://doi.org/10.1016/j.techsoc.2023.102232. Accessed 24 Oct. 2025.

Koolman, Elisa, et al. Design Computing and Cognition DCC’24. Springer, 2024, pp. 107-26, sidilab.net/wp-content/uploads/2024/07/dcc-2024-generative-design-thinking_final.pdf. Accessed 15 Oct. 2025.

Kuhail, Mohammad Amin, et al. “Integrating Generative AI into the Design Process: A Case Study on Space Engineering.” AHFE International, vol. 120, Jan. 2024, https://doi.org/10.54941/ahfe1004568. Accessed 29 Oct. 2025.

O’Sullivan, Jamie, et al. “A Case-Study in the Introduction of a Digital Twin in a Large-Scale Smart Manufacturing Facility.” Procedia Manufacturing, vol. 51, 2020, pp. 1523–30, https://doi.org/10.1016/j.promfg.2020.10.212. Accessed 20 Nov. 2025.

Odeh, Ayman. “Exploring AI Innovations in Automated Software Source Code Generation: Progress, Hurdles, and Future Paths.” Informatica, vol. 48, no. 8, May 2024, https://doi.org/10.31449/inf.v48i8.5291. Accessed 30 Oct. 2025.

Okur, Fatih, and Enes Özdemir. “Artificial Intelligence, Automation and Employment Dynamics: Empirical Evidence from G7 Economies.” Journal of Economic Studies, Oct. 2025, pp. 1–17, https://doi.org/10.1108/jes-06-2025-0414. Accessed 20 Nov. 2025.

Pickard, Nicole. “The Future of Design Is Here: How AI Is Revolutionizing Generative Design.” Transcend, 13 Jan. 2023, transcendinfra.com/generative-design-ai/. Accessed 11 Oct. 2025.

Rutgers University. “How Is AI Driving a Revolution in Engineering?” Rutgers, Rutgers University, 26 June 2025, engineeringmastersonline.rutgers.edu/articles/how-is-ai-driving-revolution-in-engineering/. Accessed 10 Oct. 2025.

Stanford University. Artificial Intelligence Index Report 2025. 2025, hai.stanford.edu/assets/files/hai_ai_index_report_2025.pdf. Accessed 22 Nov. 2025.

Strubell, Emma, et al. “Energy and Policy Considerations for Deep Learning in NLP.” Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics, 2019, pp. 3645–50, aclanthology.org/P19-1355/. Accessed 23 Nov. 2025.

Yetistiren, Burak, et al. “Assessing the Quality of GitHub Copilot’s Code Generation.” Proceedings of the 18th International Conference on Predictive Models and Data Analytics in Software Engineering, Nov. 2022, https://doi.org/10.1145/3558489.3559072. Accessed 2 Nov. 2025.

Zeff, Maxwell. “GitHub Copilot Crosses 20M All-Time Users | TechCrunch.” TechCrunch, 31 July 2025, techcrunch.com/2025/07/30/github-copilot-crosses-20-million-all-time-users/. Accessed 15 Nov. 2025.

Can an AI-Guided Assistant Accurately Summarize Chronic Pain Severity and Impact Using Responses from Validated Questionnaires? By Arav Parikh and Jesús Valdiviezo

Abstract

This study aimed to determine whether an interactive, AI-guided methodology, utilizing patient-reported data, could facilitate an enhanced evaluation of chronic pain in conjunction with standard clinical procedures. The system uses a questionnaire focused on pain intensity & characteristics, functional impact, and pain modifiers & treatment effectiveness to generate a comprehensive pain score and a clinician-ready SOAP summary Data collected revealed significant discrepancies in communication between doctors and patients about the importance of specific pain assessment questions, highlighting a gap that AI tools can help bridge. While limitations include small sample size and lack of clinical validation, this study demonstrates that an AI-guided, biopsychosocial approach can provide a more holistic and patient-centered understanding of chronic pain.

Keywords

Artificial Intelligence, Chronic Pain, Pain Assessment, Biopsychosocial Model, Multimodal Treatment, Machine Learning, Sentiment Analysis, Clinical Decision Support, Patient-Centered Care, Functional Impact

Summary

Variability in the way patients perceive and express chronic pain makes its assessment a challenging problem. The purpose of this study was to determine whether an interactive, AI-guided methodology, utilizing patient-reported data, can facilitate an enhanced evaluation of chronic pain in conjunction with standard clinical procedures. The system utilizes a questionnaire that focuses on three key areas: pain intensity & characteristics, functional impact, and pain modifiers & treatment effectiveness. It computes a comprehensive pain score, allowing for the evaluation of the severity of each of the four areas. It then generates a medical SOAP (Subjective, Objective, Assessment, Plan) summary for clinician review. The questionnaires used by this model received feedback from data collected via Google Forms. The information from the data revealed a significant discrepancy in communication between doctors and patients regarding the importance of specific questions in pain assessment. It highlights a real-world issue that can be bridged with AI tools. Limitations of the model include the lack of patient feedback and the need for real-world validation in clinical practice. To address privacy concerns, the AI model itself does not collect or store health information, and it is made publicly accessible through a Gradio interface. By engineering a questionnaire that bridges the gap between doctor and patient perspectives and integrating it into an AI tool, the system facilitates a thorough pain assessment and a multimodal approach to chronic pain management, enabling personalized treatment options. The URL to the GitHub repository used for this study can be found in the Appendix.

Introduction

Chronic pain assessment is difficult due to pain's highly subjective nature. In contrast to other medical conditions that can be measured through laboratory tests or medical imaging, chronic pain assessment currently relies primarily on an individual's pain perception, communication skills, psychological state, or even cultural background [1-3]. Tools have been established to create a standardized pain assessment, such as numeric rating scales, which attempt to quantify pain intensity, but they cannot fully capture its complexity, as they disregard emotional and daily impact [1-2]. These challenges are expanded upon by time constraints in clinical settings that limit patient and doctor interaction, and the variety of pain evaluation methods.

Several studies have attempted to deal with the problem of pain assessment, complementary to options for traditional pain assessment methods. One study developed pain assessment tools to assess pain through facial expressions using Machine Learning Analysis tools with AI to improve pain detection in populations with difficulty communicating. The results of this study showed that this tool can detect and evaluate pain through facial expressions much more effectively than Doctors. [4] Another study reviewed 50 chronic musculoskeletal pain clinical trials and highlighted the various interpretations of pain: 28 different pain scales were used, and in 34% of studies, a single-item measure was used, thus emphasizing the lack of standardization and comparability across research. [1] Researchers have also attempted the use biological markers, such as stress hormones and inflammation indicators, to provide data on the severity of pain. Yet, these methods remain experimental and difficult to adopt in clinical practice. [1-2] To address these challenges, artificial intelligence (AI) tools are integrating multidimensional data and offering more individualized pain assessment options. [5-6]

There are some lingering gaps in healthcare in the pain management sector. Doctors focus solely on pain prevalence and intensity, and often ignore the multimodal treatment aspect for chronic pain and biopsychosocial aspects, which are needed to understand all aspects of patients' pain. There is evidence proving that new assessment tools are statistically effective in clinical settings; however, widespread adoption is limited due to a higher cost compared to standard procedures. The need for an objective tool that can adequately capture pain is still missing in the field of pain, and this remains a barrier to offering efficacious pain management options. [1-6]

AI tools, such as large language models, have the potential to fill these gaps [7], and a standardized method to evaluate pain could be created through a medical questionnaire. A combination of these unique approaches could yield results that are more effective than standard procedures. This study attempts to demonstrate how an AI system using biopsychosocial data may potentially overcome the limitations of current methods used to diagnose and treat chronic pain. It aims to integrate an approach that addresses both patient and doctor perspectives. We hypothesize that such a system will give a more fine-grained and holistic understanding of the patient's pain, leading to better diagnosis and care. Our research has established that differences are present in how the patient and the doctor perceive pain, demonstrating the need for digital tools like AI that can be helpful for pain management.

Results

The workflow presented in Figure 1 outlines the model's step-by-step process: it begins by introducing the model's purpose, then conducts a baseline assessment of the patient's pain. Next, it identifies or records the user's diagnoses, evaluates how pain impacts daily life, and explores potential triggers and sources of relief. Finally, the model generates a summary of the findings and prompts the user to review it for completeness. The model utilizes this workflow when interacting with the patient shown in Figure 1.

The results of Figure 2 indicate that doctors who treat chronic pain and people suffering from chronic pain have different viewpoints regarding pain. It was observed that on average, 20% of doctors perceived Functional Impact questions to be essential, while 74% of patients perceived questions as essential. This statistical data illustrates that patients value functional impact questions over the questions regarding Pain Intensity and Characteristics. They believe that Functional Impact questions are more effective in helping with their treatment. In contrast, on average, 66.67% of doctors perceived General Pain Intensity questions to be essential, while 33.33% of patients perceived these questions as essential. Doctors place a higher importance on questions that capture Pain Intensity and Characteristics of Pain to be more valuable for treatment. This suggests a gap between patients' and doctors' understanding of pain management options, which needs to be bridged for impactful medical treatment (Figure 2A & 2B*)*. For more information about functional impact questions, view the accompanying tables (Table 1A & Table 1B) located in the appendix.

A user interface was developed to allow easy access for medical professionals and patients. The user interface utilizes Gradio and is hosted on Hugging Face Spaces. This allows for interactive conversation between the patient and the AI agent. The AI agent is engineered with prompts to follow up on the patient responses (Table 1). Once the patient has answered all questions posed by the agent, a medical SOAP summary is generated, with a scored assessment of their pain and treatment effectiveness. (Figure 3).

The AI system outputs quantitative scores for each of the three pain domains: General Pain Intensity and Characteristics, Functional Impact, and the effectiveness of the treatment, and the final overall score by analyzing patient responses for a set of pre-coded keywords determined in advance. The patient determines the endpoint of the conversation, and then a scoring calculation is performed to generate the summary. The model will go through all the conversations with the patient and look for specific words (Example: Unbearable Pain) from a pre-coded set of keywords. Words from this list may have a positive or negative value; this value is added or subtracted from the baseline score (30 for Functional Impact, 40 for Pain Intensity, and 50 for Treatment Effectiveness), and the scores range from 0 to 100. The overall score formula calculates a score by combining weighted values of the three categories of pain assessment. The model then rounds the result down to the nearest whole number, with extra emphasis given to whichever score is higher (functional impact or pain intensity). Sentiment analysis was performed using the TextBlob library, which has two functions to calculate the polarity of the users' responses and the subjectivity. The polarity calculates patients' sentiment

(positivity/negativity) and scores them on a scale from -1 to 1, where -1 indicates very unoptimistic and 1 indicates optimistic. The subjectivity calculates patients' opinion-based responses or fact-based responses and scores them on a scale from 0 to 1, where 0 highlights that the conversation was solely factual and 1 represents that the conversation was completely opinion-based. The model's scoring system allows patients to express their concerns about pain and provides the doctors with a quantitative representation to improve treatment outcomes.

Discussions

This study investigated whether an AI-guided, biopsychosocial approach could provide a more comprehensive and clinically useful assessment of chronic pain compared to standard procedures. The AI system uses patient-reported data from structured questionnaires to generate quantitative scores across all four pain domains and produce clinical summaries for provider review.

The results of the surveys revealed a notable gap in communication between patients and doctors in the areas of functional impact and domains of pain, general pain intensity, and characteristics. Patients believed functional impact questions were essential for treatment, while doctors primarily believed they were somewhat important. While doctors recognize the importance of functional impact, they only consider it to be "somewhat important" because it is often seen as secondary to establishing a clear diagnosis and initiating evidence-based interventions.[10-11] For patients, the greater importance given to these questions may arise due to patients living with chronic pain experiencing the pervasive issues daily, impacting their ability to work, care for themselves, engage in social activities, and maintain a clear mental state. For patients, the questions of functionality serve as a method to communicate these issues, as well as a way to guide more effective treatment leading to improved quality of life [8-9]. Another gap was illustrated in the domain of Pain Intensity and Characteristics. Clinicians prioritize information that directly informs diagnosis and treatment—such as pain intensity, duration, and specific characteristics.

Only three patients and six doctors were interviewed. Although additional interviews with patients and doctors may influence the trends, our current sample indicates that the opinions of both groups have contrasting viewpoints. As a result, a significant gap between the two parties' understanding needs to be addressed. The AI tool successfully captured these differences by incorporating custom instructions in the model prompt, and the questionnaire accounted for them.

Table 2: Scoring System Interpretation Sheet

Functional Impact Score	Pain Intensity Score	Treatment Effectiveness Score	Overall Score
1-33 Mild	1-33 Mild	1-33 Ineffective	1-33 Mild
34-66 Moderate	34-66 Moderate	34-66 Moderately Effective	34-66 Moderate
67-100 Severe	67-100 Severe	67-100 Effective	67-100 Severe

These findings support the hypothesis that AI can help bridge communication and understanding gaps in pain management. By prioritizing the patient's perspective and enabling patient comfort while reporting pain experiences, the system may allow for more individualized and effective care. The use of sentiment analysis tools like TextBlob allows medical providers to understand patients' outlook on their pain. Enabling the provision of treatments that are emotionally tailored to patients. These findings complement recent research indicating the need for multidimensional and patient-centered pain assessment tools for effective treatment options. [12-13]

Although this is one of the few tools prioritizing the combined usage of AI with a biopsychosocial treatment, allowing for multimodal treatment, several limitations must be acknowledged. The model has not yet been validated in clinical settings. The sample size for data collected via Google Forms was small, and all data was self-reported by both doctor and patient, which may introduce recall bias, affecting the accuracy of the results. This bias could arise from misremembering or exaggerating traumatic events that led to patients' pain; on the other hand, doctors may fail to recall ineffective or successful treatments. Privacy considerations limited the collection of health information from users of this tool, which restricts real-world validation.

Nevertheless, the results underscore differences between doctor and patient perspectives in pain diagnosis and allow a visualization of the potential for AI tools to address these gaps. Future studies should be done to validate the AI system with a patient population in real clinical settings. Incorporating additional objective measures, such as biological markers or digital monitoring, could further boost the reliability of pain assessment. Integrating a multi-agent AI approach for each pain subcategory may allow for improved decision-making and personalization. Studies done comparing the model with standard pain assessment tools would help determine the efficiency of the assessment compared to standardized procedures and allow for a clear visualization of whether the gaps the model intends to tackle were addressed correctly.

In conclusion, this research demonstrates the potential of an AI-assisted, biopsychosocial approach to improve chronic pain assessment by bridging communication gaps between patients and clinicians. Ultimately, this has the potential to allow for more holistic, patient-centered pain management and better health outcomes.

Methods and Materials

An AI algorithm was developed using a biopsychosocial and multimodal approach. The biopsychosocial approach combines a person's biological factors, like health, with psychological traits like behavior. [13] A multimodal approach utilizes multiple treatment interventions from each domain for more effective, holistic care. [14]

The biopsychosocial approach was incorporated into the model's custom prompt instructions to ensure biopsychosocial validation and collaborative goal setting. The algorithm utilized a pain questionnaire that focuses on four key categories: pain intensity & characteristics, functional impact, pain modifiers & relief, and additional questions. The questions were drawn

from 35 Medical Questionnaires, including (McGill, NPRS, ODI, FIQ), to generate a list of 500 questions. See Appendix Table 3 for examples of the subcategories.

This list of 500 questions was transformed into sentence embeddings using the Spacy tool. Then, PCA (retained questions with items loading ≥ 0.40) was performed on the embeddings to find the most effective questions to allow for a short yet effective questionnaire. Patients and doctors were sent a Google Form via email, where all data was kept anonymous. The feedback consisted of how clear the question was (on a Likert scale of four, Not-Important -> Essential) and the effectiveness of each question (on a Likert scale of three, Unclear -> Clear). The feedback was used to improve the questions, with the goal of better communication between patient and doctor. Three patients and six doctors filled out this form.

The AI algorithm was developed using this refined questionnaire set, with a prompt that has clear instructions that support a multimodal approach that fosters trust with vulnerable patients and encourages empathetic, patient-centered interactions. The AI provides treatment recommendations to help patients learn about various treatment options if asked for, or is generated in the summary. Prompt engineering was used to instruct the AI not to pressure patients, to validate their responses, and to reframe negative patient language. To maintain the privacy of the patient, the algorithm sends a notification saying that it can delete a message at any time if the patient feels unsafe.

Two models were tested: GPT-4o mini(Version 2024-07-18) and llama 3-scout. The model had a custom prompt to provide clear instructions on what was necessary. The prompt can be found on the GitHub page in the Appendix. Based upon experimentation, the results suggested that the GPT 4o-mini model performed much better than the llama-3 scout, since the llama-3 model wouldn't follow the prompt instructions clearly, while the GPT 4o-mini model was able to follow the prompt instructions. The parameters for the model were a temperature of 0.7 and 300 maximum tokens. The model testing was done on Google Colab.

Two models were used in the AI system. The primary model, based on the GPT-4o-mini architecture, was responsible for generating clinical summaries and treatment recommendations. A secondary, GPT-4o mini model was used to ask questions from the questionnaire engineered for the patient and store responses. The algorithm also performed sentiment analysis on patient responses using the TextBlob(0.19.0) library. Sentiment analysis calculated polarity and subjectivity scores, and flagged responses that indicated a need for empathy or clarification.

A keyword-based scoring algorithm was implemented to quantify patient-reported outcomes. These keywords were coded in advance, and the presence of particular keywords in a conversation contributed to scores across three domains: functional impact, pain intensity & characteristics, and treatment effectiveness. Scores were normalized according to a 1-100 scale, with 100 being the maximum. An overall condition severity score was computed as a weighted composite of these domains.

The AI generates clinical summaries using the SOAP note format. The summary incorporated both the conversation transcript and the calculated scores, ensuring that the Assessment and Plan sections were clearly labeled and valuable to clinicians.

To maintain the privacy of the patient, the algorithm sends a notification saying that it can delete a message at any time if the patient feels unsafe. The Gradio interface itself does not collect or store health information.

Study window

The online questionnaire was open for six weeks, from 1 April 2025 through 15 May 2025, and all responses were used for analysis on May 31, 2025.

Recruitment and setting

Participants were recruited by a licensed physical therapist (the researcher's parent) during routine clinical interactions. During regular physical therapy sessions, the clinician verbally informed adult patients with chronic musculoskeletal pain that a voluntary anonymous online survey about pain assessment was available.

The clinician did not disclose any protected health information (PHI) or identifiable clinical data to the researcher. Patients who wished to participate independently accessed the survey through an open online link and completed it anonymously on their own devices. Participation was voluntary and uncompensated.

Sample composition

Patients:

– Age range: 40–80 years
– Chronic-pain duration: 5–15 years
– Residency: 100 % California

Physicians:

– Specialties: 70 % Physical Medicine & Rehabilitation (PM&R); 30 % Neurology
– Years in practice: 5–20 years
– Practice location: 100 % California

Ethics and privacy

Identifiers weren't included in the form, and data were reported and recorded without any personal information to preserve confidentiality.

The model utilizes a Gradio (5.33.0) interface and is hosted on Hugging Face Spaces. 2 vCPUs are used to run the model on Hugging Face Spaces.

Acknowledgements

The author would like to thank Avani Parikh for their support in collecting relevant surveys and feedback on the methodology.

Works Cited

1.Gatchel, Robert J., et al. “The Biopsychosocial Approach to Chronic Pain: Scientific Advances and Future Directions.” Psychological Bulletin, vol. 133, no. 4, 2016, pp. 581–624.

2.“Pain Assessment Primer.” MedCentral Health System, 2024.

3.“Advances and Challenges in Pain Measurement.” Frontiers in Pain Research, 2023.

4.De Sario, G. D., et al. “Using AI to Detect Pain through Facial Expressions: A Review.” Bioengineering, vol. 10, no. 5, 2023, article 548, doi:10.3390/bioengineering10050548.

5.“New Assessment Tool for Chronic Pain.” MedCentral Health System, 2024.

6.Turk, Dennis C., and Beverly E. Thorn. “Moving Forward: A Multimodal Approach to Chronic Pain Management.” Journal of Pain, vol. 17, no. 10, 2016, pp. 1068–1075.

7.Sharma, Rohan, and Priya Desai. “Revolutionizing Patient Care: The Role of AI-Powered Chatbots in Telemedicine and Healthcare Support.” Health Informatics Review, 2024.

8.Gatchel, Robert J., and Jennifer A. Howard. “Evolution of the Biopsychosocial Model in Pain Management.” Pain Research and Treatment, 2013, article 789045.

9.Osborne, Tricia L., et al. “Individualized, Multimodal Pain Therapy: A Pragmatic Framework.” Pain Medicine, vol. 22, no. 6, 2021, pp. 1281–1290.

10.Eccleston, Christopher, et al. “Multimodal Approaches to Pain Relief: Evidence and Future Directions.” Therapeutic Advances in Chronic Disease, vol. 13, 2022, article 20406223221127871.

11.Bawa, Jaspal S., and Jane L. Fitzpatrick. "Comprehensive Multimodal Pain Management: An Interdisciplinary Review.” Frontiers in Pain Research, vol. 2, 2021, article 741123.

12.Edgman-Levitan, Susan, and Stephen C. Schoenbaum. “Patient-Centered Care: Achieving Higher Quality by Designing Care Through the Patient’s Eyes.” Israel Journal of Health Policy Research, vol. 10, no. 1, 2021, article 21.

13.“The Biopsychosocial Model: An Introductory Approach.” University of Rochester School of Medicine and Dentistry, 2023.

14.“Multimodal Approach.” ScienceDirect Topics, 2024.

Figures

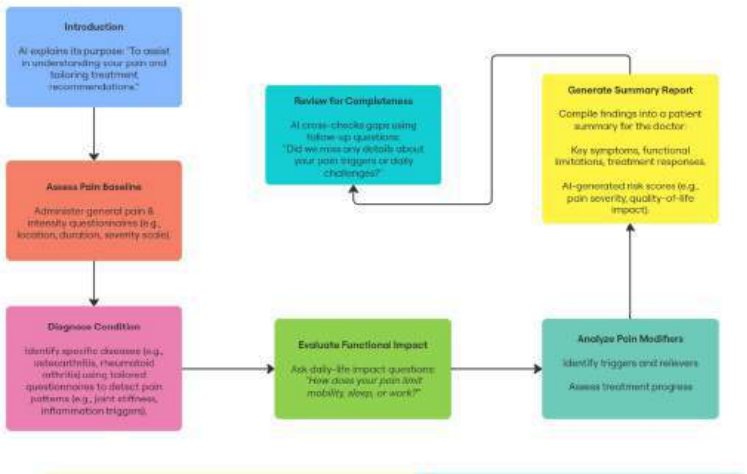
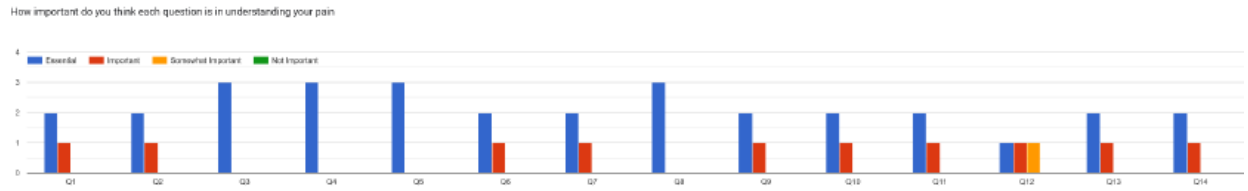


Figure 1: The model workflow is referenced above. This flowchart demonstrates how the model asks the questions and how information about the patient is used to generate results. A flow chart was implemented by using a custom prompt and summarizing this flow chart into instructions that a pretrained model can understand.

(a)



(b)

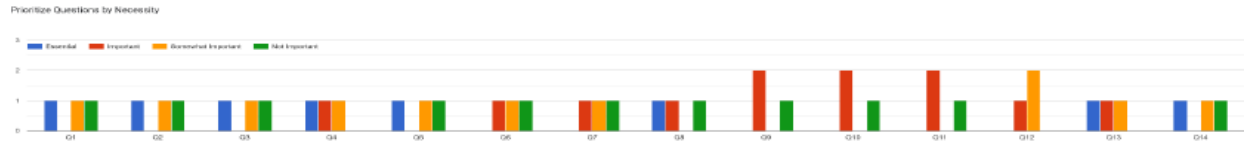


Figure 2: Functional impact questionnaire for (a) patients and (b) doctors. The Google Forms collected data on (a) three patients experiencing chronic pain and (b) five doctors who specialize in treating chronic pain. This graph was obtained by emailing patients (a) with chronic pain disorders, and asking them to fill out the Google Form and provide feedback voluntarily. A similar format was used, (b) doctors who specialize in treating chronic pain disorders were emailed, and asked to voluntarily fill out the Form, and provide feedback. All data was kept anonymized, secured, and is only available for research purposes.

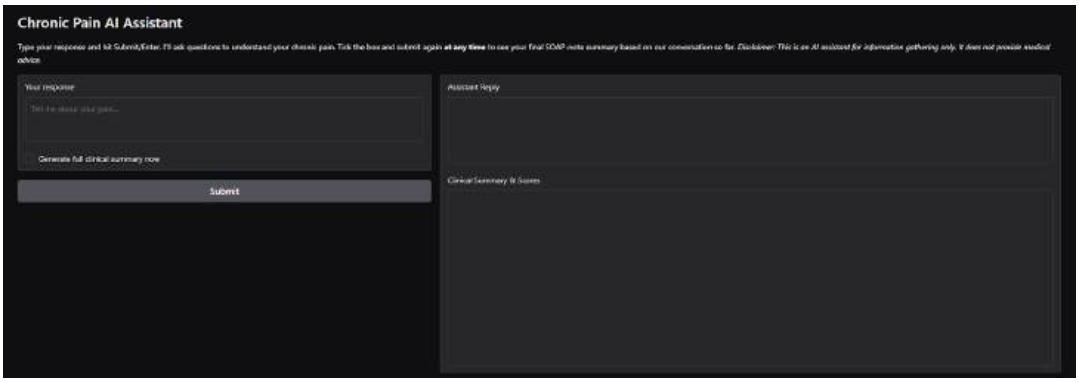


Figure 3: User interface for chronic pain AI assistant. The user interface that patients use when chatting with an AI assistant is shown above. The app was made on Gradio and is hosted on Hugging Face Spaces.

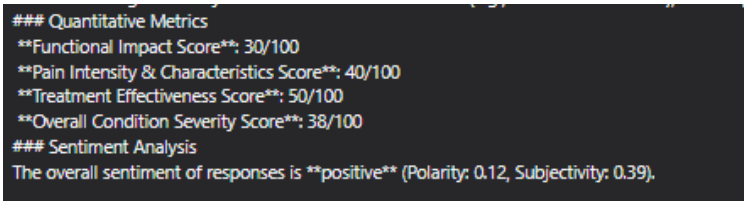


Figure 4: Generated Summary: An example of the final generated scoring is shown above. Scoring was done by keyword analysis throughout the whole patient conversation, and sentiment analysis was performed using the TextBlob library.

Appendix

1(A) Question Table for Functional Impact on Patients and Doctors

Q1: How does pain affect your ability to take care of yourself (dressing, washing, bathing, grooming, toileting)? Describe any difficulties you experience.
Q2: How does pain affect your ability to perform your job or housework? Describe any specific tasks that are difficult or impossible. If you are unable to work due to pain, please explain the impact on your life.
Q3: How does pain affect your ability to travel (car rides, flights, public transportation)? Describe any limitations or discomfort you experience.
Q4: How does pain affect your sleep? Describe any sleep disturbances you experience (e.g., difficulty falling asleep, frequent awakenings, early morning waking, restless legs).
Q5: How does pain affect your ability to concentrate?
Q6: How does your pain impact your ability to handle stressful situations?
Q7: How has your pain interfered with social activities? Do you feel less capable because of this problem? Explain how the pain affects your sense of self.
Q8: How does physical activity affect your pain?
Q9: How far can you walk before pain becomes too much? Describe how the pain affects your ability to walk (e.g., speed, gait, need for rest stops, limping).
Q10: How long can you stand before the pain becomes bothersome? Describe how the pain affects your ability to stand (e.g., stiffness, burning, throbbing).
Q11: How long can you sit comfortably? Describe how pain affects your ability to sit (e.g., posture, need to change positions, restlessness, stiffness). Are there certain types of chairs that are more or less comfortable?
Q12: Describe how different types of clothing or footwear affect your pain.
Q13: Are there any specific postures or positions that exacerbate your pain?
Q14: How does your environment (home, work, social settings) affect your pain?

1(B)Question Table for General Pain Intensity and Characteristics of Patients and Doctors

Q1: Describe the pattern of your pain. Is it constant, intermittent, or does it come and go in waves? How frequently do you experience it? Are there specific times of day when it's better or worse?
Q2: In your own words, how would you describe your pain? Be as detailed as possible, including location, sensation, and any other relevant information
Q3: Does your pain move around? If so, please describe how and where it moves. Does it spread, radiate, or feel like it is going through your body? Explain the pattern of movement.
Q4: How intense is the pain? Instead of a number, tell me how it affects you. For example, how does it limit your activities, affect your mood, or impact your ability to concentrate?
Q5: Describe your worst past pain experiences (toothaches, headaches, stomachaches, injuries, etc.). How did these compare to your current pain? Were they similar or different in quality, intensity, or duration?
Q6: How many days in the last week have you had any pain?
Q7: Are there any other general pain questions you think should be included?

Table 1: The tables above are a description of the questions that were asked to both people suffering from chronic pain and doctors regarding the functional impact aspect of chronic pain (A) and general pain intensity and characteristics (B)

Table 3: Categories and Subcategories for General Pain Intensity and Characteristics, and Functional Impact

General Pain Intensity and Characteristics	Example	Functional Impact	Example
Osteoarthritis	Do you notice any unusual sensations in your joints, such as grinding, clicking, or popping (crepitus)? If yes, which joints are affected?	Osteoarthritis	How difficult is it to walk on uneven surfaces because of your joint pain? (Scale 1-10, 1 being no difficulty, 10 being extremely difficult) Note Model identifies which joint is affected
Fibromyalgia	Do you have morning stiffness that lasts longer than 30 minutes	Fibromyalgia	Does fear of future pain or symptom flare-ups cause you to avoid certain activities or change your plans? Please give examples if possible.
Migraine / Headache	On average, how many days per week do you have headaches?	Migraine / Headache	Have you missed important events or opportunities because of headaches?
Neuropathic Pain	Do you also have numbness, weakness, or unusual sensations in the painful area?	Neuropathic Pain	How does your pain, including unusual sensations, affect your ability to concentrate or stay focused on tasks?
Rheumatoid Arthritis	Which joints are painful or stiff? Please list all affected joints.	Rheumatoid Arthritis	How do flare-ups of joint pain interfere with your work or social life?
Back Pain	Is your back pain made worse by sitting, standing, bending, lifting, twisting, or coughing/sneezing?	Back Pain	How does back pain affect your ability to sleep comfortably? Are there especially difficult positions?
Pelvic Pain	Have you experienced any physical, emotional, or psychological trauma that might be affecting your current health?	Pelvic Pain	How much does pelvic pain affect your ability to sit comfortably? Are certain chairs or cushions more helpful?
Shoulder Pain	Have you noticed any clicking, popping, or catching in your shoulder joint?	Shoulder Pain	How does shoulder pain affect your ability to carry bags or groceries?
Neck Pain	Do you ever feel weakness or heaviness in your arms or hands because of your neck pain?	Neck Pain	Has neck pain affected your ability to participate in social activities or gatherings?

https://github.com/aravparikh/Research_Paper

From Ancient Logic to Artificial Intelligence:
Evolution of Mathematical Thinking and Its Role in Modern Technology By Diyar Saken

Abstract

Mathematics has guided human reasoning for thousands of years, shaping how civilizations interpret and interact with the world. This paper explores the evolution of mathematical thought from its ancient foundations to its present-day role in artificial intelligence. By tracing the development of logic, geometry, algebra, and computation, it highlights how fundamental mathematical ideas have transformed from philosophical inquiry into technological innovation. The study reviews contributions from multiple regions, including Central Asia, Europe, and the United States, and examines how Kazakhstan is integrating mathematical education and AI research into its national development strategy. The paper concludes that the continuity of mathematical reasoning across history demonstrates its enduring role as the foundation of intelligent systems, both human and artificial.

1. Introduction

Mathematics is often described as the language of the universe, but it is also the foundation of human reasoning and modern technology. Its development reflects humanity's quest to understand patterns, relationships, and abstract structures. From the earliest counting systems to advanced computational algorithms, mathematics has continuously evolved in parallel with civilization. Today, mathematical reasoning shapes not only science and engineering but also the emerging field of artificial intelligence, where machines emulate human cognition through mathematical logic and data models.

Throughout history, mathematical thought has served as a bridge between abstract theory and real-world problem-solving. Early mathematicians created systems to measure land, trade goods, and celestial movements, laying the groundwork for centuries of intellectual progress. The philosophical roots of mathematics, developed in ancient Greece, India, and the Islamic world, emphasized logical deduction, symmetry, and the pursuit of universal truths. These early forms of reasoning still underpin the mathematical structures used in modern AI systems.
In the twenty-first century, the integration of mathematics and artificial intelligence has become one of the defining features of global technological development. Mathematical thinking now powers computer vision, natural language processing, and predictive algorithms. As countries like Kazakhstan seek to strengthen their education and innovation ecosystems, understanding the evolution of mathematical thought is vital for preparing future generations to contribute to scientific and technological progress.

2. Historical Foundations of Mathematical Thought

The history of mathematics begins with practical necessity. Early societies in Mesopotamia, Egypt, and China developed systems of counting, measurement, and geometry to manage agriculture, construction, and commerce. Clay tablets from Mesopotamia contain some

of the earliest examples of arithmetic and algebraic reasoning, demonstrating an early form of abstraction. In ancient Egypt, geometry was used to measure land after flooding, and these early practices became the precursors of formal mathematical disciplines.

Ancient Greece brought mathematics into the realm of philosophy. Thinkers such as Pythagoras, Euclid, and Archimedes emphasized logic and deductive reasoning, setting a standard for mathematical proof. Euclid's Elements introduced a structured approach to geometry that remained central to education for more than two thousand years. The Greek emphasis on abstract reasoning established mathematics as a universal language that could describe natural and conceptual phenomena alike.

Central Asia played a crucial role in preserving and expanding mathematical knowledge during the medieval period. Scholars such as Al-Khwarizmi, who lived in present-day Uzbekistan, developed the foundations of algebra and algorithms. His works were later translated into Latin, influencing the development of mathematics in Europe. The spread of knowledge through the Silk Road ensured that mathematical ideas were not isolated but global in nature. This historical continuity between East and West laid the groundwork for the mathematical principles that underpin today's technological systems.

3. The Rise of Mathematical Logic and Computation

The nineteenth and early twentieth centuries marked a turning point in mathematical history, as logic and formal systems became central to the discipline. Mathematicians such as George Boole, Gottlob Frege, and Bertrand Russell redefined reasoning by expressing logic in symbolic form. Boolean algebra, developed by Boole, created a bridge between philosophy and computation by allowing true and false statements to be represented mathematically. This development was crucial for the later invention of digital computers.

At the same time, the pursuit of mathematical completeness and consistency led to deep philosophical debates. David Hilbert sought to formalize all mathematics through axiomatic systems, while Kurt Gödel's incompleteness theorems demonstrated that no mathematical system could be both complete and consistent. These discoveries profoundly influenced how mathematicians and philosophers viewed the nature of knowledge, uncertainty, and computation. Alan Turing's work in the mid-twentieth century connected these abstract ideas to practical computation. Turing's concept of a universal machine established the theoretical foundation for modern computing, which in turn made artificial intelligence possible. What began as logical speculation about the limits of mathematics evolved into the technological infrastructure that now supports intelligent machines. The rise of computation represents the transformation of mathematical logic into a creative tool for building artificial reasoning systems.

4. Mathematics in Modern Artificial Intelligence

Artificial intelligence relies on mathematical reasoning at its core. Every AI system, whether it recognizes images, translates languages, or recommends products, operates through mathematical models. Linear algebra provides the structure for representing data, while calculus

supports optimization processes that allow algorithms to learn from experience. Probability theory enables AI to handle uncertainty, and discrete mathematics supports data organization and computational efficiency.

The global expansion of AI has brought renewed attention to the importance of mathematics education. In the United States, universities emphasize data science and mathematical modeling as essential skills for the AI workforce. European nations integrate mathematics and computer science in their early education systems to prepare students for future technological challenges. Similarly, Kazakhstan has recognized the importance of developing mathematical literacy as part of its national digitalization strategy, aiming to build a generation capable of contributing to the global AI economy.

While AI technologies appear complex, they are essentially the modern expression of centuries-old mathematical thinking. The transition from solving equations by hand to training algorithms on massive datasets demonstrates how mathematics continues to evolve with human creativity. The current challenge lies not only in developing more powerful algorithms but also in ensuring that mathematical reasoning remains aligned with ethical and social considerations.

5. Global Perspectives on Mathematics and AI

Around the world, the connection between mathematics and artificial intelligence is shaping education, industry, and policy. In the United States, public and private investment in AI research has accelerated innovation in fields ranging from medicine to climate modeling. Mathematical foundations are central to this progress, particularly in developing explainable AI that can be trusted in critical decision-making. Major universities now promote interdisciplinary research combining mathematics, statistics, and ethics.

In Europe, nations such as Germany, France, and Finland have made significant efforts to strengthen mathematical education as part of broader digital transformation policies. Finland's education model, for instance, emphasizes problem-solving and creativity over rote calculation, helping students apply mathematical thinking in diverse contexts. European research institutions are also leading initiatives in mathematical modeling for sustainable development and smart infrastructure, demonstrating the societal reach of mathematics beyond computation.

Kazakhstan is positioning itself within this global trend. Government programs promoting STEM education and AI literacy are being implemented across universities and specialized schools. Collaborations with international research institutions have begun to introduce advanced mathematical topics into high school curricula, preparing students to participate in a data-driven world. Although challenges remain, such as resource availability and teacher training, the growing emphasis on mathematics and AI education suggests a strong foundation for future technological progress.

6. Discussion

The evolution of mathematical thinking demonstrates an unbroken chain between ancient reasoning and modern artificial intelligence. The logic that once guided philosophers and

astronomers now drives the algorithms behind search engines, medical diagnostics, and autonomous systems. This continuity reveals that mathematics is not only a tool for calculation but also a framework for understanding intelligence itself. The same abstract reasoning that enabled the creation of geometry and algebra now enables machines to process language, recognize patterns, and learn from data.

A major theme emerging from this review is the universality of mathematical reasoning. While AI development may be concentrated in technologically advanced countries, the underlying mathematics belongs to no single culture or nation. Historical evidence shows that mathematical knowledge has always been global, transmitted through translation, trade, and education. The challenge today is ensuring that the benefits of AI, built on these shared foundations, are distributed equitably across societies.

Another important issue is the philosophical question of whether artificial intelligence truly reflects human reasoning or merely imitates it. Mathematics offers insight into this debate. The logical consistency of mathematical systems can simulate thought processes, but creativity, intuition, and ethical judgment remain uniquely human. Therefore, as societies like Kazakhstan invest in mathematical and AI education, they must also cultivate philosophical and ethical understanding to guide the responsible use of these technologies.

Finally, the integration of mathematics into AI highlights the importance of interdisciplinary learning. Mathematicians, computer scientists, and ethicists must collaborate to ensure that technological progress aligns with human values. This collaboration mirrors the historical dialogue between philosophers and mathematicians that shaped early scientific thought. In this sense, the story of mathematics and AI is not simply one of machines becoming intelligent, but of humanity extending its own capacity to reason and create through new tools.

7. Conclusion

Mathematics has always been more than a collection of symbols and formulas; it is a system of reasoning that connects ideas across cultures and centuries. From the logical insights of ancient scholars to the data-driven intelligence of modern computers, mathematical thought continues to shape how humanity understands and transforms the world. The relationship between mathematics and artificial intelligence represents the latest chapter in this long intellectual journey. By studying both the history and the modern applications of mathematics, societies such as Kazakhstan and others around the world can better prepare for a future where reasoning and technology are inseparable.

Works Cited

1.Al-Khalili, J. (2011). The House of Wisdom: How Arabic Science Saved Ancient Knowledge and Gave Us the Renaissance. Penguin Books.

2.Boole, G. (1854). An Investigation of the Laws of Thought. London: Walton and Maberly.

3.Russell, B., & Whitehead, A. N. (1910). Principia Mathematica. Cambridge University Press.

4.Turing, A. M. (1950). Computing Machinery and Intelligence. Mind, 59(236), 433–460.

5.McCarthy, J. (2007). What is Artificial Intelligence? Stanford University AI Laboratory Report.

6.Hilbert, D. (1902). Mathematical Problems. Bulletin of the American Mathematical Society, 8(10), 437–479.

7.UNESCO. (2022). Artificial Intelligence and Education: Guidance for Policymakers.

8.OECD. (2021). Mathematics Education and AI Readiness: Global Report.

9.Ministry of Science and Higher Education of the Republic of Kazakhstan. (2023). National Program for Digital Transformation and AI Education.

10.Norvig, P., & Russell, S. (2020). Artificial Intelligence: A Modern Approach. Pearson.

The Integration of Artificial Intelligence and Robotics in Modern Engineering: Transforming Design, Manufacturing, and Maintenance By Amirali Aldabergenov

Abstract

Artificial intelligence and robotics are at the forefront of the fourth industrial revolution, redefining how engineers design, produce, and maintain complex systems. This paper reviews the evolution of robotics and artificial intelligence in modern engineering, focusing on their convergence in manufacturing, product design, and predictive maintenance. It explores global trends, educational implications, and the ethical challenges associated with automation. By examining developments in the United States, Europe, and emerging economies such as Kazakhstan, the paper highlights how the integration of intelligent robotics and machine learning is transforming industries and reshaping the engineering profession for the future.

1. Introduction

The twenty-first century marks a profound transformation in the way engineering systems are designed and operated. The rapid advancement of artificial intelligence and robotics has created new possibilities for automation, efficiency, and precision in nearly every field of engineering. What was once considered the domain of science fiction has now become an integral part of industrial reality. Factories, laboratories, and even infrastructure projects increasingly rely on intelligent machines that can analyze, adapt, and act independently based on data and environmental feedback.

Artificial intelligence and robotics are deeply connected. Artificial intelligence provides the logic and learning algorithms that allow machines to make decisions, while robotics applies these capabilities to physical tasks. Together, they form the foundation of modern automated engineering. From manufacturing plants using robotic arms that learn optimal assembly patterns to autonomous drones inspecting bridges and pipelines, these technologies are revolutionizing both the conceptual and practical sides of engineering.

The integration of AI and robotics has also redefined the skill sets required for future engineers. Mathematical reasoning, programming, and ethical understanding now complement traditional engineering knowledge. As nations such as Kazakhstan and the United States invest in digital transformation and industrial modernization, understanding the intersection of AI and robotics becomes essential for shaping sustainable and technologically advanced economies.

2. The Evolution of Robotics in Engineering

Robotics has its origins in mechanical engineering, with the earliest designs intended to replicate human motion for industrial purposes. The introduction of programmable robotic arms in the mid-twentieth century represented the first major shift toward automation. These machines were capable of performing repetitive tasks with precision, dramatically improving productivity in manufacturing sectors such as automotive and electronics. Over time, advances in sensors,

materials, and control systems allowed robots to become more adaptable and capable of performing complex tasks.

As technology evolved, robotics expanded beyond simple automation into fields such as construction, aerospace, and biomedical engineering. In modern factories, robots are used not only for assembly but also for quality control, packaging, and logistics. Collaborative robots, often called cobots, work alongside human engineers, assisting in tasks that require both precision and creativity. Their ability to sense and respond to human presence has improved workplace safety and efficiency, blurring the boundary between human and machine labor.
In recent years, the focus of robotics has shifted from mere automation to autonomy. Robots equipped with sensors, cameras, and machine learning algorithms can now make independent decisions based on real-time data. This transformation has opened new avenues in engineering design and maintenance, where machines can diagnose problems, plan repairs, and optimize performance without direct human intervention. Robotics, once purely mechanical, has evolved into an intelligent and interconnected system central to the future of engineering.

3. Artificial Intelligence in Engineering Design

Artificial intelligence plays a critical role in the conceptual phase of engineering. Traditional design processes rely on human experience and iterative modeling, but AI now allows engineers to explore vast design spaces rapidly. Through machine learning algorithms, AI can analyze thousands of potential design configurations, predict performance outcomes, and suggest optimized solutions. This process, known as generative design, has been adopted in industries such as aerospace and architecture to create lighter, stronger, and more efficient structures.

AI-driven design tools have also enhanced the accuracy and creativity of engineering projects. For example, in automotive engineering, AI systems simulate aerodynamics and structural integrity, enabling engineers to refine designs before building physical prototypes. In civil engineering, AI helps model stress and load distributions in bridges and buildings, reducing material waste while maintaining safety standards. These innovations save time, resources, and costs while pushing the boundaries of what is technically possible.

Educational institutions around the world are recognizing the importance of integrating AI-based design methods into engineering curricula. Universities in the United States and Europe are increasingly combining mechanical engineering with data analytics and computational modeling courses. Similarly, Kazakhstan’s technical universities are beginning to adopt AI-oriented design programs, aligning education with the demands of modern industry. The result is a new generation of engineers who are both creative and computationally literate.

4. Robotics and Automation in Manufacturing

Manufacturing has been one of the primary beneficiaries of robotics and artificial intelligence integration. The combination of precision robotics and data-driven intelligence has created factories that can adapt production lines in real time. Unlike traditional automation,

which operates based on fixed programming, intelligent manufacturing systems use AI to interpret sensor data, detect inefficiencies, and adjust workflows accordingly.

Global corporations such as Siemens, Tesla, and Toyota have implemented AI-powered robotics to enhance both productivity and quality control. Robots equipped with vision systems can detect micro-defects that humans might miss, ensuring product consistency. Predictive analytics allows machines to schedule their own maintenance, reducing downtime and extending operational life. These advancements have also improved sustainability by reducing material waste and energy consumption, key goals for modern manufacturing industries.

In developing economies, including Kazakhstan, automation is gaining attention as part of national industrial modernization efforts. Smart factories and digital manufacturing initiatives are being introduced to enhance competitiveness and reduce dependency on manual labor. As these technologies mature, they hold the potential to diversify Kazakhstan's economy by fostering advanced manufacturing capabilities aligned with global engineering trends.

5. Artificial Intelligence in Predictive Maintenance and Operations

Maintenance has traditionally been one of the most resource-intensive aspects of engineering operations. AI is transforming this process through predictive maintenance, a method that uses data analytics to forecast equipment failures before they occur. Machine learning algorithms analyze vibration patterns, temperature changes, and sensor readings to identify anomalies, enabling engineers to perform maintenance only when necessary. This approach reduces downtime, lowers costs, and enhances safety.

In the aerospace industry, predictive maintenance has become standard practice. Jet engines are equipped with thousands of sensors that transmit real-time data to AI systems, which detect deviations from normal operation and alert maintenance teams. Similar systems are used in energy plants and transportation infrastructure. The result is a shift from reactive to proactive engineering, where decisions are guided by continuous data feedback rather than periodic inspections.

AI-enabled predictive maintenance also contributes to environmental sustainability. By improving equipment efficiency and reducing material waste, these systems support greener engineering practices. Kazakhstan, for instance, can benefit from such technologies in its mining and energy sectors, where maintenance efficiency and resource optimization are crucial for sustainable development.

6. Global Perspectives on AI and Robotics in Engineering

Around the world, the integration of artificial intelligence and robotics has become a defining feature of industrial policy. The United States leads innovation through a combination of private sector research and public investment. Companies like Boston Dynamics and NVIDIA are developing advanced robotic systems that combine machine learning with mobility, making them capable of adapting to unpredictable environments. The U.S. government's support for AI

research has also strengthened collaboration between academia and industry, fostering rapid technological advancement.

European nations focus on the ethical and regulatory aspects of AI integration. The European Union promotes responsible automation through initiatives that ensure safety, transparency, and employment protection. Research institutions in Germany, France, and the Netherlands are advancing the field of collaborative robotics, emphasizing human-machine interaction and workplace inclusion. Europe's approach balances innovation with ethical oversight, creating sustainable frameworks for long-term technological adoption.

Kazakhstan's engagement with AI and robotics is growing steadily. The government's national digitalization strategy includes investments in AI-based automation for industry and infrastructure. Collaboration with international universities and technology companies aims to build local expertise and create new research centers. As the country expands its engineering education and technology industries, the integration of AI and robotics represents both an opportunity for growth and a challenge in ensuring equitable access to emerging technologies.

7. Discussion

The convergence of artificial intelligence and robotics marks a new era in engineering. These technologies are not replacing human intelligence but extending it, allowing engineers to focus on creativity, problem-solving, and innovation. The machines of today operate as collaborators rather than mere tools, learning from data and human input to make informed decisions. This partnership between humans and intelligent systems represents a major step in the evolution of engineering practice.

The transformation also raises important ethical and social questions. As automation expands, concerns about job displacement and data privacy must be addressed. Engineering organizations are increasingly discussing frameworks for responsible AI, ensuring that technology enhances human welfare rather than undermining it. Education will play a key role in preparing future engineers to navigate these challenges, emphasizing not only technical skills but also ethical reasoning and interdisciplinary collaboration.

Finally, the globalization of AI and robotics underscores the need for international cooperation. No single country can develop or regulate these technologies in isolation. By sharing research, setting international standards, and promoting knowledge exchange, nations can ensure that technological progress benefits humanity as a whole. The integration of artificial intelligence and robotics is not just an engineering revolution but a global movement toward intelligent, sustainable, and ethical progress.

8. Conclusion

Artificial intelligence and robotics are redefining the future of engineering. Their integration has created a new paradigm where machines learn, adapt, and collaborate with humans to design, manufacture, and maintain the infrastructure of modern life. From advanced factories to predictive maintenance systems, these technologies are enhancing efficiency, safety,

and sustainability across industries. As countries like the United States and Kazakhstan continue to invest in digital transformation, the fusion of AI and robotics will remain central to economic growth and innovation. The enduring challenge for the global engineering community is to harness these technologies responsibly, ensuring that intelligence, whether human or artificial, continues to serve the progress of society.

Works Cited

1.Russell, S., & Norvig, P. (2020). Artificial Intelligence: A Modern Approach. Pearson.
2.International Federation of Robotics. (2022). World Robotics Report.
3.European Commission. (2021). Ethics Guidelines for Trustworthy AI.
4.McKinsey & Company. (2020). The Future of Automation in Manufacturing.
5.World Economic Forum. (2023). AI and Robotics in the Fourth Industrial Revolution.
6.Ministry of Digital Development of the Republic of Kazakhstan. (2023). Digital Economy and Industrial Modernization Strategy.
7.Boston Dynamics. (2022). Human-Robot Collaboration in Industrial Environments.
8.Siemens. (2021). Smart Manufacturing and Predictive Maintenance Solutions.
9.Tzafestas, S. (2018). Introduction to Autonomous Robots. Springer.
10.United Nations Industrial Development Organization. (2022). AI and Robotics for Sustainable Industrial Development.

6G Communication Networks: Engineering Challenges and Future Directions - A Global Perspective Including the United States, the European Union, China, and Kazakhstan

By Arnur Maratov

Abstract

The emergence of sixth-generation (6G) communication networks represents the next transformative stage in global telecommunication engineering. Building upon the advances of 5G, 6G aims to achieve terabit-level data rates, sub-millisecond latency, enhanced reliability, and energy efficiency through intelligent, AI-driven infrastructures. This review explores the conceptual foundations, enabling technologies, and engineering challenges associated with 6G development. It analyzes the global research landscape, focusing on leading initiatives in the United States, the European Union, and China, while examining Kazakhstan's evolving participation in advanced wireless innovation. The paper also identifies key research frontiers in terahertz communication, edge intelligence, holographic and semantic transmission, and quantum-safe security. Despite major progress, issues such as spectrum scarcity, power consumption, and standardization remain critical. This review concludes that interdisciplinary collaboration, ethical governance, and equitable access to 6G technologies will be essential for achieving truly global connectivity and sustainable technological progress.

Keywords: 6G communication networks, terahertz communication, artificial intelligence, edge computing, quantum-safe security, global telecommunications, Kazakhstan, United States, European Union, China, sustainability, spectrum management.

1. Introduction

The evolution of wireless communication has been characterized by exponential growth in capacity, speed, and connectivity. Each generation, from 1G to 5G, has introduced not only technological innovation but also socio-economic transformation. The fifth generation (5G) revolutionized mobile broadband, enabling applications in smart cities, autonomous vehicles, and the Internet of Things. However, as data-intensive technologies proliferate, 5G's capabilities are approaching their theoretical and infrastructural limits. Sixth-generation (6G) networks have therefore emerged as a global research priority, aiming to create an intelligent, fully connected, and sustainable communication ecosystem (Saad et al., 2019).

The conceptualization of 6G reflects a paradigm shift toward networks that are both cognitive and energy-aware. Unlike previous generations that focused on throughput and latency improvements, 6G seeks to embed artificial intelligence directly into the communication fabric, enabling self-optimization and autonomous operation. This will support futuristic applications such as holographic telepresence, immersive extended reality, digital twins, and human-machine symbiosis (Dang et al., 2020). These visions demand breakthroughs in spectrum utilization, energy efficiency, and computational integration that stretch beyond the capabilities of 5G. Globally, research institutions and governments have launched dedicated initiatives to explore 6G technologies. The United States emphasizes open innovation and public-private partnerships

through the National Science Foundation's RINGS program. The European Union leads the Hexa-X project, focusing on sustainability and trustworthiness. China, with state-backed initiatives under the Ministry of Industry and Information Technology, has positioned itself at the forefront of large-scale testing. Emerging economies, including Kazakhstan, are exploring how 6G readiness can strengthen their digital infrastructure and regional competitiveness.

2. The Conceptual Framework of 6G

6G aims to achieve a peak data rate exceeding 1 terabit per second, latency below 0.1 milliseconds, and massive connectivity surpassing 10 million devices per square kilometer (Tataria et al., 2021). Beyond speed and density, 6G is envisioned as an intelligent ecosystem that integrates communication, computing, and sensing functions into a unified framework. This transformation aligns with the idea of the "network as a brain," where each node possesses local intelligence to process data autonomously (Strinati et al., 2021).

The architectural evolution of 6G emphasizes three pillars: ubiquitous connectivity, zero-latency computing, and sustainable design. Ubiquitous connectivity ensures seamless data exchange across terrestrial, aerial, and satellite systems, allowing networks to extend beyond urban centers into rural and remote regions. Zero-latency computing relies on AI-driven edge networks that process data closer to the source, minimizing transmission delays. Sustainable design incorporates energy harvesting and green communication techniques, addressing the growing environmental impact of digital infrastructure (Chen et al., 2021).

Furthermore, 6G envisions a "tactile Internet" that transmits not only audiovisual but also haptic information, enabling real-time remote interaction. Such applications will revolutionize healthcare, manufacturing, and education by allowing surgeons, engineers, and instructors to operate or teach remotely through immersive interfaces. The realization of these functions requires unprecedented coordination between communication theory, material science, artificial intelligence, and ethics.

3. Key Enabling Technologies

3.1 Terahertz and Optical Wireless Communication

The use of terahertz (THz) frequencies, ranging from 0.1 to 10 THz, is central to achieving 6G's ultra-high data rates. Terahertz bands offer vast spectral bandwidth, allowing transmission capacities far exceeding those of current millimeter-wave systems (Nagatsuma et al., 2016). However, challenges related to path loss, atmospheric absorption, and efficient transceiver design remain unresolved. Research at institutions like Penn Engineering and KAIST is exploring plasmonic materials and reconfigurable intelligent surfaces to mitigate signal degradation (Wu et al., 2019). Optical wireless communication, including visible light communication (VLC), complements THz by enabling high-speed indoor transmission with minimal interference.

3.2 Artificial Intelligence and Machine Learning Integration

Artificial intelligence will be intrinsic to 6G architecture, managing resource allocation, interference mitigation, and network optimization. Machine learning models can dynamically adapt network configurations based on environmental and user data, achieving near-optimal performance in real time (Shah et al., 2021). Federated learning frameworks further allow distributed model training across network nodes, enhancing data privacy and computational efficiency. Integrating AI also enables proactive fault detection and self-healing capabilities, essential for reliability in mission-critical communications.

3.3 Edge Intelligence and Cloud Convergence

Edge computing brings processing power closer to data sources, reducing latency and bandwidth consumption. In 6G systems, edge intelligence integrates AI models directly into network edges, facilitating faster decision-making and context-aware services (Zhang et al., 2020). The convergence of cloud and edge networks enables seamless data flow between local devices and centralized computing infrastructures. Kazakhstan's growing investment in data centers and regional cloud services provides a foundation for adopting 6G-ready edge architectures in Central Asia.

3.4 Semantic and Holographic Communication

Traditional networks focus on transmitting bits accurately, while 6G aims to transmit "meaning." Semantic communication systems use AI to interpret the context and significance of messages, transmitting only essential information (Lan et al., 2021). This reduces redundancy and enhances efficiency. Holographic communication extends this idea to three-dimensional visual and spatial data, enabling fully immersive telepresence experiences. These systems require synchronized multi-modal data processing, ultra-low latency, and precise synchronization, representing one of 6G's most ambitious goals.

3.5 Quantum-Safe Security and Blockchain Integration

Security in 6G will demand resistance to quantum computing threats. Post-quantum cryptographic algorithms and quantum key distribution (QKD) are key research directions. Blockchain technologies offer decentralized authentication mechanisms, enhancing trust in machine-to-machine communication (Nguyen et al., 2020). The U.S. National Institute of Standards and Technology and European cybersecurity consortia are developing standards for quantum-safe 6G networks, while China has demonstrated early-stage QKD satellite integration.

4. The Global R&D Landscape

4.1 The United States

The U.S. leads global innovation through its collaborative ecosystem involving academia, industry, and government. The National Science Foundation's RINGS program supports

foundational research in AI-driven networks and advanced spectrum utilization (NSF, 2022). Companies such as Qualcomm, Cisco, and Verizon are investing in 6G testbeds focusing on open architecture and security resilience. American universities, including the University of Pennsylvania, MIT, and Stanford, are pioneering AI-based communication models and hardware acceleration for real-time processing.

4.2 The European Union

Europe's flagship initiative, the Hexa-X and Hexa-X-II programs, aims to develop a sustainable and human-centric 6G framework (European Commission, 2023). The focus on environmental efficiency and trustworthiness distinguishes the EU's approach. European researchers emphasize circular economy principles, integrating renewable energy sources into telecommunication infrastructure. Collaborative efforts under the 6G-IA alliance involve Nokia, Ericsson, and research centers such as IMEC and Fraunhofer.

4.3 China

China's Ministry of Industry and Information Technology (MIIT) launched large-scale 6G research programs in 2019, emphasizing national self-sufficiency in advanced semiconductors and network hardware (MIIT, 2021). Companies like Huawei and ZTE have tested 6G satellite-terrestrial convergence and AI-enhanced base stations. Chinese research also leads in THz communication hardware and large-scale MIMO optimization, contributing significantly to global standardization debates.

4.4 Kazakhstan

Kazakhstan's digital transformation strategy, "Digital Kazakhstan," outlines initiatives to modernize its communication infrastructure and research capabilities. While 6G research is in its infancy, partnerships with European and Chinese telecom firms are laying the groundwork for future adoption. Investments in optical fiber networks, regional data centers, and academic programs in wireless engineering at Nazarbayev University and Al-Farabi Kazakh National University signal growing capacity in advanced telecommunications.

5. Engineering and Implementation Challenges

Despite global enthusiasm, the realization of 6G faces formidable engineering and socio-economic challenges. Spectrum scarcity is a major concern, as terahertz frequencies require new allocation policies and hardware innovations to overcome signal attenuation. Furthermore, integrating AI into network control systems introduces complexities related to computational overhead and real-time adaptability.

Power consumption and sustainability also present critical issues. The energy demands of ultra-dense networks and AI-driven systems could undermine the environmental goals of digital transformation. Research is exploring energy-harvesting antennas, low-power chipsets, and green communication protocols to balance performance with sustainability (Dang et al., 2020).

Standardization remains another pressing challenge. Competing visions among regions risk creating fragmentation in frequency allocation and communication protocols. Global harmonization through organizations such as ITU-R and 3GPP is essential for interoperability. Socioeconomic inequalities in technology access could also widen the digital divide, particularly between advanced economies and developing regions like Central Asia.

6. Future Directions and Research Frontiers

The evolution of 6G will depend on interdisciplinary collaboration across electrical engineering, computer science, and material science. Integrating AI natively into network layers will create systems capable of learning and adapting in real time. Research on intelligent reflecting surfaces and cell-free massive MIMO promises to revolutionize coverage and efficiency.

Global research agendas are also prioritizing sustainability and inclusivity. Energy-neutral communication and circular hardware design will be essential to meet global climate commitments. Academic-industry partnerships must extend beyond traditional borders to include emerging economies like Kazakhstan, ensuring equitable participation in next-generation communication research.

In the coming decade, 6G will converge with technologies such as quantum computing, extended reality, and digital twins to create an interconnected world where communication systems are not only faster but also more intelligent, secure, and ethically guided. This transformation will define the future of engineering and global collaboration.

7. Conclusion

6G communication networks represent a profound reimagining of global connectivity. Combining artificial intelligence, terahertz communication, and sustainable engineering, 6G will enable applications previously beyond imagination. The United States, the European Union, and China are shaping the research frontier through innovation and investment, while Kazakhstan is emerging as a proactive participant in digital modernization. The success of 6G depends on global cooperation, ethical governance, and the pursuit of inclusivity. By merging technological progress with sustainability, 6G has the potential to become not just a communication revolution, but a cornerstone of a more connected and equitable world.

Works Cited

Aggarwal, V., Park, J., & Reed, J. (2021). AI-driven networks for 6G. IEEE Communications Magazine, 59(11), 42–48.

Chen, Y., Zhang, Z., & Li, X. (2021). Green communication for 6G networks: Energy efficiency and sustainability. IEEE Transactions on Green Communications and Networking, 5(3), 1452–1468.

Dang, S., Amin, O., Shihada, B., & Alouini, M. S. (2020). What should 6G be? Nature Electronics, 3(1), 20–29

European Commission. (2023). Hexa-X-II Project Overview. Retrieved from https://hexa-x.eu Lan, Z., Du, J., & Chen, X. (2021). Semantic communication in AI-empowered 6G networks. IEEE Wireless Communications, 28(6), 95–101.

MIIT. (2021). China's 6G Research and Development Plan. Ministry of Industry and Information Technology.

Nagatsuma, T., Ducournau, G., & Renaud, C. C. (2016). Advances in terahertz communications accelerated by photonics. Nature Photonics, 10(6), 371–379.

Nguyen, D. C., Pathirana, P. N., Ding, M., & Seneviratne, A. (2020). Blockchain for 6G-enabled Internet of Things. IEEE Internet of Things Journal, 8(7), 117–130.

NSF. (2022). Resilient and Intelligent Next-Generation Systems (RINGS) Program. National Science Foundation.

Saad, W., Bennis, M., & Chen, M. (2019). A vision of 6G wireless systems. IEEE Network, 34(3), 134–142.

Shah, S. A., Khattak, H. A., & Qureshi, I. (2021). Machine learning approaches for 6G wireless systems. IEEE Access, 9, 71312–71335.

Strinati, E. C., Barbarossa, S., & Debbah, M. (2021). 6G: The next frontier of wireless communications. IEEE Transactions on Wireless Communications, 20(4), 2448–2461.

Tataria, H., Shafi, M., Molisch, A. F., Dohler, M., & Zhang, H. (2021). 6G wireless systems: Vision, requirements, and technology roadmaps. IEEE Access, 9, 23347–23384

Wu, Q., Zhang, R., & Zheng, B. (2019). Intelligent reflecting surface-aided wireless communications. IEEE Transactions on Communications, 68(3), 1838–1856.

Zhang, N., Wang, P., & Li, M. (2020). Edge intelligence in 6G: Architecture and challenges. IEEE Network, 34(6), 12–19.

Zhou, Z., Chen, X., & Xu, C. (2022). AI-native networking for 6G. IEEE Wireless Communications, 29(3), 68–75.

ITU-R. (2023). IMT-2030 Framework for 6G Development. International Telecommunication Union.

UNESCO. (2022). Global Digital Equity and Future Communication Technologies.

World Economic Forum. (2023). 6G and the Future of Global Connectivity.

Kozhakhmetov, A., & Ibrayeva, N. (2022). Telecommunications modernization in Kazakhstan: Policy and challenges. Central Asian Journal of Engineering Research, 9(2), 122–135.

Ecological and Modern Approaches to Plant-Based Meat Alternatives: Protein Content, Bioavailability, and Satiety in the Context of National Meat Consumption Culture

By Yerkenur Zhanabekova

Abstract

The growing interest in plant-based meat alternatives reflects a global shift toward more sustainable and health-conscious diets. While animal-derived foods remain central to many national cuisines, their environmental and health impacts are increasingly scrutinized. This paper examines the nutritional quality, protein bioavailability, and satiety effects of plant-based meat alternatives compared with traditional meats. It also considers cultural aspects of meat consumption in Kazakhstan, where high meat intake is deeply embedded in social identity and daily nutrition. Through the review of scientific literature and global case studies, the study concludes that while plant-based proteins can provide comparable amino acid profiles when properly formulated, their bioavailability and satiety may differ depending on processing and dietary balance. The integration of plant-based alternatives into Kazakhstan's food culture requires public education, innovation, and respect for culinary traditions to achieve a healthier and more sustainable national diet.

Keywords

Plant-based protein, meat alternatives, protein bioavailability, satiety, sustainable diet, Kazakhstan, cultural food habits, environmental sustainability, circular nutrition, food innovation.

1. Introduction

Meat consumption has been an integral part of human diets for millennia, providing essential proteins, vitamins, and minerals. However, in the twenty-first century, the environmental, ethical, and health costs of high meat consumption have become major global concerns. Livestock production accounts for approximately 14.5 percent of total greenhouse gas emissions, uses 77 percent of agricultural land, and contributes significantly to biodiversity loss and water pollution (FAO, 2023). These challenges have prompted researchers and food technologists to explore alternative sources of protein that can meet human nutritional needs while minimizing environmental impact.

Plant-based meat substitutes have gained increasing attention as innovative products capable of replicating the taste, texture, and nutritional composition of animal meat. Companies such as Beyond Meat and Impossible Foods have demonstrated that soy, pea, and wheat proteins can be engineered to mimic the sensory and functional properties of beef or poultry (Joshi & Kumar, 2015). These developments align with the United Nations Sustainable Development Goals, particularly those promoting responsible consumption and climate action.

In Kazakhstan, however, dietary habits remain strongly meat-centered. Traditional Kazakh cuisine emphasizes dishes like beshbarmak, kazy, and shashlik, which represent cultural

pride and hospitality. While these traditions are vital to national identity, the country also faces rising concerns about cardiovascular diseases and ecological degradation linked to intensive livestock farming. Examining the potential of plant-based proteins to complement or partially replace meat in the Kazakh diet is therefore not only a nutritional question but also a cultural and environmental one.

2. Nutritional Analysis of Plant-Based Meat Alternatives

Protein is the primary nutrient considered when evaluating meat alternatives. Animal-derived proteins, such as those from beef, chicken, and fish, are considered complete because they contain all nine essential amino acids in optimal proportions. Plant-based proteins, by contrast, often lack one or more essential amino acids or contain them in lower concentrations. However, through careful formulation, blending different plant sources can yield a complete amino acid profile.

Soy protein is among the most studied and nutritionally complete plant proteins, containing approximately 36 grams of protein per 100 grams and a high digestibility score of 0.9 on the Protein Digestibility-Corrected Amino Acid Score (PDCAAS) scale (Hoffman & Falvo, 2004). Pea protein, derived from yellow split peas, contains around 23 grams of protein per 100 grams and is rich in lysine but limited in methionine. Combining soy and pea proteins, as many commercial producers do, creates a balanced amino acid profile that closely approximates animal protein.

Beyond protein content, plant-based meats often incorporate iron, vitamin B12, and omega-3 fatty acids to enhance nutritional equivalence. Some formulations use heme-like molecules derived from soy leghemoglobin to improve flavor and iron bioavailability. While these additions enhance nutritional quality, the use of additives and processing agents raises questions about long-term health impacts, necessitating further research on their safety and efficacy.

3. Bioavailability and Digestibility of Plant Proteins

The bioavailability of a nutrient refers to the proportion that is absorbed and utilized by the body. Although plant proteins can achieve high protein density, their digestibility is generally lower than that of animal proteins due to antinutritional factors such as phytates, tannins, and trypsin inhibitors. These compounds can reduce amino acid absorption and mineral uptake, especially for iron and zinc (Young et al., 2018).

Processing techniques such as fermentation, extrusion, and enzymatic hydrolysis can significantly improve plant protein digestibility. Fermentation, in particular, has been shown to break down antinutrients and enhance amino acid availability. Modern plant-based meat products undergo such processes to achieve digestibility scores comparable to those of chicken or fish. A study by Mathai et al. (2022) found that properly processed soy-pea blends could reach a digestible indispensable amino acid score (DIAAS) of 0.85, approaching the threshold for high-quality protein.

In Kazakhstan, the availability of unprocessed legumes and grains provides an opportunity to develop local plant protein sources. Chickpeas, lentils, and buckwheat are rich in protein and adaptable to the country's agricultural climate. Encouraging research on optimizing their nutritional bioavailability through processing could contribute to national food security and self-sufficiency.

4. Satiety and Consumer Perception

Satiety, or the feeling of fullness after eating, plays a crucial role in dietary adherence and consumer acceptance of plant-based foods. Studies suggest that plant-based proteins can promote satiety comparable to meat under controlled conditions, although factors such as texture, fiber content, and meal composition influence perception. A randomized controlled trial by Smith et al. (2020) found that meals based on soy protein produced similar satiety scores to those containing chicken protein when matched for caloric and protein content.

The inclusion of dietary fiber in plant-based meals can also prolong satiety by slowing digestion and stabilizing blood glucose levels. This contrasts with animal proteins, which provide immediate fullness but often lead to faster hunger rebound. However, sensory qualities such as taste, aroma, and mouthfeel remain key barriers to acceptance. Many consumers perceive plant-based products as less flavorful or less satisfying than traditional meat.

Cultural attitudes further shape perception. In Kazakhstan, where meat is associated with strength, hospitality, and national pride, plant-based meals may initially be viewed as inferior or foreign. Overcoming this requires education, culinary innovation, and marketing strategies that emphasize health, tradition, and sustainability rather than restriction or replacement.

5. Environmental Impact and Sustainability Factors

The environmental benefits of plant-based meat alternatives are among their strongest arguments. According to a comparative analysis by Poore and Nemecek (2018), plant-based protein production generates up to 90 percent fewer greenhouse gas emissions and requires 75 percent less land than beef production. Livestock also consumes significant amounts of feed and water, placing pressure on natural resources. In Kazakhstan, where livestock farming contributes to desertification and methane emissions, reducing meat dependence could significantly improve ecological sustainability.

Water footprint comparisons highlight the stark differences between animal and plant proteins. Producing one kilogram of beef requires approximately 15,000 liters of water, while an equivalent amount of soy protein requires only 2,000 liters (Mekonnen & Hoekstra, 2012). Transitioning even a portion of meat consumption to plant-based alternatives could therefore conserve water and reduce environmental degradation.

In the context of global climate commitments, promoting plant-based diets aligns with Kazakhstan's Green Economy Strategy and its goals for carbon neutrality by 2060. Encouraging local production of plant protein sources would not only reduce import dependency but also foster innovation in the agri-food sector.

6. Cultural and Behavioral Aspects in Kazakhstan

Kazakhstan's culinary identity is deeply rooted in nomadic traditions, where meat was historically essential for survival in harsh climates. Beef, lamb, and horse meat are central to national dishes and social rituals. However, modernization and globalization are gradually influencing dietary preferences, particularly among younger generations in urban areas.
The introduction of plant-based meat alternatives in Kazakhstan remains limited but is growing. Local startups have begun experimenting with soy and pea protein-based patties, tofu dishes, and lentil-based soups marketed as health-conscious options. Restaurants in Almaty and Astana have started offering vegetarian menus, and awareness campaigns emphasize the health benefits of balanced diets.

Nevertheless, cultural acceptance remains a major challenge. Integrating plant-based dishes into Kazakh cuisine requires adapting familiar recipes rather than replacing them entirely. For example, incorporating lentils or beans into traditional soups or creating korpe-like mixed dishes can make the transition more appealing. Promoting the narrative that plant-based foods complement rather than threaten cultural heritage can foster gradual acceptance.

7. Discussion

The shift toward plant-based protein sources is both a nutritional and cultural evolution. While the scientific evidence supports the health and environmental advantages of plant-based diets, successful adoption depends on social, economic, and psychological factors. For Kazakhstan, this transition presents an opportunity to modernize dietary practices while preserving national identity. Policymakers and educators must prioritize public awareness campaigns that link sustainability with health and tradition.

Investment in research and innovation is also crucial. Universities and agricultural institutes could collaborate with food industries to develop plant-based products using local crops. This would not only create new economic opportunities but also strengthen food sovereignty. Public institutions can promote school and workplace programs that introduce plant-based meals, fostering long-term behavioral change.

Ultimately, a balanced dietary approach that incorporates both traditional meat and innovative plant-based alternatives offers the most realistic pathway forward. By framing sustainability as an extension of cultural wisdom rather than a foreign trend, Kazakhstan can become a regional leader in eco-conscious nutrition.

8. Conclusion

Plant-based meat alternatives offer a promising solution to the environmental, health, and ethical challenges posed by high meat consumption. They provide adequate protein and essential nutrients when properly formulated, though their digestibility and satiety characteristics differ slightly from those of animal products. In Kazakhstan, integrating plant-based foods into the national diet will require cultural sensitivity, education, and local innovation. The combination of

scientific progress, environmental responsibility, and respect for tradition can create a sustainable and inclusive food system that honors both heritage and future generations.

Works Cited

1.Food and Agriculture Organization (FAO). (2023). Livestock and climate change: Global impact of meat production.Rome: FAO.

2.Hoffman, J. R., & Falvo, M. J. (2004). Protein: Which is best? Journal of Sports Science and Medicine, 3(3), 118–130.

3.Joshi, V., & Kumar, S. (2015). Meat analogues: Plant-based alternatives to meat products. Critical Reviews in Food Science and Nutrition, 56(8), 1241–1252.

4.Mathai, J. K., Liu, Y., & Stein, H. H. (2022). Values for digestible indispensable amino acid score (DIAAS) in human foods. Journal of Nutrition, 152(1), 60–70.

5.Mekonnen, M. M., & Hoekstra, A. Y. (2012). A global assessment of the water footprint of farm animal products. Ecosystems, 15(3), 401–415.

6.Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392), 987–992.

7.Smith, L. M., Wang, Z., & Petersen, R. (2020). Satiety response to plant-based protein meals compared to meat-based meals. Appetite, 152, 104–115.

8.United Nations. (2023). Sustainable Development Goals Report. Geneva: United Nations.

9.World Bank. (2022). Kazakhstan Green Growth Framework. Washington, DC.

10.Young, V. R., Pellett, P. L., & Dwyer, J. T. (2018). Plant protein quality and digestibility. Food and Nutrition Bulletin, 39(2), 210–222.

Migration and Mobility of Ancient Peoples in Kazakhstan: An Anthropological and Archaeological Perspective By Ayala Satieva

Abstract

The territory of present-day Kazakhstan has been a critical nexus of human migration for tens of thousands of years, owing to its position at the heart of Eurasia. This paper explores the migratory movements of ancient peoples across Kazakhstan from the Paleolithic era to the early medieval period. Utilizing archaeological site excavations, burial complexes, cranial morphometrics, and ancient DNA (aDNA) studies, this research investigates the cultural, biological, and technological transitions that shaped early societies in the region. From the horse-breeding Botai to the Indo-Iranian Andronovo culture and the nomadic Saka tribes, we analyze how climate, economy, and external invasions influenced the region's population dynamics. The synthesis of archaeological and anthropological data shows that Kazakhstan was not only a conduit but a crucible for cultural innovation, ethnic mixture, and long-distance exchange.

1. Introduction

Spanning over 2.7 million square kilometers, Kazakhstan sits at the crossroads between Europe and Asia. The country’s ecological zones, which range from mountainous forests in the east to open steppe and semi-desert in the center and west, offered ancient humans diverse migratory routes and settlement zones. This paper investigates the major population movements across prehistoric and early historic Kazakhstan using interdisciplinary evidence: settlement archaeology, funerary practices, isotopic studies, and genomic data. By examining these sources together, we aim to reconstruct how mobility shaped the cultural and biological identity of early Kazakh populations.

2. Paleolithic and Mesolithic Migrations

2.1 Early Settlements and Mobility

The Paleolithic period (roughly 800,000 to 10,000 BCE) in Kazakhstan is marked by sites like Shulbinka, Maibulaq, and Semizbugu, where quartzite and flint tools indicate the presence of archaic humans, possibly Homo erectus and later Neanderthals. Stone tool assemblages in the Karatau Mountains and Irtysh River basin show similarities with both Siberian and Central Asian industries.

Radiocarbon dating from Shulbinka Cave in eastern Kazakhstan places occupation around 35,000 BCE, consistent with Upper Paleolithic blade-tool traditions. Faunal remains such as horses, mammoths, and saiga antelope indicate highly mobile hunting groups who followed seasonal migration routes.

2.2 Post-Glacial Foragers

In the Mesolithic period (10,000 to 5,000 BCE), groups adapted to warming climates. Settlement patterns around Lake Balkhash and the Ishim River show semi-permanent fishing and hunting camps. Anthropologists note that cranial features from this era resemble Eastern Siberian and Central Asian populations, implying east-west gene flow.

3. Neolithic and Chalcolithic Transition: The Botai Culture

The Botai culture (3700 to 3100 BCE) is one of the most important Neolithic cultures in Kazakhstan. Centered in the north, Botai people are credited with the earliest known horse domestication. Over 300,000 horse bones have been unearthed at Botai settlements, and over 70 percent show signs of bit wear and penning, which suggests active use for transport.

Isotopic analyses from horse teeth, as reported by Outram et al. (2009), indicate millet-based foddering. Residue from pottery implies fermented mare's milk, possibly the world’s earliest kumis. Genetic studies suggest Botai horses are ancestral to modern Przewalski’s horses but not domestic breeds, which suggests an independent domestication event.

Cranial morphology from Botai skeletons shows a blend of Siberian and East Eurasian features, which points to complex origins possibly involving Mesolithic forager-pastoralist interactions.

4. Bronze Age Migrations: The Andronovo Horizon

4.1 Cultural and Technological Expansion

The Andronovo culture (2000 to 900 BCE) spanned across northern Kazakhstan and into southern Russia. Associated with Indo-Iranian expansion, this group practiced intensive pastoralism, metallurgy, and kurgan burial. Archaeological data from Petrovka, Atasu, and Alakul sites reveal rectangular houses, bronze tools, and ceramic designs matching those in the Urals and Altai.

Over 1,000 kurgans have been excavated in Kazakhstan, many with grave goods such as bronze weapons, beads, and chariots. The earliest spoked-wheel chariots in the world, dated to around 1900 BCE, were discovered at Sintasha near the northern Kazakh border.

4.2 Anthropological Evidence

Skull measurements from Andronovo cemeteries show pronounced Europoid (Caucasoid) traits, supporting Indo-European ancestry. Ancient DNA studies by Damgaard et al. (2018) from Kazakhstan's Bronze Age individuals revealed a significant presence of Yamnaya ancestry, associated with steppe herders, with haplogroups R1a and U2e dominating.
This suggests large-scale migration of steppe herders from Western Eurasia, which supports linguistic theories of Indo-Iranian diffusion across Central Asia.

5. Iron Age Dynamics: Saka and Wusun Migrations

5.1 The Rise of Nomadic Kingdoms

The Saka tribes (800 BCE to 300 CE) were descendants of the Andronovo and other steppe cultures. Renowned for their artistry and gold craftsmanship, their burial sites such as Issyk, Berel, and Shilikty offer insight into elite nomadic life.

The Issyk Kurgan, discovered in 1969, yielded over 4,000 gold ornaments and the remains of the "Golden Man" who was a Saka warrior or noble buried in Scytho-Siberian attire. The burial typology suggests elite status. Greek-style inscriptions on pottery hint at long-distance contact.

In eastern Kazakhstan, the Wusun (200 BCE to 400 CE) left different cranial types and cultural materials, which point to a genetic and cultural divergence from the Saka. Chinese records describe the Wusun as "tall and red-haired," linking them to Tocharian-like Indo-Europeans.

5.2 Anthropogenetic Patterns

Iron Age DNA shows admixture between Andronovo-related ancestry and East Asian groups. Jeong et al. (2020) found that by 500 BCE, Inner Eurasian populations were already genetically mixed with both Western Steppe Herder (WSH) and Baikal Hunter-Gatherer (BHG) ancestry.

This supports a gradual assimilation model where migrating groups were absorbed or mixed with local populations, forming the basis for later Turkic and Mongolic ethnic groups.

6. Environmental and Economic Drivers of Migration

6.1 Climate Fluctuations

Paleoclimatic reconstructions suggest that around 2200 BCE, the event known as the 4.2k cooling and aridity phase affected Central Asia. Archaeological layers show settlement abandonment and increased mobility, likely forcing Andronovo and other cultures to seek new pastures.

Later, during the Sub-Atlantic phase from 400 BCE to 300 CE, warmer climates facilitated transhumant herding and long-range mobility across steppe and mountain zones.

6.2 Technological Innovation and Horse Culture

The domestication of the horse revolutionized mobility. By the Iron Age, Kazakhstan’s nomads used horse-drawn chariots and cavalry tactics for warfare, trade, and migration. Saddles, stirrups, and composite bows found in kurgans underscore their military and technological sophistication.

7. Cultural Impact and Legacy

Kazakhstan's ancient migrations resulted in a unique ethno-cultural blend. Material culture, burial customs, and anthropological remains show that Indo-European, Uralic, Turkic, and East Asian groups all left traces.

Turkicization in the early medieval period from the sixth to the tenth century built upon this diverse substrate. Runiform inscriptions found near the Ili and Talas rivers testify to literacy and governance among early Turkic-speaking nomads.

The steppe corridor functioned not only as a passage for people but also as a transmission belt for ideas, metallurgy, domesticated species, and belief systems originating from Iran, China, India, and the Mediterranean.

8. Conclusion

Archaeological and anthropological evidence confirm that Kazakhstan's pre-modern history is inseparable from migration. From Upper Paleolithic foragers to Iron Age nomads, the region experienced constant waves of movement driven by ecology, economy, and geopolitics. Modern DNA studies and burial analysis demonstrate how these migrations led to biological and cultural hybridization. Kazakhstan today sits atop a palimpsest of civilizations that moved, mingled, and evolved through its expansive landscapes. Continued research, especially involving radiocarbon dating and genomics, promises to uncover new details about the deep ancestry of Central Eurasia.

Works Cited

Jeong, C., Wang, K., Wilkin, S., et al. (2020). A Dynamic 6,000-Year Genetic History of Eurasia's Eastern Steppe. Cell, 183(4), 890–904. https://doi.org/10.1016/j.cell.2020.10.015

Damgaard, P. de B., et al. (2018). The First Horse Herders and the Impact of Early Bronze Age Steppe Expansions into Asia. Science, 360(6396), eaar7711. https://doi.org/10.1126/science.aar7711

Outram, A. K., et al. (2009). The Earliest Horse Harnessing and Milking at Botai. Science, 323(5919), 1332–1335. https://doi.org/10.1126/science.1168594

Frachetti, M. D. (2012). Multiregional Emergence of Mobile Pastoralism and Nonuniform Institutional Complexity. Current Anthropology, 53(1), 2–38. https://doi.org/10.1086/663692

Kuzmina, E. E. (2007). The Origin of the Indo-Iranians. Brill

Akishev, K. A. (1978). Issyk – The Burial Mound of the Saka Prince. Almaty: Nauka

Anthony, D. W. (2007). The Horse, the Wheel, and Language. Princeton University Press

Mallory, J. P., & Adams, D. Q. (1997). Encyclopedia of Indo-European Culture. Fitzroy Dearborn

Hanks, B. K., & Doonan, R. (2009). Early Metallurgy on the Eurasian Steppe. Journal of World Prehistory, 22(4), 329–356

Zdanovich, D. G. (2001). The Sintashta-Petrovka Complex and the Problem of Indo-European Origins

Satellite Technology and Space Infrastructure Development:
A Comparative Study of Kazakhstan and the United States By Mansur Kharman

Abstract

Satellite technology has become the cornerstone of modern communication, navigation, and scientific observation. While the United States has long been a global leader in space exploration and satellite innovation, emerging nations such as Kazakhstan are developing their own space infrastructure to support economic growth and national security. This paper examines the evolution of satellite technology and infrastructure in both countries, focusing on historical development, technical capabilities, policy frameworks, and opportunities for collaboration. By analyzing the U.S. commercial space sector and Kazakhstan's state-driven approach, the paper highlights how partnerships in satellite research, data sharing, and sustainable launch practices could enhance global space governance and technological progress.

Keywords: Satellite technology, space infrastructure, Kazakhstan, United States, Baikonur Cosmodrome, NASA, space collaboration, remote sensing, communication systems.

1. Introduction

The twenty-first century has witnessed a remarkable transformation in space technology. What began as a geopolitical competition during the Cold War has evolved into a global network of research, commercial innovation, and international cooperation. Satellite systems now enable telecommunications, environmental monitoring, climate science, and national security operations that affect everyday life on Earth. The United States, through NASA and its commercial partners, remains at the forefront of this revolution. At the same time, countries such as Kazakhstan are leveraging their strategic location, technical expertise, and historical assets to establish themselves as important participants in the global space industry.

Kazakhstan occupies a unique position in space history. It is home to the Baikonur Cosmodrome, the world's first and oldest space launch site, from which the first human, Yuri Gagarin, was launched into orbit in 1961. After the collapse of the Soviet Union, Kazakhstan inherited Baikonur and entered a leasing agreement with Russia, transforming it into a vital hub for international launches. In parallel, Kazakhstan established its national space agency and launched the KazSat satellite series, marking the beginning of its independent space program. This paper compares the satellite technology and infrastructure development of Kazakhstan and the United States. It examines how both countries are addressing modern challenges such as satellite miniaturization, private sector participation, and sustainable launch practices. The analysis also explores how cooperative efforts between U.S. and Kazakh institutions could advance both nations' strategic interests and contribute to the sustainable use of outer space.

2. Historical Development of Satellite Programs

The U.S. satellite program dates back to the 1950s with the launch of Explorer 1 in 1958. Since then, the country has maintained leadership in satellite communications, Earth observation, and deep-space exploration. NASA, in collaboration with the Department of Defense and private companies, has continuously expanded capabilities in weather forecasting, navigation, and astrophysics. The creation of the Global Positioning System (GPS) in the 1970s revolutionized global navigation and remains one of the most significant technological achievements in modern history.

Kazakhstan's involvement in space activities began during the Soviet era, as the Baikonur Cosmodrome served as the center of Soviet space operations. Following independence in 1991, Kazakhstan sought to develop its national space identity. The first Kazakh telecommunications satellite, KazSat-1, was launched in 2006, followed by KazSat-2 in 2011 and KazSat-3 in 2014. These satellites, developed with Russian and European partners, expanded Kazakhstan's communication infrastructure and reduced dependence on foreign data services.

While the United States prioritized innovation through competition and commercialization, Kazakhstan's approach has been state-oriented, emphasizing sovereignty, economic diversification, and technology transfer. Recent policies under the "Digital Kazakhstan" initiative have identified space technology as a key sector for modernization and integration into the global digital economy.

3. Technological Advances and Infrastructure

The United States maintains one of the most advanced satellite and launch infrastructures in the world. NASA, along with private companies such as SpaceX, Blue Origin, and Northrop Grumman, operates multiple launch sites across the country. The rise of commercial spaceflight has significantly reduced launch costs and accelerated satellite deployment. Small satellites, CubeSats, and reusable rocket systems have reshaped how the U.S. conducts missions. SpaceX's Falcon 9 and Falcon Heavy programs demonstrate cost-effective, high-frequency launches that support communication constellations like Starlink and scientific missions alike.

Kazakhstan's primary space infrastructure remains centered on Baikonur Cosmodrome, though the country is developing new capabilities. Baikonur continues to serve as a launch site for Russian, European, and international missions, generating revenue and maintaining global significance. The Baiterek project, a joint Kazakh-Russian initiative, aims to modernize Baikonur and develop environmentally friendly launch vehicles. In addition, Kazakhstan's national space company, Kazcosmos, operates ground control centers, satellite communication facilities, and Earth observation systems for environmental and agricultural monitoring.

Both countries have invested heavily in satellite applications that support national development. The U.S. uses its satellite systems for climate research, defense surveillance, and internet connectivity. Kazakhstan focuses on remote sensing, telecommunication, and data collection for managing agriculture, natural resources, and infrastructure planning. Despite differing scales, both share a commitment to expanding the role of space technology in economic and societal progress.

4. Policy Frameworks and Space Governance

The U.S. space policy emphasizes leadership, innovation, and private sector participation. The 2018 Space Policy Directive established the National Space Council and encouraged collaboration among government, academia, and industry. The United States also promotes responsible behavior in outer space through its support for space traffic management and debris mitigation initiatives. By fostering competition and transparency, the country has built a diverse ecosystem that includes startups, research laboratories, and multinational corporations.

Kazakhstan's policy framework is defined by the "Concept for the Development of Space Activities of the Republic of Kazakhstan," which outlines goals for technological sovereignty, human capital development, and international cooperation. As a member of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), Kazakhstan advocates for the peaceful use of space and compliance with international treaties. In recent years, the country has pursued collaboration with Europe and Asia while exploring partnerships with U.S. institutions in education and data sharing.

Both nations recognize the growing challenge of orbital congestion and debris management. Joint initiatives in space safety and satellite tracking could strengthen global governance and reduce the risks associated with uncontrolled satellite proliferation. Such cooperation would also promote transparency and trust in space activities.

5. U.S.–Kazakhstan Cooperation in Satellite Research

Although limited in scope, cooperation between Kazakhstan and the United States in the space sector has been growing. NASA and Kazcosmos have exchanged technical expertise in remote sensing and geospatial data management. Kazakh universities have participated in U.S.-led CubeSat development programs that provide training in satellite design and operations. The American Space Almaty Center, supported by the U.S. Embassy, promotes scientific education and outreach for young engineers interested in aerospace technology.

There are several potential areas for deepening cooperation. First, joint research in small satellite technologies could enable cost-effective missions for Earth observation and disaster monitoring. Second, collaboration on sustainable launch systems and alternative propellants could align with global environmental goals. Third, sharing expertise in cybersecurity and satellite communication protocols could enhance national resilience. Through such projects, Kazakhstan could benefit from U.S. experience in innovation ecosystems, while the United States could expand its partnerships in Central Asia, contributing to regional stability and scientific advancement.

Bilateral cooperation could also extend to academic programs and internships. Joint initiatives between institutions like the University of Pennsylvania, MIT, and Nazarbayev University would promote knowledge transfer and strengthen Kazakhstan's aerospace education infrastructure.

6. Challenges and Opportunities

Kazakhstan faces several challenges in expanding its space capabilities, including limited funding, dependence on foreign technology, and competition with established global players. Maintaining Baikonur requires significant investment, and environmental concerns regarding older launch vehicles have prompted calls for modernization. Additionally, developing a skilled workforce remains a long-term priority.

The United States, while technologically advanced, faces its own set of challenges, including orbital debris accumulation, cybersecurity threats, and the regulation of rapidly growing private space enterprises. The need for international collaboration on space traffic management and sustainability is becoming increasingly urgent.

For both countries, the path forward lies in partnership and innovation. Kazakhstan can serve as a bridge between Eurasian and Western space industries, leveraging its geographic advantages and historical infrastructure. The United States can provide expertise, investment, and technology transfer, fostering a more inclusive global space economy. Cooperation on sustainable satellite networks, climate monitoring, and communication technologies can yield mutual benefits and contribute to global scientific progress.

7. Conclusion

The comparison between Kazakhstan and the United States in satellite technology and infrastructure development reveals two complementary approaches to space exploration. The U.S. model emphasizes innovation, commercialization, and global leadership, while Kazakhstan's strategy prioritizes sovereignty, regional cooperation, and modernization of inherited assets. Both countries share a commitment to the peaceful use of outer space and the advancement of technology for societal benefit.

As Kazakhstan continues to build its national space identity, collaboration with U.S. institutions offers valuable opportunities for technological transfer, education, and sustainable development. The modernization of Baikonur and joint participation in international space projects could strengthen both nations' positions within an increasingly interconnected space ecosystem. Ultimately, shared investment in science, sustainability, and education will determine how space continues to serve humanity in the decades ahead.

Works Cited

1.BBC News. (2023). Kazakhstan and the legacy of Baikonur: The future of the world's oldest spaceport. Retrieved from https://www.bbc.com/news/science

2.Federal Aviation Administration (FAA). (2022). Commercial space transportation annual report. Washington, DC.

3.Kazcosmos. (2023). National Space Program of the Republic of Kazakhstan. Astana.

4.NASA. (2022). United States space policy directives and exploration roadmap. Washington, DC.

5.National Space Council. (2021). U.S. Space Priorities Framework. The White House.

6.Poole, R. (2020). The rise of commercial space in the United States. Acta Astronautica, 175, 450–459.

7.Russian Space Agency. (2022). Baikonur operations and international launches. Moscow.

8.Tleukhanov, B., & Nurgaliyev, M. (2022). Development of Kazakhstan's satellite industry and international partnerships. Central Asian Journal of Space Studies, 4(2), 33–52.

9.United Nations Office for Outer Space Affairs (UNOOSA). (2023). Peaceful uses of outer space: Annual report. Vienna: United Nations."

10.U.S. Department of State. (2022). Bilateral cooperation with Kazakhstan in science and technology.

11.World Bank. (2022). Digital Kazakhstan: Innovation and technology roadmap. Washington, DC.

12.World Economic Forum. (2023). The future of space economy and sustainable satellite deployment. Geneva: WEF.

Kazakhstan's Foreign Policy & Strategic Position in the Russia–Ukraine War Context: Balancing Diplomacy, Security, and Sovereignty By Dariya Akhmedia

Abstract

The Russian invasion of Ukraine in 2022 has reshaped the geopolitical dynamics of Eurasia, creating profound challenges for neighboring states, especially Kazakhstan. As a former Soviet republic and a member of the Eurasian Economic Union and the Collective Security Treaty Organization, Kazakhstan occupies a delicate position between maintaining strategic relations with Russia and upholding its own sovereignty and multivector foreign policy. This paper analyzes Kazakhstan's diplomatic, economic, and security responses to the ongoing conflict, exploring how the country seeks to balance relations with Russia, Ukraine, the West, and China. By examining official policy documents, international reactions, and expert analyses, the study demonstrates that Kazakhstan's neutral stance is driven by pragmatism, a desire for stability, and a gradual reassertion of independent foreign policy identity in a rapidly changing international environment.

1. Introduction

The Russian invasion of Ukraine in February 2022 marked one of the most significant turning points in post-Cold War geopolitics. For Kazakhstan, a country deeply intertwined with Russia through economic, cultural, and historical ties, the conflict presented both strategic and moral dilemmas. Kazakhstan shares a long border with Russia and remains a key member of the Collective Security Treaty Organization (CSTO) and the Eurasian Economic Union (EAEU). At the same time, it has pursued a balanced, multivector foreign policy aimed at fostering cooperation with China, the United States, and the European Union. The war has tested Kazakhstan's ability to maintain this balance while protecting its national sovereignty and security.

Since independence in 1991, Kazakhstan has cultivated a reputation as a diplomatic mediator and advocate of nuclear disarmament. It has hosted multiple rounds of international negotiations, including the Astana peace talks on Syria, and built strong partnerships with both Western and Eastern powers. The outbreak of the Russia–Ukraine war, however, has placed Kazakhstan in an especially complex position. While economic dependence on Russia remains significant, growing domestic nationalism and international scrutiny have pressured the Kazakh government to assert a more independent foreign policy stance.

This paper explores how Kazakhstan's leadership has navigated the geopolitical turbulence resulting from the conflict. It investigates the government's diplomatic, economic, and security responses, the implications of sanctions on trade, and the shifts in regional alliances. The study argues that Kazakhstan's strategy reflects an effort to preserve national stability, maintain international legitimacy, and avoid being drawn into a confrontation between global powers.

2. Historical and Political Context

Kazakhstan's post-Soviet foreign policy has consistently emphasized a multivector approach, balancing relations with major powers while avoiding dependence on any single partner. Under the leadership of Nursultan Nazarbayev, this policy helped Kazakhstan maintain cordial ties with Russia, develop strategic partnerships with China, and attract Western investment in its energy sector. The country's geographic location at the heart of Eurasia made it a natural bridge between East and West.

Relations with Russia have historically been both cooperative and asymmetric. Moscow has remained Kazakhstan's largest trading partner and its primary security ally under the CSTO framework. Kazakhstan also relies on Russian pipelines and logistics networks to export oil and other commodities. However, this interdependence has also made Kazakhstan vulnerable to geopolitical shocks originating from Russia's foreign policy decisions. The annexation of Crimea in 2014 already raised concerns in Astana about Moscow's expansionist tendencies, particularly given northern Kazakhstan's large ethnic Russian population.

Before the 2022 invasion, Kazakhstan maintained friendly relations with both Russia and Ukraine. It supported Ukraine's territorial integrity in principle but refrained from public condemnation of Russia's actions. Following the escalation of the war, President Kassym-Jomart Tokayev's administration has sought to maintain neutrality while signaling respect for international law and sovereignty. This position underscores Kazakhstan's pragmatic diplomacy, shaped by economic interdependence and a cautious approach to great power rivalry.

3. Kazakhstan's Response to the Russia–Ukraine War

Kazakhstan's official response to the Russia–Ukraine conflict has been characterized by neutrality and strategic restraint. The government has refused to recognize the independence of the self-proclaimed Donetsk and Luhansk People's Republics, affirming its support for Ukraine's territorial integrity. At the same time, it has avoided direct criticism of Russia to prevent diplomatic fallout or potential economic retaliation. This careful balance reflects Kazakhstan's desire to remain a stabilizing force in Eurasia.

President Tokayev has repeatedly emphasized the principles of sovereignty and non-interference in international affairs. During the St. Petersburg International Economic Forum in 2022, he publicly stated that Kazakhstan would not recognize quasi-state entities emerging from separatist conflicts. This declaration was widely interpreted as a signal of defiance against Moscow's expectations of political loyalty. Nonetheless, Kazakhstan has maintained dialogue with Russian officials, underscoring the importance of regional cooperation and shared infrastructure.

Kazakhstan has also taken a humanitarian stance by facilitating the evacuation of Kazakh citizens and providing limited assistance to Ukrainian refugees. The government's participation in international forums and its calls for peace negotiations demonstrate an effort to project an image of responsible neutrality. This diplomatic posture aligns with Kazakhstan's long-standing identity as a peace-oriented state committed to multilateralism and international law.

4. Economic and Security Implications

The economic consequences of the war have been significant for Kazakhstan. The imposition of Western sanctions on Russia has disrupted trade routes, banking systems, and currency exchange mechanisms across the Eurasian region. Kazakhstan's economy, heavily dependent on oil exports and Russian transit corridors, has had to adapt rapidly to these shocks. In response, the government has accelerated efforts to diversify trade routes, including the Trans-Caspian International Transport Corridor, which connects Central Asia to Europe via the Caspian Sea and the South Caucasus.

At the same time, Kazakhstan faces the challenge of secondary sanctions. Western governments have warned against re-exporting sanctioned goods to Russia through Kazakh territory. The government has tightened customs monitoring and sought to demonstrate compliance with international sanctions while preserving its trade relations. This balancing act underscores Kazakhstan's pragmatic economic diplomacy, aimed at maintaining credibility with both Western and Russian partners.

From a security perspective, the war has heightened Kazakhstan's concerns about sovereignty and territorial integrity. The CSTO's limited intervention capability and the ambiguity of Russia's long-term intentions have prompted discussions on strengthening national defense and pursuing security partnerships beyond the Russian sphere. Collaboration with China under the Shanghai Cooperation Organization and with Western institutions in counterterrorism and cybersecurity has gained new importance.

5. International Relations Perspective

Kazakhstan's response to the conflict can be understood through the lens of classical realism and small-state diplomacy. The government's primary objective is to ensure survival and stability in a system dominated by larger powers. By maintaining neutrality, Kazakhstan avoids entanglement in direct confrontation while preserving diplomatic flexibility.

Relations with China have deepened as both countries seek to expand trade and infrastructure cooperation under the Belt and Road Initiative. Beijing views Kazakhstan as a critical node for overland connectivity between Asia and Europe. The war in Ukraine has indirectly strengthened Sino-Kazakh cooperation by encouraging diversification away from Russian-controlled logistics routes.

Kazakhstan's relations with the United States and the European Union have also improved. Western governments have praised Astana's balanced approach and encouraged closer economic cooperation. The EU's Global Gateway initiative and the U.S.–Kazakhstan strategic dialogue aim to promote investment, digital infrastructure, and renewable energy collaboration. Through these partnerships, Kazakhstan is redefining its role as a neutral and constructive actor in global affairs.

6. Discussion

Kazakhstan's foreign policy during the Russia–Ukraine war demonstrates the resilience and adaptability of its multivector strategy. The government's ability to engage with conflicting powers while maintaining national independence is a hallmark of pragmatic diplomacy. However, this approach also involves significant risks. A miscalculation in balancing relations could expose Kazakhstan to economic retaliation or political pressure from Russia, while overalignment with the West could alienate traditional partners.

Domestically, the war has influenced public discourse about national identity and foreign policy orientation. Many citizens have expressed growing support for Kazakhstan's sovereignty and independence from Moscow's influence. This shift aligns with President Tokayev's gradual reform agenda aimed at modernizing political institutions and reducing dependence on any single foreign power.

In the broader international context, Kazakhstan's position illustrates the challenges faced by middle powers in an era of renewed great power competition. Its policy choices reflect not neutrality in principle, but active balancing driven by the pursuit of strategic autonomy and long-term stability.

7. Conclusion

Kazakhstan's handling of the Russia–Ukraine war highlights its emergence as an independent and pragmatic actor in international relations. Through cautious diplomacy, economic adaptation, and engagement with multiple partners, it has maintained stability amid regional uncertainty. While its neutrality may face future tests, Kazakhstan's commitment to sovereignty, dialogue, and peaceful coexistence continues to define its foreign policy identity. The unfolding geopolitical shifts will determine whether Kazakhstan can sustain its delicate balance in a world increasingly divided by strategic competition.

Works Cited

Allison, R. (2023). Russian power and Central Asian sovereignty. International Affairs, 99(2), 331–349.

BBC News. (2022). Kazakhstan refuses to recognize separatist republics in Ukraine. Retrieved from https://www.bbc.com/news/world-asia

Blank, S. (2022). Kazakhstan's multivector foreign policy under strain. The Diplomat.

Cooley, A., & Laruelle, M. (2021). The Empire strikes back: Russia and Central Asia after Crimea. Columbia University Press.

Eurasianet. (2023). Kazakhstan's quiet balancing act during the Ukraine war. Retrieved from https://eurasianet.org

European Council on Foreign Relations. (2022). Kazakhstan's foreign policy amid Russia's war. Policy Brief.

Freedom House. (2023). Kazakhstan: Nations in Transit 2023. Retrieved from https://freedomhouse.org

Kassenova, N. (2022). Central Asia and the Ukraine war: Implications for sovereignty. Carnegie Endowment for International Peace.

Ministry of Foreign Affairs of the Republic of Kazakhstan. (2023). Foreign Policy Concept of the Republic of Kazakhstan 2023–2029. Astana.

Putz, C. (2022). Kazakhstan's response to Russia's invasion of Ukraine. The Diplomat.
Reuters. (2022). Kazakhstan diversifies trade routes amid sanctions on Russia. Retrieved from https://www.reuters.com

Stronski, P. (2023). Kazakhstan's geopolitical balancing act. Carnegie Endowment for International Peace.

Tokayev, K.-J. (2022). Speech at the St. Petersburg International Economic Forum. President of the Republic of Kazakhstan.

Trenin, D. (2023). Russia and Central Asia: A changing relationship. Russia in Global Affairs, 21(1), 77–95.

UN News. (2022). Kazakhstan calls for peaceful resolution in Ukraine. Retrieved from https://news.un.org

World Bank. (2023). Kazakhstan Economic Update: Navigating global uncertainty. Washington, DC.

Artificial Intelligence in Financial Markets: Global Trends, Ethical Implications, and the Future of Data-Driven Investment

By Diana Abdrakhim

Abstract

The integration of artificial intelligence into financial markets marks a defining shift in the way investment strategies, risk assessment, and market forecasting are conducted. Machine learning, natural language processing, and data analytics have transformed decision-making processes once guided by human intuition into algorithmic precision. This paper explores the evolution of AI in finance, its global applications, and the ethical and regulatory challenges associated with automation. Case studies from the United States, Europe, and emerging economies illustrate how AI reshapes investment behavior and financial stability. The study concludes that while AI enhances efficiency and market insight, its reliance on opaque algorithms raises concerns about fairness, accountability, and systemic risk in global finance.

1. Introduction

Artificial intelligence has emerged as one of the most disruptive technologies in the global economy. Within financial markets, its influence is profound, redefining the structure of trading, asset management, and risk analysis. For decades, financial systems relied on human analysts, statistical models, and historical data to forecast prices and manage portfolios. However, the exponential growth of data and computational power has outpaced traditional analytical methods. AI-driven systems now process massive datasets in real time, detect patterns beyond human capability, and execute trades with unmatched speed and precision.

Financial institutions across the world have adopted AI not only to enhance profits but also to manage complex systems that govern global capital flows. Investment banks employ AI for automated trading, hedge funds use predictive algorithms for portfolio management, and insurance firms rely on machine learning to optimize risk evaluation. These developments are transforming how financial decisions are made, often replacing human judgment with algorithmic models.

At the same time, the growing influence of AI introduces critical questions about transparency, ethics, and regulation. Automated trading systems can amplify market volatility, and opaque algorithms may reinforce biases embedded in financial data. This paper examines how AI's role in financial markets continues to expand, highlighting both the technological opportunities and the ethical challenges that accompany data-driven finance.

2. The Evolution of AI in Financial Markets

The application of computational models in finance began in the 1970s, when early forms of algorithmic trading emerged on Wall Street. These systems relied on simple statistical relationships and fixed rules for executing trades. The rise of high-frequency trading in the 1990s represented the first major wave of automation, allowing traders to capitalize on

millisecond-level price differences. However, these algorithms lacked adaptability and often failed during periods of market instability.

The introduction of machine learning in the early 2000s marked a turning point. Unlike rule-based algorithms, machine learning models could learn from historical data and adapt to changing market conditions. Neural networks, regression trees, and reinforcement learning models enabled more sophisticated predictions of price movements and volatility patterns. Major financial institutions began integrating AI into risk management and fraud detection, marking the beginning of the era of intelligent finance.

Recent advancements in deep learning and natural language processing have further accelerated this transformation. Modern AI systems can interpret unstructured data such as news articles, social media sentiment, and even satellite imagery to assess market conditions. Tools like sentiment analysis and alternative data processing provide investors with nuanced insights that were previously inaccessible. This evolution has blurred the line between traditional financial analysis and data science, creating an interdisciplinary field that demands both economic and technological expertise.

3. Applications of AI in Modern Finance

AI has become a cornerstone of quantitative finance, where mathematical modeling and statistical inference are used to make trading decisions. Algorithmic trading platforms execute millions of transactions per day, guided by predictive models that analyze price movements and liquidity. These systems reduce human error, increase execution speed, and exploit small but consistent market inefficiencies.

Another critical application is portfolio management. Robo-advisors, such as Betterment and Wealthfront, use AI algorithms to design personalized investment strategies based on individual risk preferences and market forecasts. These systems democratize access to professional investment advice by offering low-cost, automated financial planning to millions of users.

AI also plays an increasingly important role in risk assessment and fraud detection. Financial institutions deploy anomaly detection algorithms to identify irregular transactions and potential cyber threats. Machine learning systems continuously adapt to new patterns of fraudulent behavior, strengthening the resilience of global financial systems. The integration of AI in these areas demonstrates its potential not only as a profit-generating tool but also as a mechanism for promoting market integrity and security.

4. Global Case Studies and Comparative Insights

The United States remains a leader in AI-driven finance, with firms like JPMorgan Chase, Goldman Sachs, and Citadel employing advanced algorithms for both trading and compliance monitoring. American regulatory bodies, such as the Securities and Exchange Commission (SEC), are also exploring the use of AI to detect insider trading and market

manipulation. Universities and research institutions collaborate with financial firms to develop ethical frameworks for algorithmic transparency and accountability.

In Europe, financial innovation is guided by a more cautious and regulatory-driven approach. The European Union's General Data Protection Regulation (GDPR) has influenced how AI systems manage data privacy and user consent. The European Central Bank encourages the responsible use of machine learning while emphasizing model explainability and auditability. Fintech hubs such as London and Frankfurt are pioneering the development of interpretable AI for sustainable finance and environmental, social, and governance (ESG) investments.

Emerging markets, including Kazakhstan, are beginning to adopt AI technologies in banking and investment sectors. Kazakhstan's financial institutions are implementing predictive analytics for credit scoring and automated decision systems for investment portfolios. Government initiatives under the "Digital Kazakhstan" program aim to strengthen data infrastructure and support AI research in financial technology. These developments signal the country's intention to integrate into the global AI economy while ensuring transparency and accountability.

5. Ethical, Economic, and Regulatory Considerations

The rise of AI in financial markets presents not only technological innovation but also significant ethical challenges. One major concern is algorithmic bias, which occurs when machine learning models trained on historical data inadvertently reinforce discriminatory patterns. For example, biased datasets can lead to unfair lending decisions or unequal access to credit. Addressing these issues requires transparent data governance and regular algorithmic audits to ensure fairness and inclusivity.

Economic stability is another critical concern. Automated trading systems, while efficient, can contribute to market volatility. Flash crashes, which are sudden and severe market drops caused by algorithmic interactions, have occurred several times in the past decade. Regulators are increasingly focused on developing circuit breakers and monitoring tools to mitigate systemic risks associated with AI-driven trading.

Regulatory frameworks differ significantly across regions. The United States emphasizes innovation and competitiveness, whereas Europe prioritizes ethical compliance and consumer protection. Kazakhstan, still developing its regulatory capacity, can benefit from adopting international best practices. Policymakers must balance the need for innovation with the imperative of maintaining market stability and ethical integrity. Establishing global standards for algorithmic transparency and accountability remains a central challenge in the evolving landscape of AI finance.

6. Discussion

Artificial intelligence is reshaping the foundations of financial markets in ways that extend beyond automation. It represents a paradigm shift toward predictive and self-learning systems that continuously improve with exposure to new data. This transformation, however,

raises questions about human oversight and professional accountability. As algorithms become more autonomous, ensuring that financial decision-making aligns with human values becomes increasingly important.

The integration of AI also has social implications. While it enhances efficiency and expands access to financial services, it may also concentrate power in the hands of technologically advanced institutions. Smaller firms and developing economies could find themselves at a disadvantage without sufficient access to data and computational infrastructure. Therefore, equitable access to AI technologies is essential for preventing global financial inequality.

Future research and policy should focus on building hybrid models that combine human judgment with machine learning insights. Ethical AI design, interdisciplinary education, and cross-border regulatory cooperation are essential to ensure that artificial intelligence serves as a tool for inclusive and sustainable financial growth. The challenge is not merely technological but philosophical, balancing innovation with fairness, speed with stability, and intelligence with ethics.

7. Conclusion

The application of artificial intelligence in financial markets is transforming how economies function and how wealth is managed. From algorithmic trading to risk management, AI has introduced precision, speed, and adaptability on an unprecedented scale. Yet, its growing influence demands careful ethical consideration and international collaboration. The United States, Europe, and emerging economies like Kazakhstan each offer distinct models of innovation and governance. Together, they illustrate that the future of finance depends not only on technological advancement but also on humanity’s capacity to use intelligence responsibly.

Works Cited

Brynjolfsson, E., & McAfee, A. (2017). Machine, platform, crowd: Harnessing our digital future. W. W. Norton & Company.

Chakraborty, C., & Joseph, A. (2017). Machine learning at central banks. Bank of England Working Paper Series

Chen, Y., Huang, A., & Zhu, Y. (2021). Artificial intelligence in financial risk management. Journal of Risk and Financial Management, 14(11), 518.

Dastile, X., Celik, T., & Potsane, M. (2020). Statistical and machine learning models in credit scoring. Expert Systems with Applications, 139, 112–117.

European Central Bank. (2022). Artificial intelligence and the future of financial supervision.

Goodfellow, I., Bengio, Y., & Courville, A. (2016). Deep learning. MIT Press.

Kirilenko, A., & Lo, A. W. (2013). Moore's law versus Murphy's law: Algorithmic trading and its discontents. Journal of Economic Perspectives, 27(2), 51–72.

Kozhakhmetov, A., & Ibrayeva, N. (2022). AI integration in Kazakhstan's financial institutions: Progress and prospects. Central Asian Journal of Economics and Finance, 8(2), 45–61.

LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. Nature, 521(7553), 436–444.

Lin, T., Guo, T., & Hu, X. (2022). Predictive modeling for algorithmic trading: A machine learning perspective. Finance Research Letters, 48, 102–119.

Lo, A. W. (2019). Adaptive markets and the future of finance. Journal of Portfolio Management, 45(5), 18–32.

Nakamura, T., & Wong, J. (2021). The rise of robo-advisors in global finance. International Journal of Financial Studies, 9(4), 61.

Nguyen, Q., & Pham, D. (2022). AI ethics in financial markets: Challenges and recommendations. Journal of Business Ethics, 180(3), 595–610.

OECD. (2023). Artificial intelligence, data, and financial markets: Policy implications.

Russell, S., & Norvig, P. (2021). Artificial intelligence: A modern approach (4th ed.). Pearson.

Schwartz, E., & Wiggins, R. (2020). AI in asset management: Machine learning and portfolio optimization. Journal of Finance and Data Science, 6(2), 45–63.

Securities and Exchange Commission (SEC). (2023). AI and market integrity: Regulatory perspectives.

Shiller, R. (2019). Narrative economics: How stories go viral and drive major economic events. Princeton University Press.

World Economic Forum. (2022). Artificial intelligence and the future of financial systems.

Zhang, L., & Chen, S. (2020). Machine learning in algorithmic trading: A survey. IEEE Access, 8, 144–168.

Zuboff, S. (2019). The age of surveillance capitalism: The fight for a human future at the new frontier of power.PublicAffairs.

Sustainable Fashion and Cultural Innovation:
Transforming Old Clothing into "Korpe" as a National Product of Kazakhstan
By Aidana Kobentai

Abstract

The global fashion industry faces an unprecedented sustainability crisis as overproduction, fast fashion, and textile waste threaten environmental balance. In response, many nations are exploring creative recycling practices that combine environmental awareness with cultural expression. This paper examines how Kazakhstan can transform old clothing through the traditional craft of making korpe, a handmade quilt deeply embedded in Kazakh culture. By merging modern sustainability principles with national heritage, korpe-making can evolve into a sustainable business model that promotes local craftsmanship, reduces waste, and strengthens cultural identity. This research analyzes global upcycling trends, Kazakhstan's textile industry, and the economic potential of korpe as a national product and symbol of ecological responsibility.

1. Introduction

The fashion industry is one of the largest and most resource-intensive sectors in the world, responsible for approximately 10 percent of global carbon emissions and 20 percent of wastewater production. With millions of tons of textile waste discarded annually, the urgent need for sustainable alternatives has inspired innovations in recycling and upcycling. In recent years, creative entrepreneurs and designers have begun transforming old clothing into new products that merge artistic expression with environmental responsibility.

Kazakhstan, with its rich cultural heritage and growing interest in sustainability, is uniquely positioned to develop eco-friendly fashion solutions rooted in traditional crafts. One promising idea is the transformation of old clothing into korpe, a handmade quilt that has been part of Kazakh domestic life for centuries. Korpe-making, historically passed down through generations of women artisans, represents warmth, creativity, and cultural continuity. Reimagining it through the lens of sustainability allows for a unique fusion of tradition and modern ecological awareness.

This paper explores the potential of creating korpe as a national sustainable product by collecting and recycling old textiles. It argues that such an initiative can strengthen Kazakhstan's cultural industries, empower local artisans, and align with global efforts toward a circular economy in fashion. Through analysis of international sustainability practices and domestic opportunities, the study highlights how Kazakhstan can position itself as a leader in ethical and cultural fashion innovation.

2. Background and Global Context

Globally, the problem of textile waste has become critical. According to the Ellen MacArthur Foundation (2021), every second, the equivalent of one garbage truck of textiles is

landfilled or incinerated worldwide. The rise of fast fashion has accelerated consumption patterns, encouraging short-term trends and rapid disposal. This model has led to social and environmental costs, including low wages in developing countries, overuse of water resources, and the release of microplastics into oceans.

In response, the sustainable fashion movement has gained significant momentum. Brands in Europe and North America are increasingly incorporating recycled fibers, ethical production methods, and circular design systems. Examples include Patagonia's clothing repair programs, Stella McCartney's use of eco-friendly materials, and H&M's "Garment Collecting Initiative." These strategies reflect a shift toward rethinking production and consumption cycles.
The concept of upcycling, transforming waste materials into higher-value products, has become central to this movement. Upcycling not only reduces environmental harm but also fosters creativity and local craftsmanship. By adapting global principles of upcycling to traditional crafts like korpe-making, Kazakhstan can align with sustainable development goals while promoting its own cultural heritage.

3. Kazakhstan's Cultural Heritage and the Role of Korpe

Korpe holds a special place in Kazakh cultural and domestic life. Traditionally, korpe are handmade quilts created from colorful fabrics, symbolizing warmth, hospitality, and artistic skill. They have been used in homes, yurts, and ceremonial contexts for centuries. Each korpe design reflects regional patterns, family traditions, and the creativity of the maker. Beyond their practical function, korpe embodies the essence of Kazakh identity and community connection. Historically, korpe were made from leftover textiles, repurposed garments, or donated fabrics. This reflects an early form of sustainability long before the concept was formally defined. The reuse of materials not only saved resources but also carried emotional meaning, as each piece of fabric preserved memories of past events or family members. Thus, korpe-making has always been both an ecological and a sentimental act.

Today, korpe remains a symbol of cultural continuity. However, modern industrialization and mass-produced textiles have reduced the prevalence of handmade korpe in daily life. Reviving this tradition through sustainable fashion initiatives could reintroduce korpe-making as both an environmental solution and a national brand of cultural craftsmanship.

4. Innovation in Sustainable Design: From Textile Recycling to Cultural Entrepreneurship

Transforming old clothing into korpe represents a form of cultural upcycling that merges environmental sustainability with artistic innovation. The process begins with the collection of used garments from communities, charities, or donation centers. These textiles are sorted, cleaned, and categorized by material type and color. Skilled artisans then cut, layer, and sew the fabrics into korpe using traditional patterns, embroidery, and patchwork techniques. The result is a functional and artistic product that embodies both modern sustainability and national heritage. Entrepreneurs can create small-scale businesses or cooperatives focused on korpe-making. Such enterprises would support women artisans, local designers, and young entrepreneurs interested in

sustainable fashion. Collaboration with universities and art schools could also foster innovation in design and marketing, combining modern aesthetics with traditional motifs.

By framing korpe as a symbol of environmental responsibility and cultural pride, Kazakhstan can establish a new market niche for ethically made products. This aligns with global consumer trends that increasingly value authenticity, sustainability, and craftsmanship over mass production.

5. Business Model and Market Potential

The market potential for sustainable textiles and handcrafted goods is expanding rapidly. According to Statista (2023), the global ethical fashion market is expected to surpass 10 billion USD by 2026, driven by consumer demand for environmentally responsible products. Kazakhstan's korpe-making industry could capitalize on this trend by combining sustainability with cultural branding. A feasible business model would involve community-based production supported by public-private partnerships. Local governments could provide microgrants or tax incentives for businesses engaged in textile recycling and artisanal manufacturing. The private sector could contribute through marketing, logistics, and export promotion. Non-governmental organizations focused on environmental and women's empowerment could help facilitate training programs and quality certification.

In the international market, korpe could appeal to eco-conscious consumers and collectors of cultural crafts. Branding korpe as a "Kazakh Sustainable Heritage Product" could enhance global recognition of Kazakhstan's creative industries. Moreover, korpe production has potential for tourism integration, where workshops and exhibitions promote both culture and sustainability.

6. Social and Environmental Impact

The korpe initiative offers significant environmental and social benefits. From an ecological standpoint, textile recycling reduces waste, conserves resources, and lowers carbon emissions. Reusing fabrics extends the life cycle of materials that would otherwise contribute to pollution. This supports Kazakhstan's broader goals under the United Nations Sustainable Development Goals, particularly Goal 12 on Responsible Consumption and Production. Socially, korpe-making provides employment opportunities for rural women, artisans, and small business owners. It revives traditional skills and encourages intergenerational knowledge exchange. Empowering communities through creative work strengthens cultural cohesion while contributing to economic independence. In addition, korpe-making programs can promote social inclusion by engaging marginalized groups in meaningful and sustainable labor.

By merging sustainability with social entrepreneurship, the korpe project serves as a model for inclusive development. It demonstrates that environmental responsibility and cultural heritage can coexist as pillars of innovation and community resilience.

7. Discussion

The integration of sustainable fashion and traditional craftsmanship reflects a growing recognition that cultural heritage can play a vital role in addressing global environmental challenges. Kazakhstan's korpe-making tradition offers a tangible pathway for achieving this integration. By transforming old clothing into new cultural products, the nation can reduce textile waste, create jobs, and strengthen its creative economy.

However, successful implementation requires coordinated policy and infrastructure support. Government agencies must prioritize waste management systems that facilitate textile collection and recycling. Education programs in design, business, and sustainability are also essential to prepare young professionals for roles in green industries. Partnerships with international organizations can further enhance visibility and credibility in global markets. Ultimately, the korpe initiative represents more than a recycling project. It is a vision of cultural renewal and sustainable identity. By embedding environmental awareness into a deeply rooted national tradition, Kazakhstan can present itself as a global example of how heritage and innovation can work together to build a more sustainable future.

8. Conclusion

Transforming old clothing into korpe as a national product exemplifies the harmony between tradition and innovation. This initiative combines the values of sustainability, creativity, and cultural continuity while addressing the urgent problem of textile waste. Through korpe-making, Kazakhstan can strengthen its identity in the global creative economy, promote ethical fashion, and inspire new generations to value both environmental responsibility and cultural pride. The future of sustainable fashion lies not only in technology but also in rediscovering the wisdom of traditional crafts that honor both people and the planet.

Works Cited

1.Ellen MacArthur Foundation. (2021). A new textiles economy: Redesigning fashion's future.

2.Fashion Revolution. (2022). The state of sustainable fashion 2022.

3.Kazakh Ministry of Culture and Sports. (2022). Cultural heritage and creative industries development program. Astana.

4.Kazakh National Museum. (2023). The art of korpe-making in Kazakh tradition. Exhibition guide.

5.Niinimäki, K. (2020). Sustainable fashion in a circular economy. Routledge.

6.Statista. (2023). Ethical fashion market report.

7.UNESCO. (2021). Cultural heritage and sustainable development. Paris: UNESCO Publishing.

8.United Nations. (2023). Sustainable Development Goals Report. Geneva: United Nations.

9.World Bank. (2022). Kazakhstan: Green economy transition strategy. Washington, DC.

10.World Economic Forum. (2023). Circular fashion and the future of sustainability. Geneva: WEF.

The Impact of Oil Production on Government Spending and Well-Being of Residents: Evidence from Saudi Arabia By Faaz Ali

I would like to extend my thanks to Professor Hammad Shaikh for his guidance in this project and his support throughout. I would also like to thank my father for the inspiration for this topic.

Abstract

This study looks at how the reductions in production by OPEC + affect indicators in the Middle East, such as inflation, fiscal spending, and well-being, focusing on Saudi Arabia. The study starts by performing a literature review on oil price volatility and how it affects economic behavior and household consumption, as well as macroeconomic stability. The analysis in this report uses data from 2012 to 2024, including crude oil output values, government spending, movements of price, and CPI trends in Saudi Arabia. This data was analyzed using regression analysis to see how changes in Saudi Arabia's oil production levels and the fiscal decisions by OPEC+ are shaping Saudi Arabia's internal economy. This is done by incorporating time-series analysis and several regression models, which include quarterly and monthly estimates. This is done so that the causal pathways can be isolated to see the effect of oil output on different macroeconomic indicators. Results showed that there is a link between oil revenue in Saudi Arabia and their fiscal decision making. Quantitatively, it is shown that every additional thousand barrels of oil per day is linked to an additional 22 million SAR in government spending. I also look at how changes in oil prices affect Saudi Arabia's long-term plans for economic diversification and fiscal policy. The findings show that although oil revenue remains integral to Saudi Arabia's fiscal stability, they do not mean that the population will have a sense of well-being and happiness, suggesting that diversification under Vision 2030 is going to be extremely important.

Keywords Oil Production, Oil Price, Happiness, and Government Spending

Introduction

OPEC+ (a group that consists of nations that control the largest oil reserves) is responsible for around 71. 5% of the world's crude oil. (A. Ganti) And within this group, Saudi Arabia plays a large role as its oil alone is responsible for around 42% of its GDP, which shows how influential Saudi Arabia is within OPEC+, as well as other oil markets around the world. (The Growth Lab) Large changes to oil prices are known to have large effects on the economies of oil-reliant countries, including inflation rates and prices for consumers. OPEC+'s production deals are important in order for us to understand macroeconomic patterns and how member countries achieve stability. Because of the volatility in global oil markets, large shifts in production can cause extreme price shocks, which in turn affect government budgets. This shows again how OPEC+'s management of the supply and demand of oil is one of the most important

factors of economic stability for countries that are reliant on oil. Periods of high fluctuation, including the 2020 pandemic and the 2014 collapse of oil prices, show the vulnerability of oil exporters due to the volatility of oil prices.

The purpose of this study is to see how OPEC+ reductions can influence the spending by the government of Saudi Arabia, their CPI, and their happiness levels. The data used is from 2012 to 2024, such as production levels in Saudi, OPEC output, oil prices, government spending, consumer prices, and happiness index values. By combining these variables using linear regression, a good understanding of how OPEC+ influenced price movements for oil affects Saudi's economic conditions can be formed. Since multiple indicators were included, the interconnected nature of oil markets with economies can be seen. For example, an increase in oil production might be beneficial for a government in the short term, but might place pressure on consumer prices in the long term. This allows this investigation to isolate the causal effect of OPEC+ decisions on the economic performance of Saudi. This study looks at a time-series analysis to show trends over time to see if production adjustments have a strong correlation or if they are simply due to chance. While most past pieces of literature have focused on global oil price fluctuations in a broader context, few have looked into how OPEC+ decisions specifically impact inflation and government spending within oil-producing economies. This study also expands on existing research by giving an analysis that is region-specific to Saudi Arabia.
The analysis finds that oil production in Saudi Arabia is strongly and positively correlated with government spending, with statistically significant results showing that an increase of 1,000 barrels per day in production is associated with approximately 22 million Saudi Riyals of additional government spending. Also, there is very little relationship between oil production and Saudi Arabia's happiness scores, suggesting that oil production has a very small practical impact on reported happiness levels. Lastly, the results show that oil production is strongly associated with increases in the Consumer Price Index (CPI), pointing to inflationary pressures that may be caused by rising levels of production.

Following this, section 2 discusses OPEC+ trends in oil production and its significance. In Section 3, the associated literature is discussed. Finally, section 4 shows the sources of data used and the related statistics. Section 5 discusses the empirical framework, and the results are discussed in Section 6. Finally, section 7 discusses the conclusion and future research.

Institutional Background

For several years, OPEC+ has made deliberate and careful decisions in order to regulate the oil market, often through production cuts to control oil prices from fluctuating too much. Currently, OPEC+ has reduced production by about 5.86 million barrels a day, making up nearly 5. 7% of global demand (A. Ghadda). The intention behind these cuts is to avoid saturating the market with too much supply while still making sure that prices stay at a level that supports countries that are oil-dependent, most of which OPEC+ is made up of. Saudi Arabia, being one of the most dominant members in OPEC+, has had a heavy hand in these policy shifts, reinforcing its influence over the oil market. To have an economy less dependent on oil, Saudi

Arabia introduced their Vision 2030: a long-term economic plan that will aim to increase exposure to other industries such as tourism, entertainment, and technology (Vision 2030). According to the International Monetary Fund (IMF), the country's non-oil economic sector has picked up the pace since 2021, with an average growth of 4. 8% in 2022. (M. Villafuerte) However, oil remains the most dominant factor in Saudi Arabia's economy, speaking to the results of OPEC+'s oil production decisions affecting the country's fiscal future.

Oil prices, despite OPEC+'s best efforts to stabilize them through production cuts and other forms of intervention, still often fluctuate due to factors out of their control, such as the demand and production of other non-OPEC+ countries. Right now predictions suggest that the global oil supply will exceed the current demand by an average of around 1.2 million barrels a day. This would push down prices from an average of $80 a barrel of Brent crude oil currently to $73 in 2025 and then $72 in 2026. (Petrol and food prices will fall thanks to oil glut, says World Bank | Economics | The Guardian) On the other hand, though, oil-importing countries could actually benefit from these reduced oil costs, as it leads to lower energy costs. The strategies of production by OPEC+ can interact with market conditions, complicating oil supply management. On top of this, there is a lot of uncertainty in the Middle East geopolitically, which makes forecasting for oil prices even harder. There are not many studies to show how oil production has effects on consumer prices and happiness in places like Saudi which depend on oil, even though OPEC+ policies are known to influence global oil prices and inflation. Saudi is pursuing Vision 2030, looking to diversify its economy. This makes it very important to see how its dependency on oil affects its policies, seeing how necessary these changes are.

Literature Review

There exists work that investigates how oil production and oil revenues are able to influence government spending in nations that rely on oil exports. (Arezki) provides evidence empirically that oil windfalls increase government consumption and investment. Their findings show that there is a link between increases in oil revenue and increased fiscal spending, which is especially visible in countries with strong institutions. (Villafuerte) looks at fiscal behavior during the oil cycle in the 2000s, seeing that many oil-exporting countries increased their spending greatly during booms in oil prices. They also looked at how this increase in spending led to vulnerability when oil prices ended up falling. (Mehrara) sees that there is an asymmetric effect with this changing spending. When governments spend more due to rises in oil prices, they do not reduce this spending in a similar way when oil prices fall, causing long-term imbalances. (Arouri) looks at this from a policy standpoint, showing that these countries often do not have the frameworks to enforce fiscal policies that counteract these oil cycles, often getting stuck with the previous imbalances in spending. As a result of all of these investigations, it is easy to see how these countries are exposed to global fluctuations in oil prices, and there is a high level of fiscal risk from changing fiscal policies depending on oil prices. These investigations are very relevant to Saudi Arabia, since they fit the context of oil-exporting countries that have fiscal policies that historically move with cycles in oil prices. However, there

are fewer studies that examine how these decisions in fiscal policy affect aspects such as well-being.

The effect of prices on inflation and macroeconomic stability

The general findings show that oil fluctuations are more than just increases in costs for energy, but also influence the price levels of many goods and the stability of entire currencies. This shows that oil prices are known to be a very important force for shaping many different macroeconomic trends. (Ahmed) looks at how oil prices have a strong relationship to inflation, which is especially relevant during times of global economic disruption. He shows that when oil prices go up, the costs of production and transportation follow, since energy itself becomes more expensive. This makes companies increase their prices to maintain profit margins, causing consumer inflation. (European Central Bank) shows the macroeconomic responses to changing oil prices are different depending on the time and the economic regime. In some economic regimes, inflation reacts very strongly to oil price shocks, whereas in others the reaction isn't as bad, showing how important different policy frameworks are to managing inflation. (Mustafayev) shows that oil-rich countries such as Azerbaijan only have inflation due to oil price increases in the short term. It shows how the budget controls by the government and exchange-rate policy can help to stabilize this inflation due to volatility in the market. (Upadhyaya) looks at how inflation rates are not the only variable affected by oil prices, but also exchange rates and GDP in different countries within Eastern Europe. Countries that did not have strong fiscal buffers felt the effects much more and for longer periods of time. Oil prices are a very powerful part of molding macroeconomics and a country's performance, especially when the country itself is heavily reliant on oil and doesn't have much economic diversity.

The emerging literature on the link between oil wealth and subjective well-being in rentier states such as Saudi Arabia

Recent literature shows how researchers are looking at how oil revenue for a country can affect the well-being of its people. Revenue from oil can provide money for a country to create very generous welfare programs and public services. This literature indicates that oil wealth might not always lead to an increase in happiness for its residents. (S. Hertog) investigates how, when institutions are funded by oil revenue, this can lead to a reduction in entrepreneurship and engagement from the people. In Saudi Arabia, there is a feeling of 'economic passivity' for its citizens, showing that even though its citizens might have material things, they do not have the drive to create innovations and start businesses, and the reduction in satisfaction from this is linked to a reduction in happiness. Later, (S. Hertog) discusses the 'rentier mentality' in different Gulf countries, where there is even an expectation that the state will give benefits, further reducing innovation and economic participation. Even in economies like Saudi Arabia or the UAE, wealth can actually lead to a reduction in certain areas of well-being if the wealth is used in a way that replaces personal growth or satisfaction through work.

Contributions of this paper to the literature

This paper contributes to the existing work on this topic in several ways, while much of the previous work on this subject looks at oil shocks and macroeconomic outcomes and has looked at large diversified economies such as the US or Eastern Europe, my analysis looks specifically at Saudi Arabia, which is one of the most oil-reliant countries. This focus lets me target my understanding of oil production and fiscal and social outcomes very specifically.

Also, the period covered in this paper is a big distinction from other similar work as my study includes data up to 2024, which includes the most recent OPEC+ production cuts and global price fluctuations, and this makes it so it is more reflective of the economy of today. Many other studies only go up to the end of the 2010s or similar, so they do not account for shifts that occurred around the pandemic.

Moreover, this study includes the aspects of well-being measured by national happiness as an economic outcome. Earlier research looked at how macroeconomic factors affect happiness, but few have investigated the link between well-being and oil directly. This adds a social dimension to the investigation, which helps to add the human element to an investigation on economic policy.

To summarize, my study by looking at one specific oil-dependent country and in doing so including data that is not only relevant but also incorporates elements of wellbeing, expands on previous literature and provides new insights into broader impacts of oil production as a whole.

Data

This paper uses a dataset covering information for Saudi Arabia and OPEC+ from the years 2012 to 2024. The dataset includes six important variables: the production of Saudi Arabian oil, OPEC's oil production, Global oil prices, Saudi government spending, Consumer Price Index, and Saudi happiness level. These variables are looked at the monthly, quarterly, and annual time levels and have been taken from reliable sources like the OPEC Monthly Oil Market Report and Saudi Arabian Monetary Authority, the World Happiness Report, and other well-known economic databases.

Oil Production Data

Data for Saudi Arabia's oil production levels as well as OPEC+'s come from OPEC+'s Monthly Oil Market Report, which tracks OPEC's and its members' monthly levels of production. This is important because Saudi Arabia's production figures show its commitment towards OPEC+'s goals, like reductions in output and trading. Also, OPEC+'s production statistics combine the total member states' outputs ,which show each country's international demand and availability. The amount of production does diverge a lot, however, which shows that there are periods of time where there is increased production amongst the states; however, these are organized to fix price imbalances.

Oil Prices and Consumer Prices

The data on monthly oil prices measured in USD per barrel is taken from the U.S. Energy Information Administration and Index Mundi, a reliable platform containing statistics on several countries. The prices are determined by global market forces such as geopolitical factors, economic instability, and government policies. Saudi Arabia's Consumer Price Index figures are from the Saudi Arabian Monetary Authority, which contains data on inflation rates for food, housing, and transport. These CPI levels show periods of price stability, but also inflationary pressures in relation to international oil prices and domestic economic policies, helping us observe the correlation between the two.

Government Spending and Happiness

The government of Saudi Arabia provides its data through the Saudi Ministry of Finance. This provides quarterly data for categories including infrastructure and social services. The level of this spending appears to vary depending on their revenue from oil. The data for happiness comes from the World Happiness Report, who amalgamates happiness data from around the world. The report uses variables like income and life expectancy to give 'happiness scores', which overall show relatively stable levels of life satisfaction in Saudi even when their economic conditions fluctuate. Together, these sets of data provide a foundation on which to study the macroeconomic impacts of OPEC+ production levels on inflation and consumer prices in Saudi Arabia, and therefore the Middle East in general.

Variable	Frequency	Unit	Additional Notes
Government Spending	Quarterly	Millions of Saudi Riyal	Government expenditure on infrastructure
Oil Production Saudi	Monthly	Thousand barrels per day (b/d)	Saudi Arabia's crude oil production
Oil Production OPEC	Monthly	Thousand barrels per day (b/d)	Total crude oil production from OPEC+ members
Happiness Saudi	Annually	Score (0-10)	Based on the World Happiness Report rankings
Oil Price	Monthly	USD per barrel	Average price of crude oil
CPI Saudi	Monthly	Index (base year = varies)	Consumer Price Index for Saudi Arabia

Table 1: Data Dictionary

Table 1 represents the data dictionary, which includes the time frequency, unit of measurement, and a description of each variable in the data set.

Histogram of Outcomes

The histograms of the three main outcome variables were plotted: government spending (Figure 1), happiness (Figure 2), and the Consumer Price Index (CPI) (Figure 3). The spending seen by the government (Figure 1) shows a distribution which is extremely uniform, given that the observations are evenly spread out and there is no clustering. This shows that there is steady government expenditure over the period which was studied.

Distribution of Government Spending

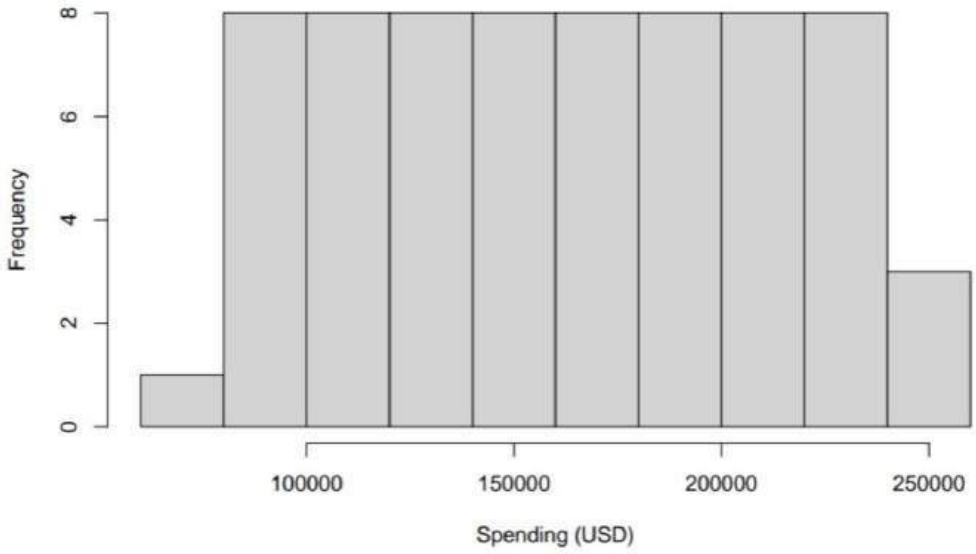


Figure 1: Oil Production and Government Spending

Distribution of Happiness

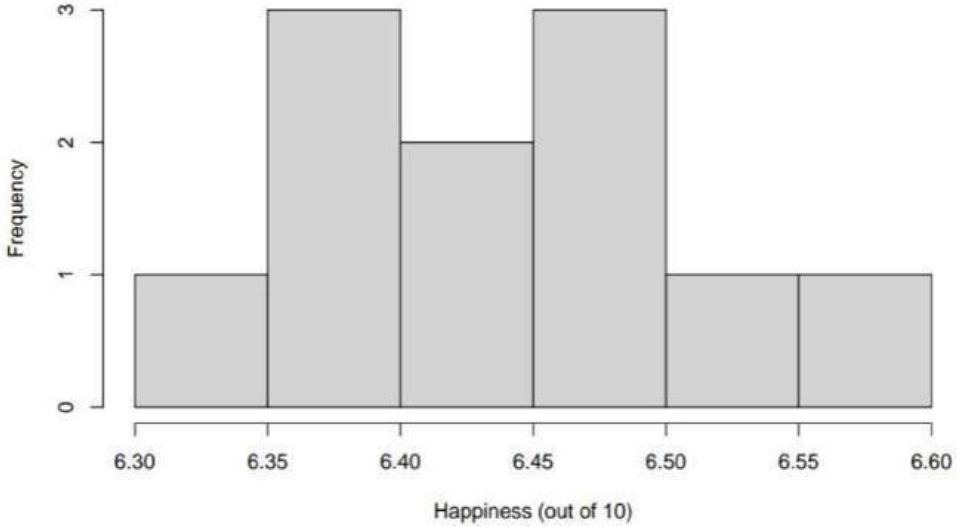


Figure 2: Oil Production and Saudi Happiness

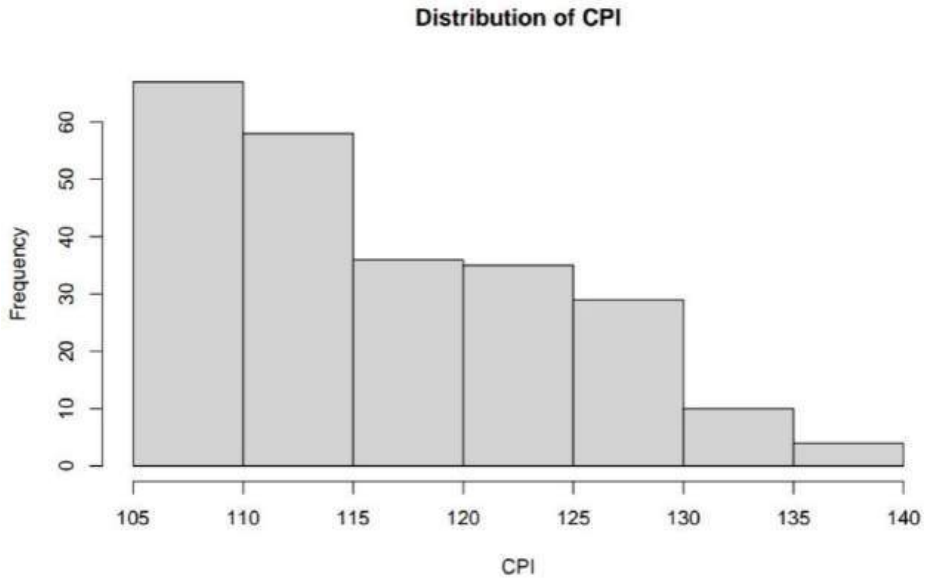


Figure 3: Oil Production and Saudi CPI

On the other hand, the distribution of happiness is slightly skewed to the right, with most values clustering between 6.40 and 6.50. This indicates that the variation is quite limited in reported national happiness scores, which is expected given that happiness is usually a more stable macroeconomic indicator, especially over a short time.

Finally, the distribution of CPI is strongly skewed to the right, with a heavy concentration of values in the lower range (around 105-115), and a long tail extending toward higher values above 130. This shows that there is a gradual increase in consumer prices over time in Saudi Arabia, especially in the later years of the data. The skew is most likely due to periods of inflationary pressure after global oil price volatility adjustments that were made after the pandemic in 2020.

Table 2 shows summary statistics for the monthly data that is used in this analysis. It shows Saudi Arabia's average oil output is approximately $12,101.11$ thousand barrels a day with a standard deviation of around 956.32. The minimum amount of oil produced was 9,326, while their highest was around 13,937, and this shows how OPEC+ quotas and world demand can severely impact Saudi Arabia's production. The average monthly oil production for OPEC itself is $33,171.50$ thousand barrels per day, with oil production amongst its member countries ranging from 29,047 to 37,106 . OPEC+'s standard deviation, however, is pretty high at $1,942.23$, showing the impact of its member states' decisions. Currently, the average oil price is 89.47 USD per barrel; however, it has been priced as low as 56.82 and as high as 144.50 , showing its volatility based on political and economic factors. With an average of 116.28 and a standard deviation of around 8.16, Saudi Arabia's Consumer Price Index shows a range of values from 105.00 to 137.00 , this does fluctuate due to changes in domestic policy as well as fluctuations in world oil prices.

Statistic	N	Mean	St. Dev.	Min	Max
Oil Production (Saudi)	239	12,101.110	956.323	9,326	13,937
Oil Production (OPEC)	239	33,171.500	1,942.229	29,047	37,106
Oil Price	239	89.465	18.792	56.820	144.500
CPI (Saudi)	239	116.280	8.160	105.000	137.000

Table 2: Monthly Data Summary Statistics

Table 3 provides the summary statistics for quarterly data, showing that the quarterly oil production in Saudi Arabia has a mean figure set at 13,690.13 thousand barrels, and the standard deviation figure reaches 2,232.80, showing that oil production varies each quarter, mostly due to adjustments in OPEC+ production, from 10,300 to 17,300. OPEC's oil production averages 38,975.59 thousand barrels per day, implying a further range cap due to production cuts and other policies meant to stabilize global oil prices and achieve an average variance of 6,291.72. Saudi Arabian government expenditure has a mean value of 163,699.30 million Riyals, throughout a wide range from 76,200 to 247,500 due to fiscal policy changes and infrastructure spending under Vision 2030. There is also a suggestion that there are disruptions in global economic conditions alongside increased government spending, meaning recessions or an increase in oil spending is taking place. Also, the data identifies that increased government spending is known to occur alongside extra-high oil prices, hinting at greater reliance on oil revenues for public spending.

Statistic	N	Mean	St. Dev.	Min	Max
Oil Production Saudi	68	13,690.130	2,232.799	10,300	17,300
Oil Production Opec	68	38,975.590	6,291.722	29,200	50,150
Government Spending Saudi	68	163,699.300	49,527.890	76,200	247,500

Table 3: Quarterly Data Summary Statistics

Table 4 shows summary statistics for Saudi Arabia's annual data, showing an oil production average of around 11,620 thousand barrels per day with a standard deviation of 777.14, showing low variability, making the data range from 10,450 to 12,800 barrels, suggesting that there is somewhat stable long-term production despite global market changes. OPEC's production, on the other hand, has a mean of around 32,446.15 thousand barrels a day with a standard deviation of 1399.02, showing stability in production once again. Saudi Arabia's

Happiness Index annually averages 6.44 out of 10 with a small range of 6.34 to 6.59 , showing both low variability and stable life satisfaction. The average happiness ranking is 30.55 for Saudi, with values between 25 and 37. Even though there is economic volatility and reforms, the overall happiness in Saudi is still quite high. This shows that there is a connection between stable production in oil and the happiness levels of the country, indicating the potential for oil prouction aiding increased public well-being.

Statistic	N	Mean	St. Dev.	Min	Max
Oil Production Saudi	13	11,620.770	777.136	10,450	12,800
Oil Production Opec	13	32,446.150	1,399.027	30,150	34,550
Happiness Saudi	11	6.440	0.077	6.344	6.594
World Rank Happiness	11	30.545	4.034	25	37

Table 4: Annual Data Summary Statistics

Empirical Framework

The approach for this examination looks at how production of oil impacts oil prices, Saudi happiness, and Saudi CPI, using different timelines (monthly, quarterly, and yearly) between 2012 and 2024. The models are estimated using Ordinary Least Squares in R with the $lm()$ command.

The regression model below identifies the relationship between oil production and government spending:

$$GovtSpending_t = \alpha_0 + \alpha_1 OilProduction_t + \epsilon_t,$$

Where $GovtSpending_t$ is government spending (millions of Riyals) as the outcome; $OilProduction_t$ is barrels of oil (millions per day) as the policy variable. The time index t represents the quarter. The main coefficient of interest is the slope α_1, reflecting the effect of oil production on government spending.

Oil Production and Happiness

Using the following regression model, the impact of oil production on Saudi's consumer prices is calculated:

$$log(SaudiHappiness_t = \beta_0 + \beta_1 OilProduction_t + \epsilon_t,$$

Where $SaudiHappiness_t$ is Saudi's Happiness on a scale of $1 - 10$ analyzed annually, as the outcome; $OilProduction_t$ is defined identically as discussed above. The time index t

represents the year. The main coefficient of interest is the slope β_t, showing the effect of oil production on Saudi Arabia's happiness. We take the log of Saudi Happiness to ease the interpretation of this coefficient as a percent.

Oil Production and CPI

Using the following regression model, I can calculate the impact of oil production on Saudi's consumer prices:

$$SaudiCPI_t = \gamma_0 + \gamma_1 OilProduction_t + year_t + \epsilon_t$$

Where SaudiCPI $_t$ is Saudi Arabia's consumer price index each month (the outcome), and production is also defined the same as above. The time index t represents the month. This model also controls year-fixed effects year, which are annual shocks to consumer prices that are constant across months. The slope γ_t is the most interesting part of this, showing the effect of oil production on Saudi Arabia's CPI.

Results

The figure below indicates a very strong linear relationship between government spending and oil production in Saudi Arabia (Figure 4). The graph shows how government spending almost perfectly rises with oil production. This makes sense, since economically Saudi relies heavily on oil revenues to fund its public spending, and therefore its fiscal policy would also match this trend. There are also no significant pressures from external forces evident for this observation.

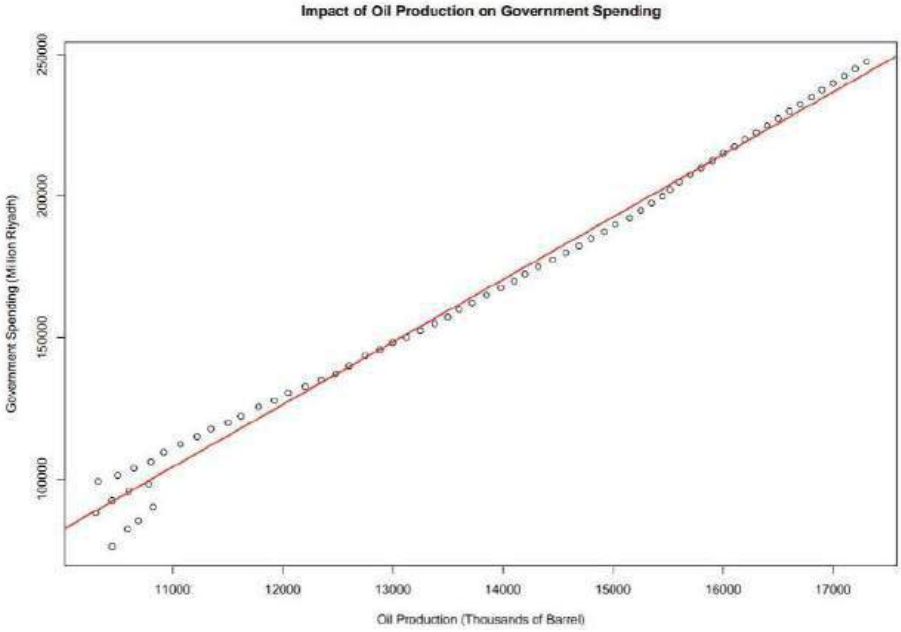


Figure 4: Graph of Oil Production against Government Spending

To quantify the extent to which oil production is linearly associated with government spending, a linear regression model is used. Table 5 presents the results. It's found that increasing oil production by a thousand barrels, on average, increases government spending by around 22 million Saudi Riyals (or 5.9 million USD). The result is statistically significant with a p-value $<$ 0.01.

	Dependent variable:
	Government Spending Saudi
Oil Production Saudi	22.087*** (0.252)
Constant	-138,674.700*** (3,500.246)
Observations	68
R^2	0.991
Adjusted R^2	0.991
Residual Std. Error	4,612.753 ($df = 66$)
F Statistic	7,658.211*** ($df = 1; 66$)
Note:	$^{*}p < 0.1; ^{**}p < 0.05; ^{***}p < 0.01$

Table 5: Oil Production and Government Spending (Quarterly Data)

Next, the relationship between the Happiness of people in Saudi Arabia and the level of oil production in Saudi is examined. Table 6 shows that increasing oil production by 10 million barrels a day, on average, increases happiness by 0.01%. This is a weak positive correlation, and the result is only marginally significant with a p -value < 0.1. Figure 5 confirms the weak positive relationship from the linear regression.

	Dependent variable:
	Log(happiness)
Oil Production Saudi	0.00001* (0.00000)
Constant	1.749*** (0.056)
Observations	11
R^2	0.312
Adjusted R^2	0.235
Residual Std. Error	$0.010 (df = 9)$
F Statistic	4.073* (df = 1; 9)
Note:	$^{*}p < 0.1; ^{**}p < 0.05; ^{***}p < 0.01$

Table 6: Oil Production and Happiness (Annual Data)

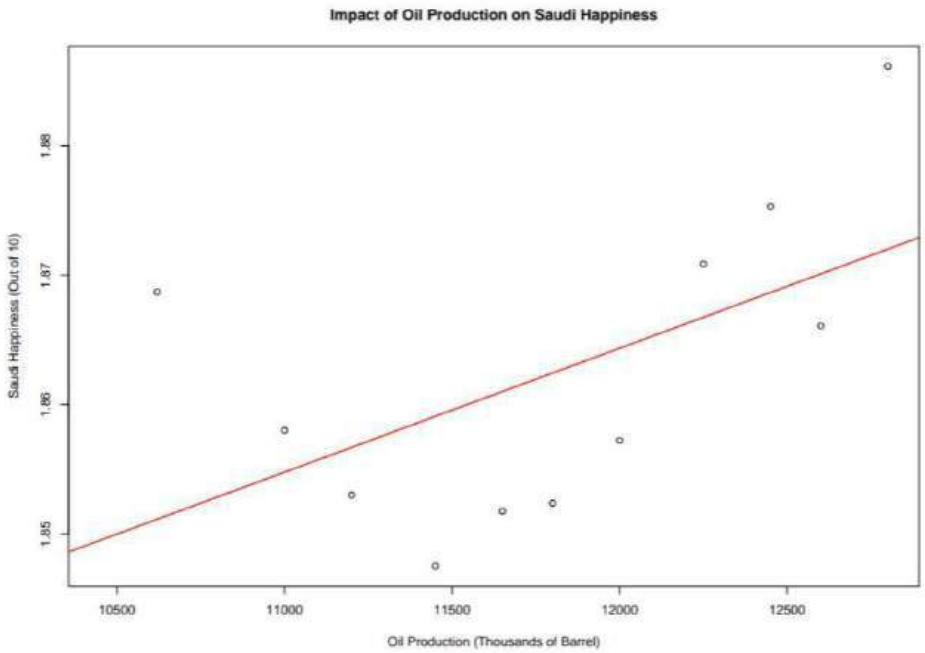


Figure 5: Graph of Oil Production and Saudi Happiness

Then, the relationship between oil production and consumer prices is examined (Figure 6). Table 7 presents the results; it is found that increasing oil production by one million barrels a day, on average, increases the CPI index by 0.003 . This result is statistically significant at the 1% significance level, with a p -value less than 0.01 . This analysis also controls for year-fixed effects (Annual shocks to oil production, such as COVID-19).

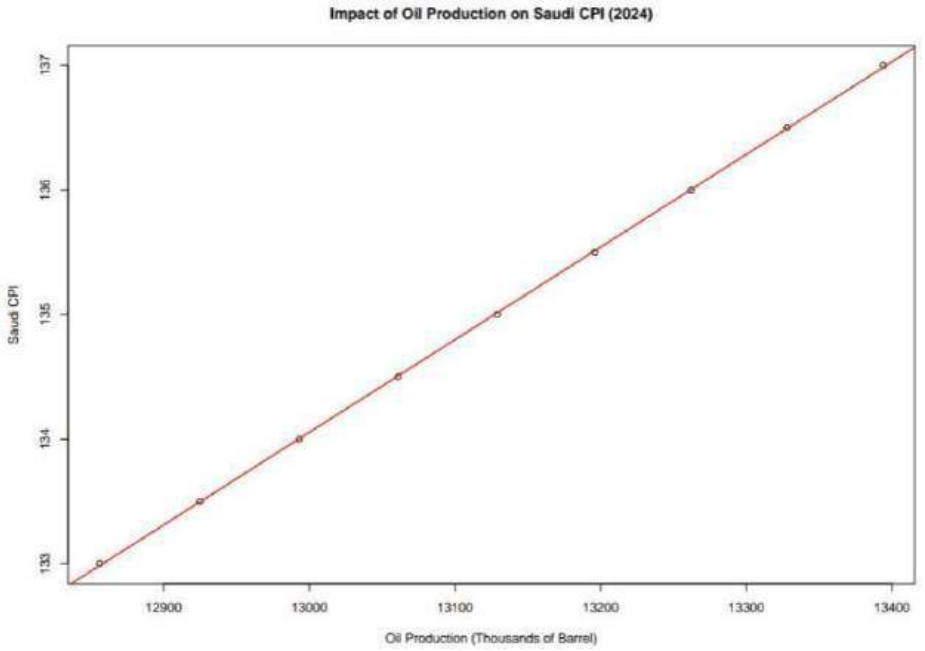


Figure 6: Graph of Oil Production and Saudi CPI

	Dependent variable:
	CPISaudi
OilProductionSaudi	0.003*** (0.0001)
Year)2005	-0.960 (0.581)
Year)2006	-2.234*** (0.614)
Year)2007	-2.568*** (0.648)
Year)2008	-2.580*** (0.682)
Year)2009	-2.163*** (0.710)
Year)2010	-1.587** (0.695)
Year)2011	-2.572*** (0.609)
Year)2012	-2.605*** (0.656)
Year)2013	0.006 (0.641)
Year)2014	0.757 (0.678)
Year)2015	1.590** (0.721)
Year)2016	2.732*** (0.758)
Year)2017	6.333*** (0.647)
Year)2018	12.932*** (0.591)
Year)2019	13.631*** (0.614)
Year)2020	14.229*** (0.648)
Year)2021	14.418*** (0.666)
Year)2022	13.810*** (0.620)
Year)2023	17.564*** (0.667)
Year)2024	20.946*** (0.727)
Constant	80.580*** (1.278)
Observations	239
R^2	0.992
Adjusted R^2	18
Residual Std. Error	$0.753 (df = 217)$
F Statistic	$1,321.137^{***} (df = 21; 217)$

Table 7: Oil Production and CPI (Monthly Data)

Conclusion

This paper looked at the macroeconomic effects of OPEC+ oil production levels for Saudi Arabia's economy, including government spending, well-being, and inflation. Data between 2012 and 2024 was analysed using a linear regression, which showed a strong positive relationship between government spending and oil production. The findings imply that Saudi fiscal policy is dependent on oil revenue within the country. There is a strong correlation as well between oil production and CPI, which suggests that shifts in supply affect inflation. There was no meaningful correlation found between government spending and happiness, which suggests that higher spending by the country does not lead to higher life satisfaction for their people. These results are very relevant for Saudi's Vision 2030, which looks to diversify the economy away from the reliance on oil. Saudi Arabia must change its economic frameworks so that they are less sensitive to fluctuations in price fluctuations, so that they become more economically stable. This would reduce spikes in inflation caused by production changes in oil. Oil revenues are good for the country's short term economic growth, but long-term stability requires strong management of economic volatility due to oil cycles. This would therefore protect citizens from fluctuations in oil prices, which is necessary for sustained well-being. Future research could look at the allocation of oil revenue, such as if money is put into health, education, or the creation of jobs. This would be necessary to see if spending distribution is just as important as total spending value itself on the well-being of Saudi's people.

Works Cited

Ahmed, R., X. H. Chen, C. Kumpamool, and D. T. K. Nguyen. "Inflation, Oil Prices, and Economic Activity in Recent Crisis: Evidence from the UK." Energy Economics, vol. 126, 2023, article 106918. Research Portal Heriot-Watt University, https://researchportal.hw.ac.uk/en/publications/inflation-oil-prices-and-economic-activity-in-recent-crisis-evide.

Arezki, R., and M. Brückner. Oil Windfalls: Blessing or Curse? World Bank Policy Research Working Paper 5210, The World Bank, 2010. https://documents1.worldbank.org/curated/en/536401468771314677/pdf/296570paper.pdf.

Arouri, M. E. H., J. Fouquau, and C. Rault. "Oil Prices and the Fiscal Policy Response in Oil-Exporting Countries." Working Paper 2011-08, College of Business and Economics, UAE University, 2011, pp. 95-96. https://www.uaeu.ac.ae/en/cbe/research/publications/pdf/2011/wp2011_08.pdf.

European Central Bank. Macroeconomic Implications of Oil Price Fluctuations: A Regime-Switching Approach. ECB Working Paper 2119, European Central Bank, 2018. https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2119.en.pdf.

Ganti, A. "How OPEC (and Non-OPEC) Production Affects Oil Prices." Investopedia, 2024, https://www.investopedia.com/articles/investing/012216/how-opec-and-nonopec-production -affects-oil-prices.asp.

Ghaddar, Ahmad, Alex Lawler, and Maha El Dahan. "OPEC+ Extends Deep Oil Production Cuts into 2025." Reuters, 2 June 2024, https://www.reuters.com/business/energy/opec-seen-prolonging-cuts-2024-into-2025-two-so urces-say-2024-06-02.

The Growth Lab at Harvard University. "Industry Diversification and Job Growth in Saudi Arabia." Harvard Kennedy School, 2025, https://growthlab.hks.harvard.edu/applied-research/saudi-arabia.

Hertog, S. Princes, Brokers, and Bureaucrats: Oil and the State in Saudi Arabia. Cornell University Press, 2011. https://www.cornellpress.cornell.edu/book/9780801477515/princes-brokers-and-bureaucrats

Hertog, S. "The Political Economy of Distribution in the Middle East: Is There Scope for a New Social Contract?" Arab Human Development Report Background Paper, United Nations Development Programme, 2017. https://journals.openedition.org/poldev/2270.

Mehrara, M. "The Asymmetric Relationship between Oil Revenues and Economic Growth in Oil-Exporting Countries." Energy Policy, vol. 36, no. 3, 2008, pp. 1164-1168. https://doi.org/10.1016/j.enpol.2007.11.004.

Mustafayev, E., and H. Guliyev. "The Effect of Oil Price and Macroeconomic Factors on Inflation Rate in Azerbaijan." Resources Policy, vol. 89, 2024, article 104311. https://www.sciencedirect.com/science/article/pii/S2590291124003796.

Saudi Arabia Vision 2030. Homepage, https://www.vision2030.gov.sa/ar/.

Upadhyaya, K. P., F. G. Mixon Jr., and H. C. Basnet. "Oil Price Shocks and the Macroeconomy: New Evidence from Eastern Europe." Applied Economics, vol. 57, no. 12, 2025, pp. 1241-1260. https://www.tandfonline.com/doi/full/10.1080/00036846.2025.2467291.

Villafuerte, M., and P. Lopez-Murphy. Fiscal Policy in Oil-Producing Countries during the Recent Oil Price Cycle. IMF Working Paper WP/10/28, International Monetary Fund, 2010. https://www.imf.org/external/pubs/ft/wp/2010/wp1028.pdf.

The Impact of Marital Status, Race, Children, and Income on Rates of Pet Ownership
By Andrew Tang

Abstract

This study investigates how socioeconomic factors—income, marital status, race, and number of children—relate to pet ownership in the United States. Using data from the 2018 General Social Survey (GSS), variables were recorded to produce clearer cross-tabulations for analysis. Findings indicate that income level and number of children have minimal influence on pet ownership, with rates remaining relatively consistent across categories. In contrast, marital status and race show stronger associations: married respondents and White respondents report higher levels of pet ownership compared to other groups. Limitations of the study include broad racial classifications and uneven sample sizes, which constrain the depth of interpretation. Overall, the results emphasize how social structure and cultural context shape contemporary patterns of pet ownership in the United States.

Introduction

Pets are a staple companion to over 66% of the U.S. population. Understanding how pet ownership relates to broader social factors is increasingly important, especially as society becomes more consumerist. The goal of this study is to examine the relationship between socioeconomic factors and pet ownership. In a thesis titled "Pets as Social Symbols," Tadas Cekavicius stated that personal belongings—including pets—can reflect social status, lifestyle, and values. Pets, traditionally seen as companions, are now sometimes used to signal luxury and social standing.

In this study, the goal is to test four hypotheses:

- Individuals with higher household incomes are more likely to own a pet compared to those in lower-income households.
- Marital status influences the likelihood of pet ownership.
- Certain racial groups may have higher or lower rates of pet ownership.
- Having children may affect whether a household owns pets.

For this study, I used the 2018 General Social Survey (GSS) dataset, similar to the approach used in "Examining U.S. Pet Ownership Using the General Social Survey" by Jennifer W. Applebaum. Applebaum notes that the GSS has "several advantages for studying human–animal interaction," making it an effective dataset for testing these hypotheses.

Literature Review

Pet ownership and its relationship to health and socioeconomic status have been researched from numerous different perspectives. Researchers have examined whether or not pet ownership affects emotional well-being and how income, age, and social contact shape that

connection. For instance, in the study "Pet Possession and Well-Being in Elderly Women," questionnaires were used to assess mood in elderly women. The results suggested that pet ownership may benefit emotional well-being.

Across the research, there is a clear consensus that social and economic factors play a significant role in shaping patterns of pet ownership in the studies conducted by researchers. While some studies emphasize emotional well-being, the influence of socioeconomic status appears repeatedly.

The paper published in 2024, “How Is Human Socioeconomic Position Linked With Dog Ownership Practices? A Danish Study,” approached this subject differently by examining other factors, like whether the dog was mixed or purebred. The Denmark study found that higher-income families were more likely to purchase purebred dogs and pay more, while lower-income households favored mixed breeds and cited practical or emotional support reasons for ownership.

Similarly, the study “Allocating Time to People and Pets: Correlates With Income and Well-Being in a Midwest Community Sample,” revealed that income influenced how much time individuals spent with pets, even if the emotional outcomes weren’t always consistent. The study used two composite scales to measure well-being: “WellBeing” and “BadMood.” “WellBeing” combined physical and affective indicators, while “BadMood” was composed of anxiety, depression, fatigue, hostility, and confusion. I found that a major problem in this study was that “BadMood” was composed of too broad topics, particularly with symptoms like fatigue and anxiety. This may have caused certain responses to be incorrectly measured, a clear weakness in the study. The results from these studies suggest that pet ownership is not just a personal choice but one influenced by broader hidden factors like income and education.

Methodology

The objective for each hypothesis will be approached in different ways. For the dependent variable, pet ownership, I first thought to utilize the current pet variables that the GSS 2018 dataset had, including DOG, CAT, FISH, and etc. For each case, if any of the variables were true, then a new variable, called PETOWNERSHIP, would be created. However, this process was somewhat inefficient and ineffective. So instead of combining results from the variables, I decided to use the NUMPETS variable, which has the attributes 0, 1, 2, …, 8 or more, to find out whether each respondent owned a pet. I recorded the variable NUMPETS into a new variable called NUMPETSRec. The attributes of the variable NUMPETS were: No Answer, 0, 1, 2, 3, …, 20 or more. So to emulate a “Do you have a pet, yes or no?” question, I combined the attributes 1–20 or more and created a new attribute named Yes, removed missing values, and then had the 0 attribute be renamed as No.

For CHILDRec, I utilized the same process. The original variable CHILD had similar attributes to NUMPETS, but instead of going up to 20, it went up to 8. Following the same process of recording the variable, I took attributes 1–8 or more and combined them into one attribute called Yes, and renamed 0 as No. I also removed all missing values, meaning that some

data were not included. However, the race variable was a limiting factor for the third hypothesis. It only had attributes for two different named groups in the study: WHITE and BLACK. Other races were combined into the attribute OTHER. Another limiting factor for this variable was that the number of cases in WHITE was almost double the number of cases in BLACK. This shows a potential weakness in the dataset, as it shows a potential misrepresentation in the data. Even with this limitation, it is still possible to observe whether any patterns appear.

For income variables in GSS, a pattern I noticed is that the attributes are in ranges. At first, I chose the INCOME variable; however, the variable had some problems, which were that the ranges were too small. So I looked toward other options and used the variable INCOME16. This variable covered a much larger range up to 170k or more, while INCOME only went up to 25k. Each attribute had a range of one thousand dollars, which grew to 5k. For INCOME16, the variable's attributes covered larger ranges of data exponentially (up to 15k) as income increased. However, there were still a lot of attributes that had extremely small ranges. So like NUMPETSRec, I recorded the variable INCOME16 to have fewer but broader ranges. I made each new attribute have a total range of around 25k, so each attribute would be 0–24k, 25k–50k, etc. However, not all the variables used in the study needed to be recorded. The marital status variable MARITAL was already made to answer the hypothesis well, so no changes were made to the variable.

To observe the potential relationship between the variables, I used a cross-tabulation. In each cell, I included the count and row percentages. To determine the potential relationship between the variables, I checked the row percentages. I found that across all the attributes, the percentage of correlation between the two variables was consistent, and if it wasn't, this suggested a noticeable difference, which means that there is an interesting result to investigate.

Results

1. Are higher-income households more likely to own a pet compared to poorer households?

The income–pet-ownership crosstabulation does not show a clear linear relationship between income and pet ownership. Pet ownership rates remain relatively stable across most income brackets, ranging from approximately 56% to 64%. Although households in the mid-to-upper income categories (50k+) show slightly higher rates of pet ownership (about 62–64%), the differences are modest and do not suggest a strong income effect. The lowest income group shows a notably lower ownership rate (about 52%), but this gap narrows immediately in the next income tier (56.7%). Higher income is associated with slightly higher rates of pet ownership, but the differences are small. Therefore, income is not a dominant predictor of pet ownership from the 2018 GSS dataset (see Fig. 1).

INCOME16REC × NUMPETSRec

			NUMPETSRec		
			NO PET	HAS PET	Total
INCOME16REC	Under 25k	Count	123	132	255
		Row %	48.2%	51.8%	100.0%
	25k - 49k	Count	101	129	230
		Row %	43.9%	56.1%	100.0%
	50k - 74k	Count	70	115	185
		Row %	37.8%	62.2%	100.0%
	75k - 130k	Count	82	145	227
		Row %	36.1%	63.9%	100.0%
	130k OR OVER	Count	58	96	154
		Row %	37.7%	62.3%	100.0%
Total		Count	434	617	1051
		Row %	41.3%	58.7%	100.0%

Fig.1 Cross-tabulation between Income and Pet Ownership

2. Does marital status have any impact on the rate of pet ownership?

The marital-status crosstabulation suggests moderate differences in pet ownership across groups, though the pattern is not strictly linear. Married respondents show the highest rate of pet ownership (67.1%), whereas never-married respondents report the lowest rate (49.6%). Widowed and divorced individuals fall in the mid-range, with ownership levels between 52% and 57%. Married respondents show the highest rate of pet ownership (67.1%), whereas never-married respondents report the lowest rate (49.6%) (See Fig. 2). Marital status shows some relationship with pet ownership. Married individuals are the most likely to own pets, while never-married individuals are the least likely. The differences, however, are smaller than those observed for race, which do not suggest a simple linear pattern across marital categories.

Marital status × NUMPETSRec

			NUMPETSRec		
			NO PET	HAS PET	Total
Marital status	MARRIED	Count	159	325	484
		Row %	32.9%	67.1%	100.0%
		Total %	13.9%	28.4%	42.2%
	WIDOWED	Count	45	49	94
		Row %	47.9%	52.1%	100.0%
		Total %	3.9%	4.3%	8.2%
	DIVORCED	Count	81	106	187
		Row %	43.3%	56.7%	100.0%
		Total %	7.1%	9.2%	16.3%
	SEPARATED	Count	19	27	46
		Row %	41.3%	58.7%	100.0%
		Total %	1.7%	2.4%	4.0%
	NEVER MARRIED	Count	169	166	335
		Row %	50.4%	49.6%	100.0%
		Total %	14.7%	14.5%	29.2%
Total		Count	473	673	1146
		Row %	41.3%	58.7%	100.0%
		Total %	41.3%	58.7%	100.0%

Fig.2 Cross-tabulation between Marital Status and Pet Ownership

3. Are certain races more likely to own pets?

The race–pet-ownership crosstabulation shows substantial differences in pet ownership across racial groups. White respondents exhibit a considerably higher likelihood of owning a pet (67.1%) compared to respondents identified as belonging to the "Other" racial category (36.7%) (See Fig. 3). This amounts to a roughly 30-percentage-point gap, indicating that White respondents are nearly twice as likely as individuals from other racial backgrounds to own pets. This difference is notably larger than the differences observed across income or child-status categories.

RACERec × NUMPETSRec

			NUMPETSRec		
			NO PET	HAS PET	Total
RACERec	WHITE	Count	272	556	828
		Row %	32.9%	67.1%	100.0%
	OTHER	Count	202	117	319
		Row %	63.3%	36.7%	100.0%
Total		Count	474	673	1147
		Row %	41.3%	58.7%	100.0%

Fig.3 Cross-tabulation between Race and Pet Ownership

4. Does owning children have any effect on pet ownership?

The crosstabulation between the number of children and pet ownership does not reveal a consistent or meaningful trend. For households with zero to six children—which comprise the majority of the sample—pet ownership rates remain relatively stable, generally ranging from about 58% to 63% (See Fig. 4). The unusual percentages (up to 80%) for households with seven or more children are based on extremely small sample sizes, which should not be considered reliable indicators of a trend. The number of children in the household does not appear to significantly influence pet ownership. Rates remain consistent across the vast majority of family sizes, suggesting little to no meaningful relationship.

CHILDSREC × NUMPETSRec

			NUMPETSRec		
			NO PET	HAS PET	Total
CHILDSREC	ZERO	Count	149	209	358
		Row %	41.6%	58.4%	100.0%
	ONE	Count	72	90	162
		Row %	44.4%	55.6%	100.0%
	TWO	Count	113	167	280
		Row %	40.4%	59.6%	100.0%
	THREE	Count	79	109	188
		Row %	42.0%	58.0%	100.0%
	FOUR	Count	32	49	81
		Row %	39.5%	60.5%	100.0%
	FIVE	Count	15	25	40
		Row %	37.5%	62.5%	100.0%
	SIX	Count	8	14	22
		Row %	36.4%	63.6%	100.0%
	SEVEN	Count	5	4	9
		Row %	55.6%	44.4%	100.0%
	EIGHT OR MORE	Count	1	5	6
		Row %	16.7%	83.3%	100.0%
Total		Count	474	672	1146
		Row %	41.4%	58.6%	100.0%

Fig. 4 Cross-tabulation between Number of Children and Pet Ownership

Discussion

The findings from this study highlight that not all socioeconomic factors influence pet ownership to the same degree. While income and number of children showed relatively minimal variation in pet ownership rates, marital status and race demonstrated more meaningful differences, suggesting that the decision to own a pet is shaped by social structure and cultural patterns rather than economic capacity alone.

The clearest irregularity was the racial disparity in pet ownership. White respondents reported a 67.1% ownership rate, compared to only 36.7% among Other. This gap was much larger than those seen across income or household-size categories, suggesting that structural and cultural factors may play a more significant role in shaping pet-ownership norms. Prior research noted that structural barriers—such as access to pet-friendly housing, neighborhood restrictions, or cultural attitudes toward pets—can influence who is most likely to own pets.

Marital status also showed a noticeable association with pet ownership. Married individuals reported the highest ownership rate (67.1%), while never-married, widowed, and divorced respondents fell between roughly 49% and 57%. These differences suggest that household structure and lifestyle may play a role in whether people choose to own pets—for example, married households may have more stability or shared responsibility for pet care. However, because the ownership rates across the non-married groups are relatively close to one another, the effect of marital status appears to reflect social and household patterns rather than large economic differences between the groups.

In contrast, income and number of children—factors often assumed to be major influences—did not show strong associations with pet ownership in this dataset. Income-based ownership rates ranged only from about 51.8% (under 25k) to around 63.9% (75–130k), demonstrating relatively small differences across income brackets. Pet ownership remained relatively stable across most income ranges, suggesting that basic pet ownership may not be financially prohibitive for most households. Similarly, the number of children in a household did not meaningfully predict ownership, with households from 0 to 6 children remaining between roughly 58% and 63%. These narrow ranges indicate that income and family size are not major determinants of whether households choose to own pets.

Several limitations in the data should be acknowledged. The racial categories in the dataset were broad, which likely obscured important differences across ethnic groups. Uneven sample sizes across categories—especially in the race and large-family groups—may have also influenced some of the observed percentages. Additionally, because this study used descriptive comparisons rather than multivariate statistical testing, it cannot determine causation or isolate the independent effects of each variable.

Overall, the results suggest that pet ownership in the United States is shaped more by cultural and social identity factors than by economic resources or household size. These findings contribute to ongoing discussions about how pets function within modern society—not only as sources of companionship, but also as elements intertwined with lifestyle, identity, and social context. Future research should explore these relationships using more detailed demographic

breakdowns and statistical methods that can better clarify the relative weight of cultural, structural, and economic influences.

Conclusion

Overall, this study shows that the factors shaping pet ownership in the United States are more closely tied to social and cultural patterns than to purely economic ones. While income and number of children did not display big or meaningful differences in pet-ownership rates, marital status and race showed clearer patterns that suggest deeper structural influences. Married respondents and White respondents reported the highest ownership rates, which aligns with earlier research showing that lifestyle stability, cultural norms, and access to resources can all affect whether households choose to own pets.

At the same time, the relatively small differences across income levels challenge the assumption that pet ownership is mainly driven by financial capacity. Instead, the data suggests that owning a pet is a choice that cuts across most income groups at similar rates. The lack of variation across different numbers of children also shows that household size alone does not determine whether families decide to have pets.

These findings emphasize that pet ownership is not simply a personal preference but is shaped by broader social contexts, such as cultural expectations and household structure. However, the limitations in the dataset—especially the broad race categories and uneven sample sizes—mean that these results should be interpreted with caution. Future studies should rely on more detailed racial and ethnic breakdowns, as well as statistical methods that move beyond descriptive comparisons, in order to better understand how each factor independently contributes to pet-ownership trends.

Even with these limitations, this study contributes to the growing research showing that pets function not only as companions but also as reflections of lifestyle, identity, and social environment. As pet ownership continues to evolve in the United States, understanding these influences becomes increasingly important for interpreting how pets fit into modern social life.

Works Cited

Staats, S., Horner, K. “Allocating Time to People and Pets: Correlates With Income and Well-Being in a Midwest Community Sample.”The Journal of Psychology Volume 133, April 2, 2010. https://www.tandfonline.com/doi/abs/10.1080/00223989909599761

Lund, T. Forkman, B.(2024). “How Is Human Socioeconomic Position Linked With Dog Ownership Practices? A Study From Denmark”. Anthrozoös, August 19, 2024. https://www.tandfonline.com/doi/full/10.1080/08927936.2024.2384211

Ory, Marcia. Pet possession and well-being in elderly women, 1983. https://www.researchgate.net/publication/249630227_Pet_Possession_and_Well-Being_in_Elderly_Women

Smith, T. W., Davern, M., Freese, J., & Hout, M. (2019). General Social Survey, 2018 [Data set]. NORC at the University of Chicago. https://gss.norc.org/get-the-data

Pet Advocacy Network. (2025, March 26). Economic Impact of the U.S. Pet Industry- PET Advocacy Network. https://petadvocacy.org/economics

Wilson, L. (2021, February 23). The many correlations between income and pet ownership - CivicScience. CivicScience. https://civicscience.com/the-many-correlations-between-income-and-pet-ownership

Facts + Statistics: Pet Ownership and Insurance | III. (n.d.). https://www.iii.org/fact-statistic/facts-statistics-pet-ownership-and-insurance

American Pet Products Association. (2023). 2023–2024 APPA National Pet Owners Survey: Generational report. https://www.americanpetproducts.org/

Cekavicius, T., & Pajarskaite, M. (2012). Pets as status symbols. https://www.diva-portal.org/smash/get/diva2:531243/FULLTEXT02.pdf

Institutions, War, and Economic Resilience:
Comparing the United States, Russia, and Ukraine By Amber Wee

Abstract

The ongoing Russo-Ukrainian war has demonstrated how differently political systems absorb economic shocks. Ukraine's Gross Domestic Product (GDP) collapsed following Russia's full-scale invasion, while the United States and Russia experienced far more limited or short-term declines (European Parliament, 2024). This study examines how the political institutions of the United States, Russia, and Ukraine influence economic stability, business resilience, and long-term growth prospects. Drawing on Acemoglu and Robinson's theory that inclusive institutions promote investment and innovation while extractive institutions weaken long-term development, the paper analyzes how each country's governance structure shapes its ability to withstand major disruptions (Acemoglu and Robinson, 2012). The United States reflects a mature capitalist democracy supported by strong rule-of-law institutions, Russia operates a centralized model of state capitalism (Guriev and Treisman, 2022), and Ukraine struggles with long-standing institutional weaknesses that have been intensified by wartime pressures (Åslund; Bukhari et al., 2020, 2025). Using data from the World Bank, the International Energy Agency, NATO, and major policy research institutes, the study finds that the United States benefits from diversified markets and institutional independence; Russia maintains short-term stability through resource exports and centralized control (IEA, 2023); and Ukraine faces severe difficulties sustaining basic economic functions due to war-related destruction and incomplete reforms (OECD, 2023).

Introduction

Since Russia annexed Crimea in 2014 and expanded its attacks into a full-scale invasion in 2022, Ukraine has faced one of the most severe economic crises in modern European history. Its GDP dropped sharply as key infrastructure was destroyed, millions of people were displaced, and both foreign and domestic investment contracted (European Parliament, 2024). At the same time, the war has revealed how different political systems absorb major economic shocks. While the United States maintained relative stability through diversified markets and independent institutions, Russia relied on centralized authority and resource revenues, and Ukraine struggled with long-standing institutional weaknesses intensified by wartime pressures.

This study investigates how political systems shape economic stability, business conditions, and investment patterns in the United States, Russia, and Ukraine. Drawing on Acemoglu and Robinson's theory that inclusive institutions promote long-term growth while extractive institutions undermine it, the paper compares how democracy, state-managed capitalism, and Ukraine's partially reformed system influence each country's ability to withstand disruptions (Acemoglu and Robinson, 2012). By examining differences in institutional independence, economic structures, regulatory environments, and security conditions, this study

aims to explain why the same global conflict produces such unequal economic outcomes across the three nations.

Thesis Statement

This paper argues that political systems determine economic resilience by shaping how effectively countries can absorb shocks, coordinate institutions, and maintain investor trust during crises.

Political Systems and Economic Performance

Researchers widely agree that political institutions play a major role in shaping long-term economic performance. Acemoglu and Robinson explain that inclusive institutions—such as predictable legal systems, secure property rights, and accountable governance—create stronger incentives for innovation and investment, while extractive institutions concentrate power among elites and limit sustainable growth (Acemoglu and Robinson, 2012). Their framework suggests that the structure of political authority affects not only who controls resources but also how easily businesses can operate within a country.

International organizations support this view. Reports from the World Bank and the International Monetary Fund emphasize that transparency, consistent regulations, and reliable enforcement reduce investment risk and support more stable economic development (World Bank; IMF, 2024, 2022). Countries with stronger institutional capacity tend to attract more foreign investment, maintain steadier growth, and respond more effectively to major economic shocks. This literature provides a useful foundation for comparing the United States, Russia, and Ukraine, which differ sharply in terms of institutional independence and economic incentives.

The United States: Mature Capitalist Democracy

The United States is often described as a mature capitalist democracy supported by transparent courts, competitive markets, and strong protections for private property. These institutions reduce uncertainty for firms by ensuring predictable regulations, reliable contract enforcement, and stable financial systems. Such conditions encourage long-term investment and allow businesses to operate with greater confidence.

Companies like Apple illustrate how institutional stability supports large-scale economic activity. Apple reported approximately $391 billion in revenue in 2024, reflecting the advantages created by a consistent regulatory environment and deep capital markets (Apple Inc., 2024). Research also shows that the United States' strong institutional framework lowers transaction costs, supports high levels of innovation, and provides one of the world's most attractive business environments. As a result, the U.S. economy remains resilient during global disruptions and continues to foster extensive entrepreneurial activity.

Russia: State-Managed Capitalism and Resource Dependence

Russia represents a contrasting model of state-managed capitalism where political

authority is highly centralized and the government plays a dominant role in key economic sectors. Guriev and Treisman explain that Russian leaders maintain control by limiting political competition, shaping media, and directing major industries, which strengthens central authority but restricts the independence of economic institutions (Guriev and Treisman, 2022). This structure allows the government to act quickly during crises but makes long-term institutional development more difficult.

A major feature of Russia's economy is its heavy dependence on oil and gas exports. These resources provide a large share of government revenue, but they also leave the country vulnerable to global price changes and international sanctions (IEA, 2023). Scholars note that this combination of centralization and resource dependence makes it harder for Russia to diversify its economy and reduces investor confidence, especially during periods of political tension or conflict. As a result, Russia's economic stability often depends on external factors that the government cannot fully control.

Ukraine: Political System Under Pressure

Before the full-scale invasion, Ukraine already faced long-standing institutional weaknesses, including inconsistent rule of law, corruption, and slow, uneven reforms. Åslund notes that these problems created uncertainty for businesses and made it difficult for the government to build a stable economic environment (Åslund, 2020). Similarly, Bukhari and colleagues explain that weak legal enforcement and limited administrative capacity increased investment risks and reduced confidence in Ukraine's regulatory system (Bukhari et al., 2025).

The 2022 invasion greatly intensified these challenges. Ukraine's GDP fell by nearly 29 percent in the first year of the war as major infrastructure—including transportation networks, power grids, and government facilities—was damaged or destroyed (World Bank, 2024). These disruptions made basic economic functions harder to maintain and further weakened institutions that were already under pressure.

Despite these difficulties, Ukraine has shown strong social resilience. Volunteer networks, expanding digital public services, and rapid emergency responses have helped the country continue essential operations during times of intense strain (UNDP, 2024). The government has also accelerated reforms to align with European Union standards, aiming to strengthen governance and support long-term recovery.

Methodology

This study uses a comparative case study approach structured around four analytical dimensions: (1) political structure, (2) economic model, (3) business environment, and (4) external security and alliances. These dimensions allow for a clearer comparison of how different political systems respond to economic pressures and influence long-term development.

Data sources include major international organizations such as the World Bank, the International Monetary Fund, NATO, the Pew Research Center, and Transparency International,

as well as research from respected policy institutes. Because this study synthesizes findings from existing literature and official reports, it does not rely on original statistical modeling.

Limitations of this approach include dependence on publicly available data, the small number of country cases, and the rapidly changing nature of the ongoing war, which may affect the consistency and availability of information.

The United States: Institutional Stability and Business Growth

The United States operates as a federal democracy supported by long-standing checks and balances, independent courts, and a transparent regulatory system. These institutions reduce uncertainty for firms by ensuring predictable rules, fair competition, and strong protection of property rights (OECD: United States, 2023). Because companies can rely on consistent enforcement, they face lower investment risk and are able to direct capital toward long-term innovation rather than short-term survival.

Recent policy actions under the Trump administration, including expanded corporate tax cuts and deregulation in sectors such as energy and manufacturing, have further reduced compliance costs and encouraged business investment(Wallach and Kennedy, 2022). While the long-term effects of these policies remain debated, they reflect the broader U.S. approach of limiting direct government control over private enterprise.

The strength of U.S. institutions is visible in the performance of major industries. For example, NVIDIA generated more than $60 billion in revenue in 2024, demonstrating how intellectual property protections, deep capital markets, and clear regulatory guidelines support rapid innovation (NVIDIA, 2024). The diversity of the U.S. economy—spanning technology, finance, manufacturing, and services—also helps absorb economic shocks by preventing disruptions in one sector from destabilizing the entire system. Independent institutions such as the Federal Reserve further contribute to economic stability by adjusting monetary policy during periods of volatility. Together, these features create one of the most resilient and attractive business environments in the world.

Russia: Centralized Governance and Economic Weaknesses

Russia's political system is characterized by strong centralization and limited political competition, with the state playing a dominant role in major economic sectors such as energy, defense, and transportation. Scholars describe this structure as a form of state-managed capitalism in which leaders maintain control by directing strategic industries, restricting independent media, and limiting civic participation (Guriev and Treisman, 2022). As a result, political authority is concentrated within a narrow leadership circle, and independent institutions remain weak.

Russia's economy relies heavily on natural resource exports—especially oil and gas—which provide a large share of federal revenue (IEA, 2023). State-linked companies such as Gazprom and Rosneft continue to dominate production, allowing the government to stabilize budgets during periods of high global energy prices. However, this dependence also creates

structural vulnerabilities. When energy prices fall or trade restrictions increase, the effects spread quickly across the economy because alternative sectors are less developed.

International sanctions imposed after the 2014 annexation of Crimea—and strengthened following the 2022 invasion—have intensified these weaknesses. Research from the Peterson Institute for International Economics shows that sanctions have limited Russia's access to high-tech imports, global financial markets, and Western consumer goods, narrowing the country's economic options (Schott, 2023). Although Russia has maintained GDP levels close to $2 trillion, these figures mask deeper constraints on innovation, diversification, and long-term resilience (World Bank, 2024).

Overall, Russia's centralized system supports rapid decision-making and short-term mobilization but limits transparency, institutional independence, and economic flexibility. These weaknesses make sustained development difficult, reinforcing the structural risks associated with heavy resource dependence.

Ukraine: Weak Institutions and Wartime Challenges

Before the full-scale invasion, Ukraine already faced long-standing institutional weaknesses, including inconsistent rule of law, fragmented administrative capacity, and high levels of corruption (Transparency International, 2023). Scholars note that these conditions made business operations unpredictable and limited foreign investment, even during years of relative stability (Åslund; Bukhari et al, 2020, 2025). Slow and uneven reforms often created uncertainty for firms, reducing confidence in the country's regulatory environment.

The 2022 invasion dramatically intensified these problems. Ukraine's GDP contracted by nearly 29 percent in the first year of the war as major infrastructure—such as transportation networks, power grids, and communication systems—was damaged or destroyed (World Bank, 2024). The loss of key industrial regions and widespread displacement made normal business operations difficult or impossible, further weakening institutions that were already under strain.

Despite these challenges, Ukraine has demonstrated notable social resilience. Volunteer networks, expanding digital public services, and community-led emergency responses have helped maintain essential functions during periods of institutional disruption (UNDP, 2024). The government has also accelerated reforms aimed at aligning with European Union standards in hopes of strengthening governance and supporting long-term economic recovery.

However, Ukraine's security environment continues to be a major barrier to investment. NATO members provide training and equipment but remain cautious about offering full membership because doing so could trigger collective defense obligations (NATO, 2023). This uncertainty discourages many firms from making long-term commitments, making economic planning and private-sector expansion more difficult. As long as security risks persist, Ukraine will continue to face obstacles in rebuilding stable economic conditions.

NATO and International Relations

NATO plays a major role in shaping perceptions of security and economic stability across Europe. Member states benefit from collective defense guarantees that reduce geopolitical risk and reassure investors that large-scale conflict is unlikely to reach their territories. Countries such as Poland, Germany, and the Netherlands have strengthened their trade networks and attracted more investment partly because NATO membership signals long-term security and political reliability (NATO, 2023). This security framework supports stable business environments and allows firms to engage in long-term planning.

Ukraine's relationship with NATO is more complex. Since Russia's annexation of Crimea in 2014, Ukraine has expanded cooperation with the alliance through military training, equipment assistance, and political coordination. However, full membership remains uncertain. Under Article 5 of the North Atlantic Treaty, an attack on one NATO member is treated as an attack on all, meaning that other members are obligated to provide military support. Because Ukraine is actively engaged in conflict, admitting it could require NATO states to intervene directly-making many members cautious about extending full membership. Research institutions such as the Marshall Center propose alternatives, including phased integration or long-term bilateral security guarantees, as more realistic options until conditions improve (Baev et al., 2023).

This uncertainty has significant economic implications for Ukraine. Without clear security guarantees, businesses remain hesitant to make long-term investments or rebuild operations in regions affected by conflict. Investor confidence closely depends on Ukraine's evolving security environment, meaning the country's economic recovery is strongly tied to its future relationship with NATO and broader European institutions.

Comparative Discussion

A comparison of the United States, Russia, and Ukraine shows that political institutions strongly shape each country's ability to withstand economic shocks. The United States benefits from independent courts, transparent regulations, and a diversified economy, which create a predictable environment for investment and innovation (Filip and Setzer, 2025). These features help businesses adjust quickly during disruptions.

Russia follows a different pattern. Its centralized political system enables rapid, top-down decision-making but limits long-term adaptability. Heavy reliance on oil and gas further increases vulnerability; when sanctions intensify or global prices shift, the effects spread quickly across the economy (Åslund and McFaul, 2022).

Ukraine faces the most difficult conditions. Before the 2022 invasion, inconsistent rule of law and slow reforms discouraged investment and weakened administrative capacity (Bukhari et al., 2025). The invasion intensified these weaknesses by damaging infrastructure and disrupting state operations. Although Ukraine has shown strong social resilience, ongoing conflict continues to restrict economic recovery.

Institutional Strength and Business Environment Indicators

Sources: Transparency International; World Governance Indicators; IMF

Indicator	United States	Russia	Ukraine
Rule of Law (WGI)	+1.4	−0.9	−0.6
Corruption Perception Index (2023)	69	26	36
Ease of Doing Business (Rank)	6th	28th	64th
Government Effectiveness	+1.3	−0.5	−0.2

These indicators show that countries with stronger rule of law, clearer regulations, and more effective governance maintain more stable business environments and recover more easily from crises. The United States consistently performs well on these measures, Russia remains hindered by centralization and corruption, and Ukraine continues to struggle despite ongoing reform efforts.

Limitations and Future Research

This study has several limitations. It relies primarily on publicly available data and secondary research from international organizations and policy institutes. Because economic conditions in Ukraine continue to change during the ongoing war, some data may be inconsistent or incomplete. In addition, examining only three countries narrows the comparative scope; including additional cases could reveal broader regional patterns in how political systems respond to economic shocks.

Future research could expand by analyzing how entrepreneurs operate within these different institutional environments. Comparing how new firms secure capital, navigate regulatory systems, and manage risk in the United States, Russia, and Ukraine would provide deeper insight into how political structures influence innovation and small-business development. Further work could also examine how wartime disruptions—such as infrastructure damage, supply-chain instability, or security uncertainty—affect business formation in Ukraine. Studying these entrepreneurial dynamics would help clarify not only how economies recover, but also how new ventures contribute to long-term stability and growth.

Structural Shock Absorption Mechanisms: Why Systems Fail or Survive

Political systems influence not only everyday governance but also how societies absorb major economic shocks. Wars, sanctions, and global market changes affect countries differently because the structure of political authority and the independence of key institutions determine whether disruptions can be contained or whether they spread across the economy. Scholars note that stronger and more inclusive institutions generally improve a country's shock-management capacity (Acemoglu and Robinson, 2012).

United States: Distributed Institutional Buffering

The United States demonstrates a system with widely distributed political and economic authority. Independent courts, state governments, and the Federal Reserve operate separately, creating multiple layers of stability. Research on institutional resilience shows that diversified and autonomous structures allow economies to adjust more effectively during disruptions (Acemoglu and Robinson, 2012). When pressure affects one sector—such as supply-chain problems or financial volatility—other institutions can compensate. This "distributed buffering" helps prevent localized crises from escalating into systemic failures.

Russia: Centralized Shock Amplification

Russia follows a highly centralized model in which political and economic decisions flow through a narrow leadership structure. This design enables rapid mobilization during emergencies but also magnifies long-term vulnerabilities. Studies on state-managed capitalism emphasize that limited institutional independence restricts adaptability during sustained pressure (Guriev and Treisman, 2022). When shocks strike core sectors—such as sanctions on major banks or restrictions on energy exports—their effects spread quickly across the economy. Analysts describe this pattern as "shock amplification," where weaknesses expand rather than remain contained (Schott, 2023).

Ukraine: Fragmented Capacity and War-Induced Exposure

Ukraine experiences a different challenge rooted in fragmented institutional capacity. Before the invasion, inconsistent rule of law and uneven enforcement limited the government's crisis-response ability (Bukhari et al., 2025). The war intensified these weaknesses. Damage to transportation networks, power grids, and communication systems often triggers nationwide consequences because administrative agencies cannot isolate or manage disruptions effectively. Research on Ukraine's governance shows that slow and incomplete reforms left institutions vulnerable to external shocks (Åslund, 2020). As a result, the country faces high exposure to disruptions and depends heavily on external support for recovery.

Why Shock Absorption Explains Divergence

These differences clarify why the United States, Russia, and Ukraine have experienced the war's economic effects so unevenly. Distributed systems like the United States maintain continuity because authority is shared across multiple institutions. Centralized systems like Russia respond quickly at first but lack the institutional depth needed to withstand prolonged pressure. Ukraine's fragmented institutions, intensified by wartime destruction, further restrict economic stability. Together, these cases illustrate that political institutions shape not only long-term growth but also a nation's ability to survive severe disruptions.

Conclusion

The Russo-Ukrainian war demonstrates how political institutions shape countries' ability

to absorb economic shocks. The United States maintains resilience through a diversified economy and independent institutions that provide multiple layers of stability. Russia's centralized structure allows rapid short-term responses but creates long-term vulnerabilities because decision-making is concentrated and the economy depends heavily on energy exports. Ukraine faces the greatest challenges, as weak administrative capacity and widespread wartime destruction limit economic stability and reduce investor confidence.

Overall, this comparison shows that transparent governance, institutional independence, and diversified markets are essential components of long-term resilience. These findings also point toward broader directions for future research. Examining how entrepreneurs secure capital, navigate regulations, and manage risk in different political systems—especially in conflict-affected environments like Ukraine—can deepen understanding of how new businesses support recovery. Such research can help clarify not only how economies rebuild after crises, but also how entrepreneurial activity contributes to long-term stability and growth.

Works Cited

Acemoglu, Daron, and James A. Robinson. Why Nations Fail: The Origins of Power, Prosperity, and Poverty. Crown Publishers, 2012. https://ia801506.us.archive.org/27/items/WhyNationsFailTheOriginsODaronAcemoglu/Why-Nations-Fail_-The-Origins-o-Daron-Acemoglu.pdf

Apple Inc. Apple Inc. Annual Report 2024. Apple Inc., 2024, pp. 29.

Åslund, Anders. Ukraine: What Went Wrong and How to Fix It. Peterson Institute for International Economics, 2020.

Åslund, Anders, and Michael McFaul. "How Sanctions and Centralization Shape Russia's Political Economy." Peterson Institute for International Economics, 2022.

Baev, Pavel K., Mark Galeotti, and Graeme P. Herd. "NATO's Vilnius Summit, Ukraine and Security Guarantees." Clock Tower Security Series, George C. Marshall European Center for Security Studies, 18 July 2023. https://www.marshallcenter.org/en/publications/clock-tower-security-series/strategic-competition-seminar-series-fy23/natos-vilnius-summit-ukraine-and-security-guarantees

Bukhari, Aijaz Hussain S., Gul Muhammad Gaho, and Bashir Ahmed Talpur. "Implementing the Rule of Law in Ukraine.:e: Pathway to the European Union" Annals of Human and Social Sciences, vol. 6, no. 1, 2025, pp. 112–122.

Center for Strategic and International Studies. "The Russian Wartime Economy: From Sugar High to Hangover." CSIS, 2 June 2025, https://www.csis.org/analysis/russian-wartime-economy-sugar-high-hangover.

Colton, Timothy J. "Ukraine and Russia: War and Political Regimes." Slavic Review, vol. 83, no. 1, 2024, pp. 1–29.

European Parliament. Economic Impact of the Russo-Ukrainian War on Ukraine and the EU. 2024. https://www.europarl.europa.eu/RegData/etudes/BRIE/2024/757783/EPRS_BRI(2024)757783_EN.pdf

Filip, Mihai-Daniel, and Rolf Setzer. The Impact of Regional Institutional Quality on Economic Growth and Resilience in the EU. ECB Working Paper No. 3045, 2025. https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp3045~ad74f198a7.en.pdf

Guriev, Sergei, and Daniel Treisman. Spin Dictators: The Changing Face of Tyranny in the 21st Century. 2022.

IEA, International Energy Agency. World Energy Outlook 2023.

IMF. World Economic Outlook Report. International Monetary Fund, 2022.

The Kyiv Independent. "Foreign Direct Investment in Ukraine Falls to $1.1 Billion in H1 2025." The Kyiv Independent, 2025.

NATO. NATO Annual Report 2023. North Atlantic Treaty Organization, 2023.

NVIDIA Corporation. NVIDIA Annual Report 2024. NVIDIA Corporation, 2024, pp. 24, 79.

OECD. OECD Economic Survey: Ukraine 2023. Organisation for Economic Co-operation and Development, 2023.

Pew Research Center. European Public Opinion and NATO Security Commitments. Pew Research Center, 2023.
Schott, Jeffrey J. Economic Sanctions Against Russia: How Effective? How Durable? Peterson Institute for International Economics, Policy Brief No. 23-3, 2023.
Transparency International. Corruption Perceptions Index 2023. Transparency International, 2023.
UNDP. Recovery Framework for Ukraine. UNDP, Sept. 2024. https://www.undp.org/sites/g/files/zskgke326/files/2024-10/undp-ua-recovery-framework-september-2024-en_0.pdf
Wallach, Philip A., and Kelly Kennedy. “Examining Some of Trump’s Deregulation Efforts: Lessons from the Brookings Regulatory Tracker.” Brookings Institution, 8 Mar. 2022. https://www.brookings.edu/articles/examining-some-of-trumps-deregulation-efforts-lessons-from-the-brookings-regulatory-tracker/?utm_source=chatgpt.com
World Bank. “Ukraine GDP (Current US$).” World Bank Open Data, 2024, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=UA.
World Bank. “Russian Federation GDP (Current US$).” World Bank Open Data, 2024, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=RU.
World Bank. “United States GDP (Current US$).” World Bank Open Data, 2024, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=US.

Exploring the Feasibility of Estimating Drag of Car Mirrors Using Only Flow Visualization
By Ruixi Liu

1 Abstract

This study investigates the feasibility of using flow visualization as an alternative method for estimating the drag coefficient (C_d) of car mirrors. Traditional aerodynamic analyses rely on costly wind tunnel experiments or computational fluid dynamics (CFD) simulations, which may be inaccessible to many researchers. In contrast, Flow Illustrator provides a low-cost approach to visualizing airflow patterns. Using six scaled-down mirror models, this study extracts wake structures from Flow Illustrator videos and calculates C_d using a kinetic energy-based method. The results are compared against wind tunnel data from "Aerodynamics of F1 Car Side Mirror" [3, p.14]. The findings indicate that while Flow Illustrator successfully captures the trend of drag coefficient reduction with increasing mirror glass recession, it underestimates absolute C_d values due to the lack of turbulence modeling. Despite its limitations, Flow Illustrator proves to be a useful tool for preliminary aerodynamic analysis and can serve as an accessible educational platform.

2 Introduction

2.1 Background and Motivation

Aerodynamic performance plays a crucial role in modern vehicle design, particularly in high-speed applications such as Formula 1 (F1) racing. The study of aerodynamic drag is essential for improving vehicle efficiency, enhancing speed, and reducing fuel consumption. Among the many components affecting drag, side mirrors have been identified as a significant source of aerodynamic resistance. Research has shown that even minor modifications in mirror design can lead to measurable changes in drag force and airflow behavior, based on the result of "Aerodynamics of F1 Car Side Mirror" [3, p.18] when the mirror's glass is located further inside its frame a reduction in the drag is achieved with a maximum of $10\% - 11\%$. Traditionally, wind tunnel experiments and computational fluid dynamics (CFD) simulations have been the primary methods for analyzing aerodynamic performance. While these techniques provide high accuracy, they are also costly, computationally intensive, and often inaccessible to individuals and smaller research groups. Validated CFD software could enable engineers to calculate wind effects on buildings for which no aerodynamic information is currently available. However, the reliance on specialized facilities and software creates a barrier for many researchers and students interested in aerodynamic analysis. To lower the entry barrier for aerodynamic research, alternative methods must be explored. One potential solution is the use of flow visualization techniques, a publicly available website Flow Illustrator, which allows researchers to observe airflow patterns and infer aerodynamic properties without requiring direct force measurements or complex simulations. Flow Illustrator provides a simplified, qualitative representation of airflow

around objects, making it useful for visualizing wake structures and estimating aerodynamic trends. According to the official website, Flow Illustrator creates a video showing the fluid flow (air, water, etc.) past an object, such as a car, for example. This online simulation tool is very easy to use, because the shape of the object can be communicated to the server simply by uploading the picture of the object [2]. The goal of this study is to investigate whether a low-cost, simplified flow visualization method can provide meaningful drag estimations comparable to those obtained through wind tunnel testing.

2.2 Existing Research

Several studies have investigated the aerodynamic effects of side mirrors using both wind tunnel testing and CFD simulations. For example, "Computational fluid dynamics analysis of a lateral mirror and introduction to digital implementation" [4] by Núria Planes Rodríguez analyzed the aerodynamic performance of a generic lateral mirror using ANSYS Fluent, concluding that removing the mirror reduces drag by 1.4% but increases lift by 7.7%. Similarly, "Low Drag Automotive Mirrors Using Passive Jet Flow Control" [5] by Jianlei Wang explored methods to reduce mirror drag using passive jet flow control, demonstrating that modifications to mirror geometry can significantly alter the wake behavior. While these studies provide valuable insights, they all rely on high-cost experimental setups or computationally expensive CFD methods. Few studies have examined whether low-cost flow visualization techniques can provide comparable drag estimations, creating a research gap that this study aims to address. The development of an alternative method using Flow Illustrator, a simplified online aerodynamic visualization tool, presents an opportunity to evaluate the feasibility of estimating drag through purely visual analysis.

2.3 Basic Aerodynamic Concepts

To better understand the methodology used in this study, it is essential to introduce fundamental aerodynamic concepts that influence drag estimation.

2.3.1 Drag Force

Drag is the resistive force experienced by an object moving through a fluid (such as air or water). It is caused by the interaction between the fluid and
the object's surface. The higher the drag, the more energy is required to maintain motion. In vehicle aerodynamics, reducing drag is crucial for improving fuel efficiency and top speed. The drag force is given represented using the drag coefficient:

$$C_d = \frac{D}{\frac{1}{2}\rho U^2 A} \#(1)$$

Where: D is Drag, ρ is Air density, U is Speed of the object relative to the fluid, A is Reference area (frontal area of the mirror), C_d is the drag coefficient.

2.3.2 Drag Coefficient

The drag coefficient is a dimensionless number that represents the drag force. A lower C_d means the object experiences less resistance. For example:

Shape	Drag Coefficient
Sphere	0.47
Half-sphere	0.42
Cube	1.05

Table 1: Examples of different drag coefficients by different model [1, p.9]

2.3.3 Reynolds Number

Reynolds number is a dimensionless value that describes the flow characteristics around an object:

$$Re = \frac{\rho U l}{\mu} \#(1.2)$$

where: ρ is Fluid density, U is Free-stream velocity, l is Characteristic length, μ is Dynamic viscosity of the fluid. At low Reynolds numbers, flow tends to be smooth (laminar). At high Reynolds numbers, the flow becomes turbulent. This is important because turbulence affects drag force and wake structure.

2.4 Model Description

"Aerodynamics of F1 Car Side Mirror" [3], analyzed how subtle changes in mirror geometry can influence aerodynamic drag. In this research, the authors introduced the concept of the normalized mirror glass location L, defined as:

$$L = \frac{Mirror\ Glass\ Location}{d} \#(1.3)$$

This concept of a dimensionless L value allows for scalable modeling and easy comparison between geometries, making it highly suitable for both wind tunnel testing and simplified visual flow analysis like the method proposed in this paper.

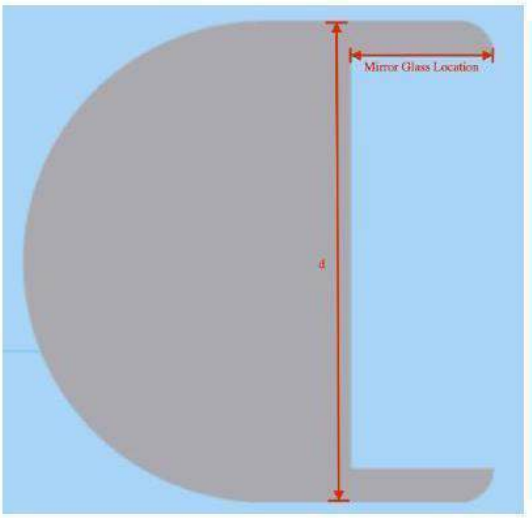


Figure 1: Car mirror model from Aerodynamics of F1 Car Side Mirror [3,p.7]

In the study, we consider six scaled-down mirror models that correspond to the different values of normalized mirror glass location (L) as defined in "Aerodynamics of F1 Car Side Mirror" [3, p.11]. This ensures that the experimental setup in Flow Illustrator remains consistent with the reference wind tunnel study, allowing for a direct comparison of drag coefficient (C_d) trends. The geometric scaling preserves the dimensionless parameter L, ensuring that variations in mirror placement relative to the main body remain proportional to the original study. This setup allows us to investigate whether Flow Illustrator can accurately estimate the aerodynamic impact of different mirror configurations.

2.5 Research Objectives and Hypothesis

This study seeks to explore the feasibility of using flow visualization to estimate drag coefficients of car mirrors. The key research questions include:

- Can flow visualization provide drag estimations that follow the same trend as wind tunnel or CFD data?
- What are the limitations and uncertainties associated with this approach?

The hypothesis of this research is that while absolute drag values obtained from flow visualization may differ from wind tunnel data, the overall trend in drag variation should be consistent. If this hypothesis holds, it would validate the use of flow visualization as a low-cost alternative for preliminary aerodynamic assessments.

2.6 Methodological Approach

To test this hypothesis, this study will use a mirror model previously analyzed in a wind tunnel experiment in "Aerodynamics of F1 Car Side Mirror" [3]. The methodology involves the following steps. First, use Flow Illustrator to generate flow visualizations around the mirror at different configurations. Then, extract flow patterns and wake structures from the visualization output. Then, estimate the drag coefficient values using fundamental aerodynamic principles. Finally, compare the results with wind tunnel data from previous research.

2.7 Contributions and Significance

This research contributes to the broader discussion on low-cost aerodynamic testing methods by demonstrating a potential complement to CFD and wind tunnel experiments. If successful, the approach could enable broader access to aerodynamic research, particularly for students, independent researchers, and budget-constrained teams. It can also reduce reliance on expensive equipment while still providing meaningful insights into flow behavior. Ultimately, this study bridges the gap between qualitative visualization and quantitative aerodynamic analysis, exploring whether a simple, accessible tool like Flow Illustrator can serve as a preliminary drag estimation method for vehicle aerodynamics.

3 Results

3.1 Drag Coefficient Estimation from Flow Illustrator

Using Flow Illustrator, the drag coefficient (C_d) was estimated for different L. The simulation results, presented in Table 2, indicate that as the mirror glass is positioned further inside its frame (L increases), the drag coefficient decreases.

$L = 0$	$C_d = 0.79$
$L = 0.035$	$C_d = 0.778$
$L = 0.07$	$C_d = 0.757$
$L = 0.105$	$C_d = 0.766$
$L = 0.14$	$C_d = 0.706$
$L = 0.175$	$C_d = 0.605$

Table 2: Effect of different L on C_d

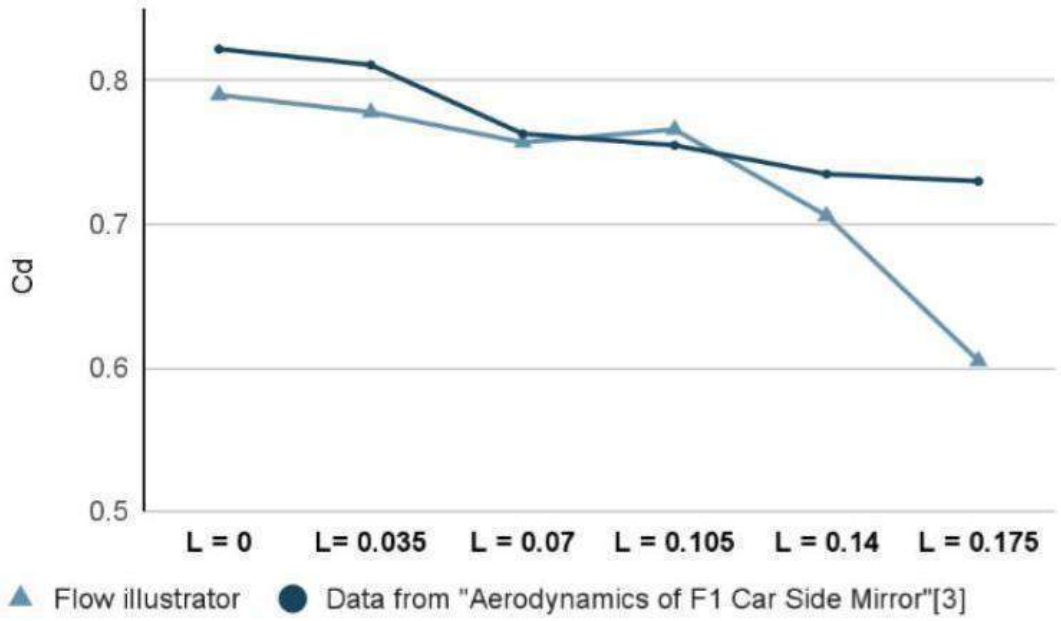


Figure 2: Drag coefficient plotted against L at $Re = 5000$

Figure 2 shows the variation of C_d with increasing L, demonstrating a clear decreasing trend. This suggests that the further the mirror glass is recessed into its frame, the lower the aerodynamic drag.

3.2 Comparison with Wind Tunnel Results

To evaluate the accuracy of the Flow Illustrator results, we compare them with wind tunnel data from "Aerodynamics of F1 Car Side Mirror" [3]. Figure 3 illustrates the experimental Cd values obtained from wind tunnel testing. It can be seen that as the glass is located further inside its frame, which corresponds to an increase in L, the drag coefficient decreases at all Reynolds numbers [3, p.14]. This agreement in trend suggests that Flow Illustrator can qualitatively capture the primary aerodynamic effects of mirror displacement.

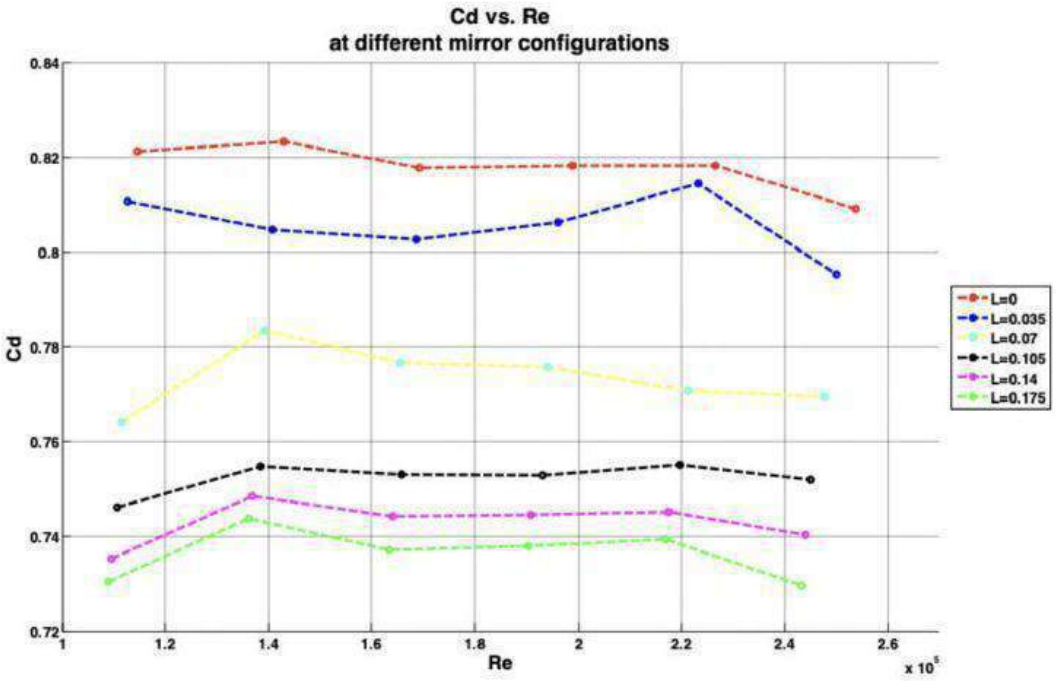


Figure 3: Drag coefficient plotted against Re at different mirror's configurations [3, p.14]

The following observations can be made: both datasets exhibit a similar trend, as L increases, C_d decreases. However, the absolute C_d values differ. Flow Illustrator generally predicts slightly lower drag coefficients compared to wind tunnel data when L is near 0 , and slightly higher than the experimental result when L is near 0.175 . This difference necessitates further investigation into potential error sources, as discussed in a later section. Although the absolute values are different, the agreement in trend between Flow Illustrator and wind tunnel results supports the feasibility of using low-cost flow visualization methods to estimate aerodynamic performance.

3.3 Influence of Reynolds Number on Drag

One limitation of Flow Illustrator is its inability to simulate high Reynolds number flows accurately. In wind tunnel experiments, values were tested at different Reynolds numbers, ranging from 1.1×10^5 to 2.6×10^5. The drag coefficient does not change much while the Reynolds number increases from 1.1×10^5 to 2.6×10^5 [3, p.14].

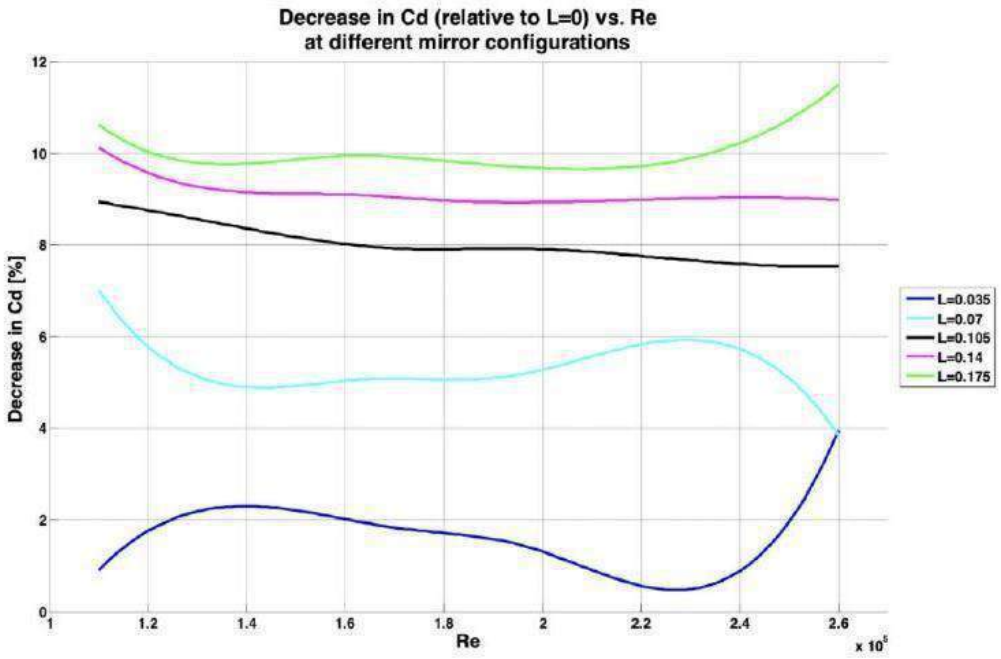


Figure 4: Decrease in Cd (relative to $L = 0$) plotted against Re for different mirror configurations [3, p.14]

Figure 4 demonstrated the trend of different L comparing to $L = 0$ against Re from 1.1×10^5 to 2.6×10^5. Because of this observation, we assume that selecting a single Reynolds number ($Re = 5000$) in Flow Illustrator is valid, as the effect of Reynolds number on C_d is relatively small. This assumption is crucial because, at higher Reynolds numbers, Flow Illustrator produces chaotic and unusable results, making it difficult to extract meaningful aerodynamic parameters. The wind tunnel results confirm that C_d is relatively insensitive to Reynolds number within a reasonable range. Thus, while Flow Illustrator cannot simulate the full range of Re, the results obtained at $Re = 5000$ still provides a meaningful comparison to wind tunnel data.

3.4 Flow Patterns and Wake Structures

Although Flow Illustrator does not provide detailed numerical flow field data, the visualized wake structures can still offer insights into aerodynamic behavior. Figure 5 presents sample wake visualizations from Flow Illustrator.

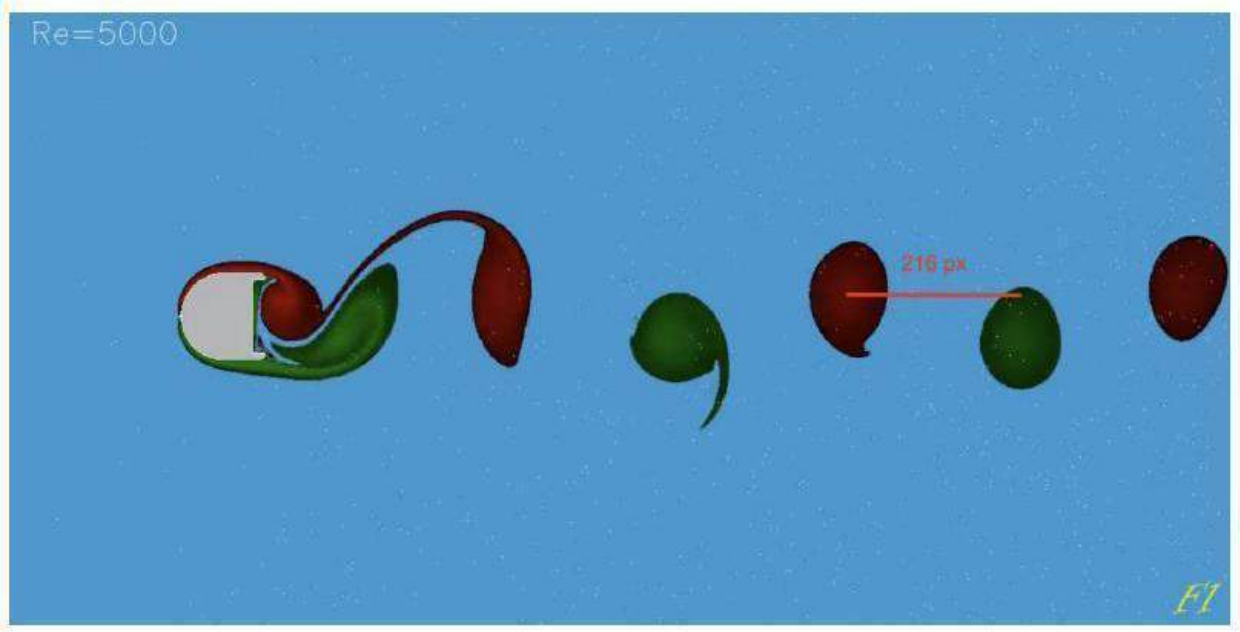


Figure 5: visualization from Flow Illustrator for $L = 0.175$

It can be seen that the distance between the vortices increases as L increases, corresponding to a decrease in drag. In addition, a clear vortex shedding pattern observable in Flow Illustrator, which remains the same as the PIV results in wind tunnel testing [3, p.13]. The wind tunnel results showed that vortex shedding occurred in an alternating pattern, leading to a flapping motion in the wake. This phenomenon was explicitly visible in Flow Illustrator results, indicating that the tool may contain the ability to capture flow behavior.

3.5 Limitations and Sources of Error

While the general trend of drag reduction with mirror displacement is captured well by Flow Illustrator, several factors contribute to quantitative differences between Flow Illustrator and wind tunnel results. One major limitation of Flow Illustrator is its inability to simulate high Reynolds number (Re) flows accurately. Wind tunnel results demonstrated that Reynolds number variations between 1.1×10^5 and 2.6×10^5 had minimal impact on C_d [3, p.14]. Due to computational constraints, Flow Illustrator simulations were conducted at $Re = 5000$. Although experimental data suggests that C_d remains relatively stable across different Reynolds numbers, the inability to simulate realistic automotive Reynolds numbers introduces potential inaccuracies. According to Flow Illustrator's official description, the tool is optimized for speed and robustness rather than accuracy, leading to potential inaccuracies. It is stated that the accuracy of the simulation is only reliable when Re is small, but in most real-world cases, this condition is not met, making the results significantly different from actual flow behavior. This further emphasizes the need for cautious interpretation of the obtained C_d values [2].

Furthermore, wind tunnel tests can capture these effects, leading to different drag values

compared to Flow Illustrator predictions. Last, unlike wind tunnel testing, which directly measures aerodynamic forces using a balance system, Flow Illustrator requires drag coefficient estimation through indirect methods. The calculations rely on wake visualization and empirical relationships, introducing additional uncertainty in the final C_d values.

4 Discussion

4.1 Applicability of Flow Illustrator

Despite its limitations, Flow Illustrator proves to be a valuable tool for preliminary aerodynamic analysis, particularly in cases where qualitative trend estimation is sufficient. It is particularly useful for rapid concept validation, allowing engineers and researchers to quickly visualize airflow behavior around different mirror designs before committing to more detailed CFD simulations or wind tunnel testing. In addition to its utility for design exploration, Flow Illustrator also proves effective in educational contexts. The visual representation of flow separation, wake structures, and pressure distribution helps students and early-stage researchers develop an intuitive understanding of core aerodynamic principles. Moreover, for projects with limited access to CFD software or wind tunnel facilities, Flow Illustrator offers a cost-effective alternative for hypothesis testing in the early stages of research. However, as stated in the Flow Illustrator documentation, the tool prioritizes speed and robustness over accuracy, explicitly mentioning that the videos should be treated as 'artist impressions' rather than precise simulations. This highlights its primary role as a qualitative visualization tool rather than a replacement for traditional CFD or wind tunnel testing [2].

4.2 Future Research Directions

While Flow Illustrator demonstrates potential as a low-cost aerodynamic tool, improvements could be made to enhance its accuracy and applicability. A promising direction is the integration of artificial intelligence (AI) and computational methods to overcome some of its current limitations. For instance, one can attempt to use AI-based image analysis with Flow Illustrator output. Using machine learning techniques, it may be possible to train a model using wind tunnel and CFD datasets to correct Flow Illustrator's underestimation of drag, automatically extract flow features (such as wake size, vortex shedding) and correlate them with experimental drag coefficients, and improve the accuracy of drag coefficient estimations without requiring complex CFD simulations. In addition to AI, Flow Illustrator could be used for preliminary trend identification and concept testing, followed by refinement using simplified CFD tools and empirical correction factors derived from validated experimental data. This combined approach may offer a practical solution for educational, research, or prototyping contexts where fullscale CFD or wind tunnel access is not feasible.

5 Methods

5.1 Data Extraction and Drag Coefficient Calculation

Since Flow Illustrator does not output numerical force values, the drag coefficient is calculated indirectly using flow visualization measurements.

5.1.1 Extracting Velocity in the wake

To estimate C_d, the velocity of the wake (U) behind the mirror is measured using the following procedure. The process begins by identifying vortex pairs within the visualization. In the video generated by Flow Illustrator, red-colored flow represents the upper vortex while green-colored flow corresponds to the lower vortex. Multiple frames are captured to measure the pixel distance between the centers of these vortex pairs. To reduce measurement noise and improve reliability, three vortex pairs are selected per simulation, typically at 40 seconds into the video when the flow transient has decayed.

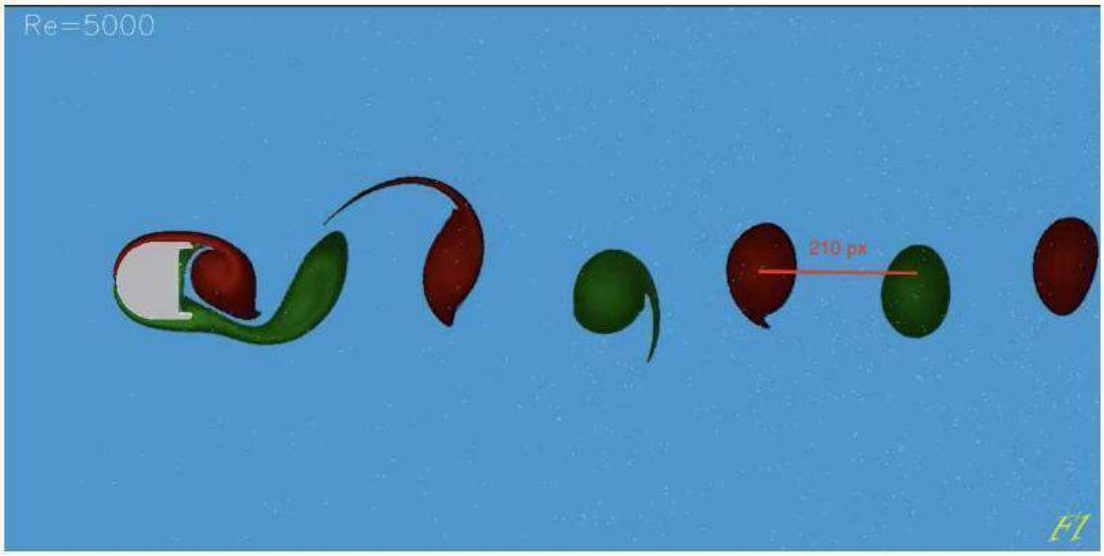


Figure 6: visualization from Flow Illustrator $L = 0.14$

Next, the displacement of the vortices is measured. Using a screenshot tool, the pixel distance between consecutive vortices is measured as shown in Figure 6. The total travel distance is then used to compute the free-stream velocity V, based on the formula:

$$V = \frac{measured\ pixel\ displacement}{time\ step\ in\ seconds} \#(1.4)$$

To determine the motion of the mirror, the mirror speed is calculated using the equation given by the Lesson part of Flow Illustrator [2]. The formula is given by:

$$V_{mirror} = H_{pic} \times dt \times 24 \#(1.5)$$

where H_{pic} is the video height (in pixels), $dt = 0.01$ is the time step per frame, multiply by 24 accounts for the video frame rate (24 fps). With both velocities known, the wake velocity U,

which reflects the reduced speed of airflow behind the mirror due to aerodynamic drag, is obtained using the following relation:

$$U = V_{mirror} - V \#(1.6)$$

5.1.2 Drag Coefficient Calculation

In this study, the drag coefficient C_d is estimated using flow visualization data obtained from Flow Illustrator. Since the software does not directly provide aerodynamic forces, an indirect method based on kinetic energy loss in the wake is applied. Based on the formula in the Lesson part of Flow Illustrator, this expression represents the work done by the mirror on the surrounding fluid [2]:

$$D = \frac{\rho WHU^2}{2} \#(1.7)$$

where W is width, H is height, U is the measured wake velocity, and ρ is the density of air. The drag coefficient is then defined using (1), where $A = W \times H$, the projected area of the wake. Substituting (1.7) into (1) gives:

$$C_d = \frac{\frac{1}{2}\rho WHU^2}{\frac{1}{2}\rho V^2 WH} \#(1.8)$$

After canceling out common terms, the drag coefficient simplifies to:

$$C_d = \frac{U^2}{V^2} \#(1.9)$$

This expression allows for the estimation of C_d based solely on velocity measurements extracted from flow visualization, without requiring direct force measurements.

5.2 Measurement Precision

Since drag coefficient estimation in Flow Illustrator relies on pixel-based measurements, several strategies are implemented to minimize errors. For each mirror configuration, three vortex pairs are measured, and the average vertex distance is computed after removing the highest and lowest values to reduce the impact of outliers. Measurements are consistently taken at the 40 -second mark. Additionally, potential measurement errors due to low image resolution are addressed by considering pixel resolution scaling. Acknowledging that slight fluctuations in vortex positioning may introduce minor deviations, these error reduction techniques collectively help to ensure that the final computed C_d values offer a reasonable approximation Flow illustrator result.

5.3 Summary

This study demonstrates that Flow Illustrator, despite its simplifications and limitations, can effectively capture the general trend of drag reduction associated with increasing mirror glass recession in vehicle side mirrors. It offers a low-cost, accessible alternative for preliminary

aerodynamic analysis. The strong agreement in trend between Flow Illustrator results and wind tunnel data supports its potential as a qualitative tool for early-stage aerodynamic assessments, particularly useful in educational contexts or for validating aerodynamic concepts in resourcelimited settings.

6 Acknowledgements

I would like to acknowledge Professor Sergei Chernyshenko for his willingness to take forward the proposed inventive research, and his great help in the Flow illustrator and for his constant support during the study.

Works Cited

[1] A. S. Aarønes and H. Nilsson, "Dynamic response of pipe rack steel structures to explosion loads," M.S. thesis, Structural Engineering and Building Technology Programme, Chalmers University of Technology, Gothenburg, Sweden, 2021.

[2] S. Chernyshenko, "Fluid dynamics of car mirrors: a Flow Illustrator lesson," Drag force. [Online]. Available: http://www.flowillustrator.com [Accessed: Mar. 3, 2025].

[3] E. Rind and Z. W. Hu, "Aerodynamics of F1 Car Side Mirror," Report No. AFM-07/06, School of Engineering Sciences, University of Southampton, Southampton, U.K., 2007.

[4] N. Planes Rodríguez, "Computational fluid dynamics analysis of a lateral mirror and introduction to digital implementation," M.S. thesis, Universitat Politècnica de Catalunya, Barcelona, Spain, Jul. 8, 2016.

[5] J. Wang, W. Bartow, A. Moreyra, G. Woyczynski, A. Lefebvre, E. Carrington, and G. Zha, "Low Drag Automotive Mirrors Using Passive Jet Flow Control," *SAE Int. J. Passeng. Cars - Mech. Syst.*, vol. 7, no. 2, pp. 429-438, 2014, doi: 10.4271/2014-01-0584.

Borders Of Belief: How National Pride Shapes Views on Immigration By Saanvi Peddi

Abstract

With the United States Immigration and Customs Enforcement — also widely known as ICE — ramping up its efforts to strictly enforce immigration rights in the United States, this research is interested in how the public's sense of national pride influences opinions toward border policies. This paper reviews topics such as nationalism, exceptionalism, and threat perception, along with Social Identity Theory and Integrated Threat Theory, to establish a theoretical foundation for the argument that the public's pride in their country can influence their attitudes toward immigration policies. Based on these theories, I argue that a heightened sense of national pride decreases the public's support for open immigration. I analyze the data collected from the Gallup Research Center, U.S. Department of Homeland Security, and Federal Reserve Bank of St. Louis to generate insights on public support for exclusionary border policies. Through my analysis, I reveal how national pride consistently correlates with public support for restrictive border and immigration policies. Lastly, the discussion section examines the implications of the findings on public sentiments toward public policies, as well as suggestions for future research.

Keywords

Nationalism; Public Opinion; Immigration Policies; Threat Perception; Social Identity

Introduction

Andrea Orea was merely five years old when her mother handed her over to a stranger to be smuggled across the United States-Mexico border. She traveled with nothing but the hand-knitted white sweater that her mother had made her, on her back, which she still has today. After a week, she finally reunited with her father and her mother at McDonald's, who had come by foot from hiking through the dangerous Sonoran desert. Despite the hardship, Andrea became very successful later in life. She excelled in school, got accepted into the University of California, Berkeley, where she majored in political science and legal studies, qualified for Deferred Action for Childhood Arrivals (DACA), got her degree, and then finally got her green card, which now allows her to publicly share her story. "I always felt like an 'other' person here in the United States because I was born in Mexico and all those things. But then I went back to Mexico, and I felt like I didn't belong there either," Andrea reflected (Ramirez). Even after all of the struggle and hardship their family had to face, Andrea's parents could still not have legal guardianship over Andrea's three brothers, who are United States citizens. Andrea's experience is, unfortunately, not unique. Numerous immigrants and refugees across the world put everything on the line for safety and opportunity. However, they have to face exclusion and suspicion, which often stem from restrictive national identity and perceived threat from members of an "outgroup." Thus, this paper examines how the public's pride in their country can shape the way they respond to border issues.

To better understand how the public can form opinions on immigration and border issues, it is necessary to define and understand the key concepts that shape those beliefs. The essential concepts are nationalism, exceptionalism, and threat perception. Nationalism can be defined as a belief in the superiority and primacy of one's nation, often accompanied by support for national interests at the expense of others (Brice). Based on this definition, we can understand that nationalism refers to a strong sense of loyalty and pride to one's nation, which can foster unity among co-nationals but can also fuel the exclusion of outsiders. This belief can cause people to view other nations and the people of those nations as threats or even inferior compared to their co-nationals. This belief becomes even more of a problem when coupled with exceptionalism. Exceptionalism is when a country believes that it is not only different from the rest but morally superior as well (Ignatieff). Citizens who hold the exceptionalist view will often believe that the rest of the countries should look up to them or try to imitate them. When citizens have a strong sense of nationalism and exceptionalism, they may hold exclusionist or prejudiced attitudes toward immigrants, viewing them as inferior. This may be due to the fear that immigrants will threaten their jobs, safety, or even culture(Prather and Albertson; Stephan et.al.). This fear factor is called perceived threat (Stephan et.al.), which is sparked from group identity and the fear of the unknown. Social Identity Theory explains this phenomenon as well as Integrated Threat Theory, both of which show how the fear of outsiders ultimately may fuel harsher assimilation policies.

This paper utilizes two theories to build the argument that the public's preferences toward immigration policies are correlated with national pride levels. The first theory is Social Identity Theory (SIT), which explains how people define themselves based on shared group mentality or characteristics (Tajfel and Turner 7-24). In this process, they also develop a bias for their own group and can view others in a more negative light. The second theory is Integrated Threat Theory (ITT), which builds on SIT by identifying four different types of threats: realistic threat, symbolic threat, intergroup anxiety, and negative stereotypes (Stephan et.al.). By understanding both of these theories, they act as a foundation for the argument, which is that the public's pride in their country is associated with their border and immigration policy attitudes.

The methodology of this paper is a quantitative analysis of existing surveys from the Gallup Research Center. Specifically, I examined a dataset that measures Americans' national pride, as well as their attitudes toward immigrants and immigration. The data used throughout the paper is not individual-level data, but rather aggregate-level data, highlighting the national public attitude. The focus of the analysis is to identify variations in national public attitudes toward immigration across time to identify a relationship between levels of national pride and public sentiments toward border policies. Specifically, heightened national pride tends to fuel restrictive attitudes toward immigration and refugees, while periods of declining national pride can correlate with greater acceptance of immigrants.

The Gallup surveys revealed the expected correlation between levels of national pride and the public's opinion toward immigrants. The trend demonstrated how, during the years with higher levels of national pride, exclusion toward immigrants was also comparatively high.

Conversely, the lower the levels of national pride, the more welcoming the public was toward immigrants. This pattern was found to be consistent throughout two different opinion data tables with varying questions to measure sentiments toward immigration. In conclusion, the results of the analysis suggest that public attitudes toward border policies vary predictably with the levels of national pride.

Understanding the reasoning behind the public's exclusionary attitudes can be crucial in today's world, which is facing both internal and transnational displacement of a mass of people due to war and political instability. These findings suggest that a heightened sense of national pride can be a powerful driver of exclusionary attitudes, which can potentially lead to the continued suffering of people who already face persecution. When citizens hold much pride in their country, they are more likely to view outsiders as threats to their cultural values, economic stability, and safety. SIT and ITT highlight how in-group psychology and perceived threat work hand in hand to shape attitudes toward immigration. This emphasizes the importance of understanding how nationalism and exceptionalism can shape public opinion, specifically as contemporary global crises, such as war and climate-induced displacement, continue to cause debates about borders and belonging.

Literature Review

In this section, I am going to review the literature on the topics of nationalism and exceptionalism, perceived threat, especially in the context of immigration, as well as social identity. The first section will discuss the impact of national pride on public attitudes toward outsiders. National pride and exceptionalism can influence policies both within and beyond borders, notably by shaping how citizens of a country view their role in the world (Smith). The following section will discuss how people's opinions on immigration are shaped by perceived threat. The articles in this section argue that immigration can be viewed as a threat to national stability, culture, and resources (Mangum and Block 1-15; Prather and Albertson; Stephan et.al.). The third section will discuss how individual or group identity can shape the public's view toward societal change, as well as how identity-based issues can influence political behavior. I will highlight which gaps exist in this existing literature, and based on the gaps identified, my research question asks how the public's pride in their country can shape the way they respond to border issues. Along with this, I am going to outline the key theories and concepts that contextualize my research question. Two theories that frame my argument are SIT and ITT, both of which are widely recognized and empirically supported frameworks in social psychology.

Nationalism/Exceptionalism

Nationalism and exceptionalism shape the way countries view their role in the world. For example, Brice and Ignatieff illuminate how nationalism and exceptionalism have shaped foreign policy decision-making in the United States. American exceptionalism is essentially the belief that the United States is fundamentally different from other nations, thus viewing itself as morally superior and not bound by the same international laws (Ignatieff). Nationalism is a

collective identity formed around shared culture, values, and a belief in a common destiny, often accompanied by the conviction that one's nation is superior to others and must protect or promote its interests above all else (Brice; Greenfeld). In particular, exceptionalism stems from the belief that the United States has a mission to promote freedom and democracy. This promotion can paradoxically and tragically lead to worse human rights outcomes when the United States uses military force or undemocratic regimes, violating the very human rights it claims to defend (Ignatieff). Furthermore, nationalism supports modern nations by providing a sense of shared identity to bring people together. Though this may be beneficial for national unity, it unfortunately can lead to exclusion or even prejudice against people who are of a different nation (Greenfeld). Nationalism has also evolved and given rise to exceptionalist sentiments in certain cases, such as the belief that the United States is superior to other countries, and thus, it should assume the role of a leader in global affairs. This evolution of nationalism also includes the idea of cultural dominance (Brice). Cultural dominance essentially means that one nation's culture, values, beliefs, language, or tradition is superior and should be upheld and imposed on others (Brice). It manifests through policies that favor assimilation, the rejection of multiculturalism, and efforts to export national values abroad.

Relatedly, many nations or countries create stories or myths about their greatness. This can be a vital tool in showing the greatness of a country, not only to its citizens but also to the broader world, fueling a "us versus them" mindset among the believers (Smith). Under such myths or collective storymaking, many people would believe that those who are not from their country do not belong and have no space in the country (both in a physical and metaphorical sense), ultimately leading to discrimination and prejudice among citizens (Smith). Furthermore, a national crisis such as 9/11 can increase the levels of national pride in the public, which builds up walls between citizens and immigrants. This can make people defensive or even suspicious of "outsiders" or those who are not a part of "them" (Huddy and Feldman 455-467). In these times, Americans who believe in their national superiority, dominance, and control tend to support harsher foreign policies and stricter immigration regulations (Prather and Albertson; Mutz). Altogether, these scholars demonstrate how nationalism and exceptionalism are not simply ideas but forces that shape foreign policy and the way people view refugees, immigrants, and the movement of people across borders more broadly.

Perceived Threat

Another key factor as to why some people have strong reactions and opinions toward refugee movements is threat perception. This would include, but is not limited to, imagined or real threats to one's physical safety, job, or cultural values (Makashvili 55-70). The root cause of this fear need not originate from facts, but rather, one's perception. Many people's negative responses to immigration stem from their perceived threat to their livelihood, as they fear immigrants are taking their jobs (Makashvili et.al. 55-70; Stephan et.al.). Additionally, the public is more favorable to policies such as the erection of border walls when they experience a sense of fear that immigrants will threaten their way of life from an economic, physical, and cultural

standpoint (Prather and Albertson). These patterns are not only present in the United States but also in Europe and Australia (Pattison and Davidson 142-149; Ignatieff; Šedovič). These opinions can also be heavily influenced by media or politics, which can convey many false or misjudged narratives, such as portraying immigrants disproportionately as criminals or unwilling to assimilate into the dominant national culture (Dražanová; Šedovič). The greater the perceived threat, the harsher and stricter public responses toward refugees become (Pattison and Davidson 142-149). For instance, after tragic events such as 9/11, many Americans swiftly supported harsher and more aggressive security policies that extended toward border security policies, including immigration. This is because people tend to view immigrants and refugees as a threat to their national safety, given an increasingly insecure environment (Huddy and Feldman 455-467).

Moreover, a perceived status loss is also a main reason why many people have strong anti-immigrant views. They feel as if their "in-group" is becoming less important or pushed to the side, both at home and on the world stage. Interestingly, this feeling is more prominent among historically privileged groups, such as white Americans (Mutz). Furthermore, people who are very strongly identified with a racial or cultural group are more likely to view immigrants as a threat, regardless of whether they themselves are being affected (Mangum and Block 1-15). Overall, feelings rather than facts appear to drive anti-immigrant attitudes.

Social Identity

So far, the literature seems to suggest that the hostility or resentment toward immigrants can be driven by how people view their identity, along with who they consider a part of their in-group, which could be national or cultural. Many studies show how the public's support for restrictive immigration policies increases when they believe their group is losing social status or influence as an outcome (Mangum and Block 1-15; Mutz). In fact, a majority of the political backlash against immigration and globalization connects to the fear of losing their social status both at home and abroad. This is incredibly prominent with white Americans who feel like their group is losing importance and value while other groups are excelling at the detriment of their in-group (Mutz). To further explain, people with strong ties to their social, racial, or ethnic groups have more negative views when it comes to immigration. This applies to everyone regardless of their income or education (Mangum and Block 1-15). Moreover, the way people define themselves is a huge factor when it comes to their view on immigration. For example, those who identify themselves as immigrants are not as likely to support harsh foreign and domestic policies when compared to non-immigrants (Šedovič). Notably, people also share national pride and a sense of belonging through stories, and when immigrants do not fit those stories, they may be viewed as outsiders (Smith). Additionally, national identity is often formed from shared history and culture, which thus decides who is included and excluded from the national community (Greenfeld). All these studies show that attitudes toward immigration are shaped by how people understand their own and others' identities and what they believe their country stands for.

While these scholars provide important insights on how nationalism, perceived threat, and identity jointly shape public opinion, most of the literature tends to look at these topics separately. My research will tie all of these topics together and look at it as a whole by asking: *How do national pride levels influence how people respond to the movement of people across borders*

To better understand why these attitudes form, I draw on two social psychological theories: SIT, ITT. By grounding my research in established theoretical perspectives, I aim to provide a deeper exploration of the issues at hand. Along with this, these theories provide support and guidance for my research and act as a foundation for my analysis. However, these theories may also provide insights into political processes. For example, they may also help explain how group dynamics and perceived threats shape the public opinion on immigration, particularly in the context where national identity and cultural boundaries are emphasized.

SIT was developed by Tajfel and Turner in 1979, and according to this theory, an individual's perception of themselves is heavily influenced by their social groups. Many people tend to belong to multiple social groups (e.g., race, religion, gender), and the cluster of groups to which they belong constitutes the "in-group," while those who do not fall in that cluster constitute the "out-group," which may fuel a dichotomous "us versus them" mindset. This may prompt people to discriminate against members of the out-group, which may relate to a sense of superiority or favoritism toward their own group (Tajfel and Turner 33-47; Dražanová; Hainmueller and Hopkins).

These in-group out-group dynamics emerge in many social situations, including but not limited to: interactions between natives and immigrants. In-group favoritism is a natural psychology that helps people feel connected and safe through their group, which manifests through social preferences, positive bias in judgment, perceived superiority, and stereotyping the out-group(Tajfel and Turner 33-47; Tajfel and Turner 7-24). Through in-group favoritism, there tends to be an exaggeration of the positive traits within the in-group and negative stereotypes toward the out-groups, which can lead to prejudice and discrimination (Mangum; Tajfel and Turner 33-47; Stephan et.al.). This mindset can lead to exclusionary attitudes, prejudice, social exclusion, and even hostility towards immigrants(Mangum and Block 1-15; Makashvili et.al., Stephan et.al., Dražanová). This is because many tend to view immigrants as cultural outsiders or can feel like they are challenging their norms and traditions (Makashvili et.al.; Pattison and Davidson; Stephan et.al.). When citizens feel like immigrants are becoming a threat to their values, language, or tradition, they may activate defensive responses in an attempt to preserve the nation's perceived sense of superiority or purity (Brice; Makashvili et.al.; Stephan et.al., Smith). Furthermore, the SIT helps explain why anti-immigration attitudes increase in the public during times of national crises. During times such as economic downturns or heightened political polarization, people may cling closer to their in-group to have a sense of belonging and safety while blaming or projecting their fear onto the out-groups (Pattison and Davidson 142-149; Mutz, Stephan et.al., Dražanová).

The second theory is ITT, which was introduced by Stephan and Stephan in 1996 (Stephan et.al.). This theory aids in understanding why citizens of a nation develop negative attitudes towards immigrants and refugees by distinctly outlining four different types of perceived threats. These categories are realistic threats, symbolic threats, intergroup anxiety, and negative stereotypes, all of which can create intergroup prejudice. The first type of threat (i.e., realistic threats) is a tangible concern, such as threats to employment, housing, education, national security, or healthcare. This results in hostile attitudes towards immigrants and even prejudice because the limited availability of these tangible concerns may be perceived as usually exclusive to only the citizens (Stephan et.al.). Along with this, there is also a sense of superiority and essentially the idea of who "deserves" certain entitlement. The second type is symbolic threats, which are far more abstract and are related to perceived threats to a group's values, norms, beliefs, or national identity. Citizens tend to believe that the culture or values of immigrants are "eroding" the nation's traditional identity and homogeneity, causing panic and painting immigration as a cultural invasion. The third type, intergroup anxiety, is what is felt when people interact with outsiders. This can stem from many reasons, such as negative past experiences (e.g., being mugged), fear of being judged, or skepticism about how to behave properly. This can involuntarily or voluntarily heighten tension and promote social distancing and exclusion. The last perceived threat is negative stereotypes. This is the belief that members of the out-group are either lazy, dangerous, untrustworthy, or even inferior. Media is a main factor that intensifies these stereotypes, along with political discourse and societal bias (Huddy and Feldman 455-467; Pattison and Davidson 142-149; Mutz; Stephan et.al.). In the context of the argument, ITT helps explain not just the empirical observation that people fear immigrants but also provides a compelling explanation for why they do. It explains how prejudice can form amongst the public even if negative experiences did not occur, and how important that fear is in shaping public attitudes.

In sum, SIT explains how group membership and intergroup comparison shape behavior and opinion, while ITT adds an emotional and cognitive layer by explaining why people feel the way they do and how fear, anxiety, and perceived threat can escalate into political and social hostilities. Drawing insights from these two complementary theories, I argue that national pride significantly influences public opinion toward immigration policies, which produce the following two hypotheses:

> *H1: The higher the perceived sense of national pride, the stronger the national support for stringent immigration policies.*
>
> *H2: The lower the perceived sense of national pride, the weaker the national support for stringent immigration policies.*

Methods and Materials

This study focuses on exploring how the levels of national pride are correlated with the public's perspective on immigration policies. Understanding the complex relationship between national pride and immigration attitudes requires a careful analysis of data over several years to detect meaningful patterns; thus, this study utilizes publicly available longitudinal data sources to investigate this question.

The first source is a dataset from Gallup titled "Immigration," published in 2025, which is historical data of the public opinion on immigration in the United States between the years 2001 and 2025. This source demonstrates the general American attitude (i.e., aggregate data at the national level) regarding immigration throughout the indicated years. This dataset reports the percentage of Americans with varying views on border policies, including but not limited to strict border control. Considering the fact that this data was collected over the course of numerous years, it will provide valuable insights into how the national public attitudes fluctuate over the years, demonstrating longitudinal variability. Among the 67 questionnaire results on the attitudes of Americans regarding questions of immigrants and refugees, two of them closely relate to my dependent variable of interest, which is the American attitudes toward immigration policies. The two survey questions are: "Would you like to see the level of immigration in this country increase, decrease, or remain about the same?" (See Table 1 in Appendix), and "On the whole, do you think immigration is a good thing or a bad thing for this country today?" (See Table 2 in Appendix).

The second source is another dataset from Gallup, titled "American Pride Slips to New Low," also published in 2025, which focuses entirely on American national pride levels. This specific dataset from Gallup keeps track of national pride levels throughout the specified years (i.e., 2001-2025).

The research methodology of this study contains several steps, each carefully designed to enable replicability and accuracy. First, I analyzed the second Gallup source and recorded the level of national pride for every given year between 2001 to 2025. To do this, I added the percentage of pride for all three political parties (i.e., Democratic, Republican, and Independent), and then divided the result by three to receive a percentage of the average levels of national pride among all the citizens in that specific year. This was done because the national-level aggregate data were not available. Next, I cross-referenced the same years with the first Gallup dataset to link national pride to public attitudes toward immigration policies. This consisted of recording the percentage of favorable and unfavorable national attitudes regarding immigration for each year between 2001-2025. Then, I created line graphs to detect patterns and associations between national pride levels and American attitudes toward immigration. Furthermore, to determine the strength and direction of the relationship between my independent and dependent variables, I calculated the Pearson Correlation Coefficient. Subsequently, to assess if the detected correlation is systematic or by chance, I also calculated the P-value for each of my independent-dependent variable pairs.

To further enhance the analysis, I examined several potential confounding variables that might influence the relationship between national pride and immigration attitudes. These

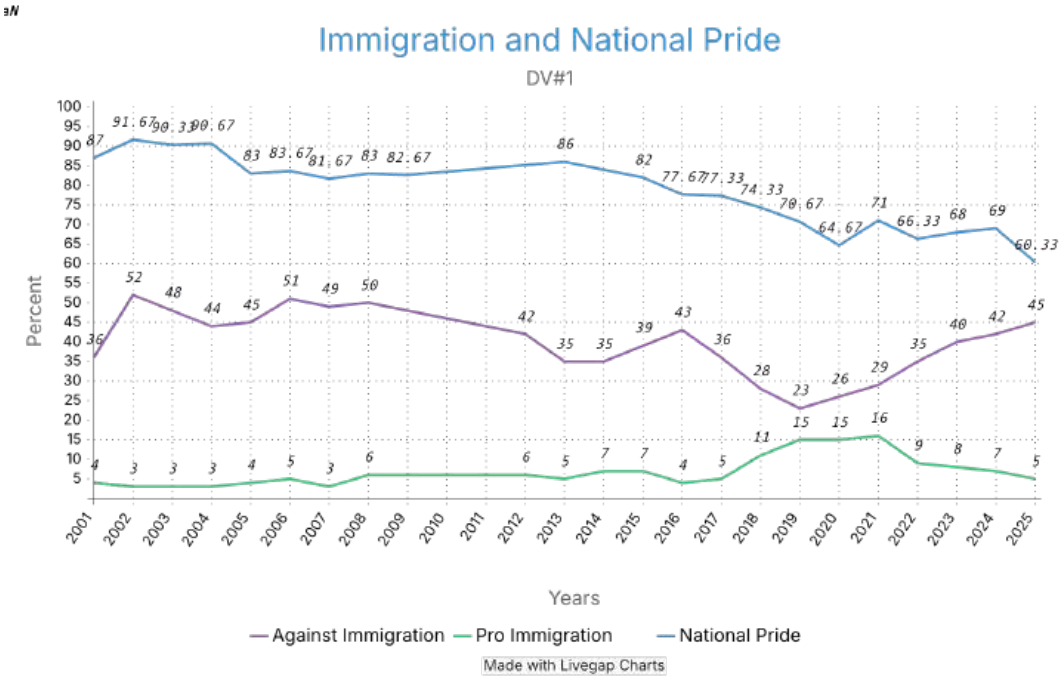
included the national unemployment rate, obtained from the Federal Reserve Economic Data (FRED) database (*UNRATE*), and annual refugee arrivals, sourced from the Department of Homeland Security Yearbook (*Immigration Yearbook 2022*). This Immigration Yearbook is cumulative, consisting of the data from 1980 to 2022. By including these confounding variables, I was able to examine whether trends in immigration attitudes were also correlated with other social or political factors beyond national pride. Similar to the analyses conducted for the dependent variable, I generated line graphs and calculated the Pearson Correlation Coefficients and the P-values for the association between the two identified confounding variables and the dependent variables.

Results

The following section provides the main findings from the analyses outlined above, focusing on trends in national pride and the public attitudes toward immigration. These results are presented to decipher how levels of national pride and immigration sentiment fluctuated over time and how they are correlated with each other.

In the first source from Gallup titled Immigration, two data tables were analyzed, with each of the two data tables representing a different measurement of the dependent variable (i.e., attitudes toward immigration). The data from Table 1 is visually represented in the line graph format in Figure 1.

Figure 1 - "Would you like to see the level of immigration in this country increase, decrease, or remain about the same?"

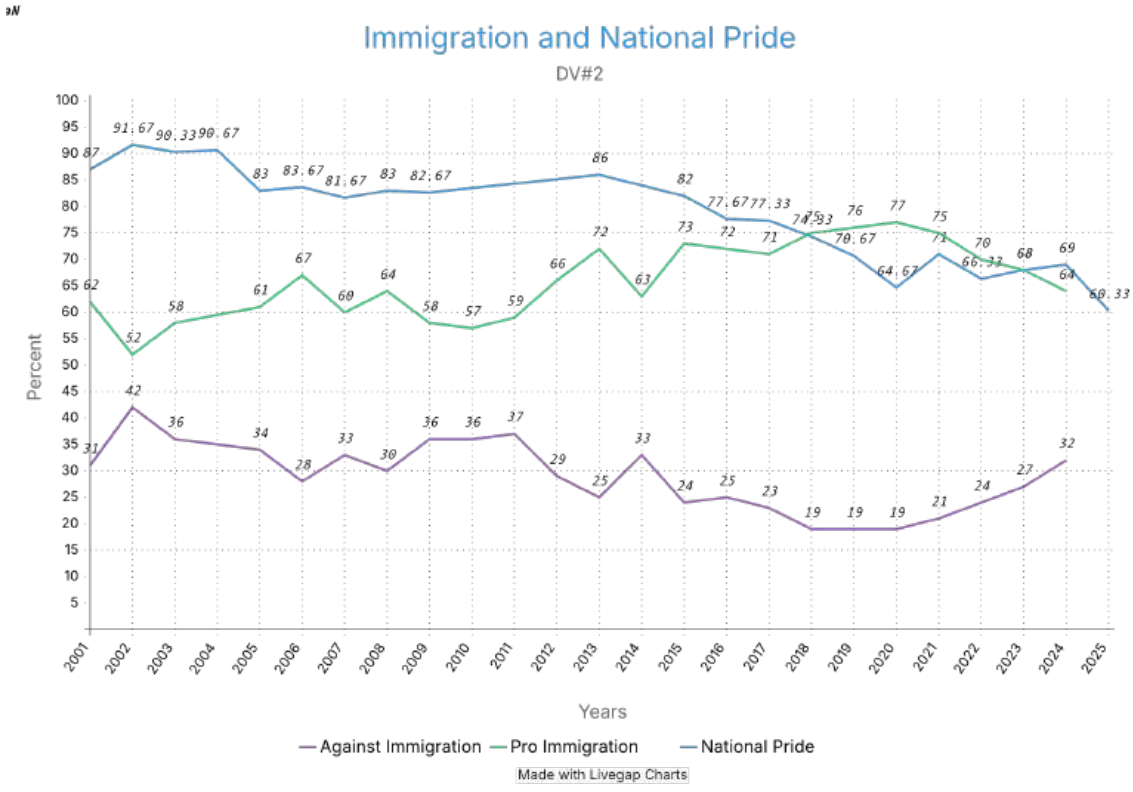


According to Figure 1, the levels of national pride and against-immigration stance seem to follow the same general trend and appear to increase and decrease around the same years (i.e.,

directly related). The pro-immigration stance, however, seems to have an opposite pattern compared to the national pride levels (i.e., inversely related). This pattern appears to be true until the year 2019. However, from 2019 onwards, the graph does not follow this pattern. After the year 2019 up until 2022, the against-immigration stance appears to go up when national pride goes down. In contrast, the pro-immigration stance follows the same general downwards pattern as the national pride levels. Unfortunately, the explanation for this change in pattern is not within the scope of this study. According to the Pearson Correlation Calculator, the Pearson Correlation Coefficient (from here on out referred to as "R-value") between the pro-immigration stance and National Pride is -0.6405, meaning that these two variables have a moderately strong negative correlation. Additionally, the P-value is 0.002372, making the probability of correlation being a coincidence highly unlikely. Furthermore, the R-value between the against-immigration stance and national pride is 0.5109, making these two variables have a moderately strong positive correlation. Lastly, the P-value for this correlation is 0.021333, meaning it is once again highly unlikely that these results were by coincidence. Based on all of the findings from the first table, my hypothesis appears to be supported.

Now moving on to Table 2, which also similarly presents the percentage of people pro and against immigration. This data is represented in Figure 2.

Figure 2 - "On the whole, do you think immigration is a good thing or a bad thing for this country today?"

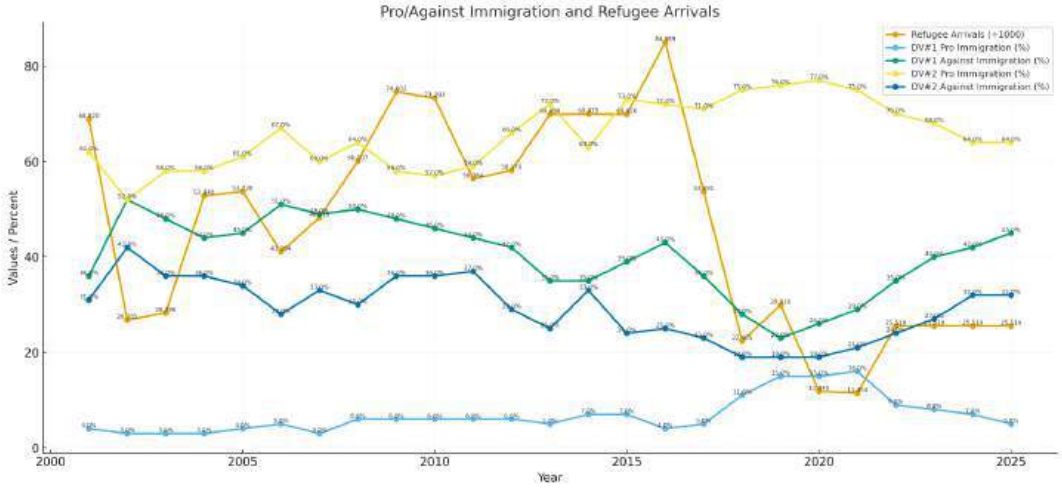


Based on Figure 2, the general trend of the against-immigration stance matched the national pride levels (i.e., increasing and decreasing at around the same time). The

pro-immigration stance, however, did not follow this pattern and went the opposite direction compared to the national pride levels (i.e., pro-immigration increased when national pride decreased, and vice versa). This pattern was more or less consistent throughout the years. The R-value is -0.67 for the relationship between the pro-immigration stance and the national pride levels, indicating a moderately strong negative correlation. Furthermore, the P-value is 0.001698, meaning that this correlation is highly unlikely to be by coincidence. Additionally, the R-value for the relationship between the against-immigration stance and national pride is 0.6821, indicating a moderately strong positive relationship. Moreover, since the P-value is 0.001295, this association also appears systematic. Collectively, the findings from both Figure 1 and Figure 2 support my hypotheses that the higher the sense of national pride, the lower the support for immigration, and the lower the sense of national pride, the higher the support for immigration.

In addition to the national pride comparisons, potential confounding variables were examined, including annual refugee arrivals and national unemployment rates (U.S. Department of Homeland Security, *Immigration Yearbook 2022*). Line graphs were also created to visually assess the relationships between these confounding variables and immigration attitudes (Figure 3 and Figure 4).

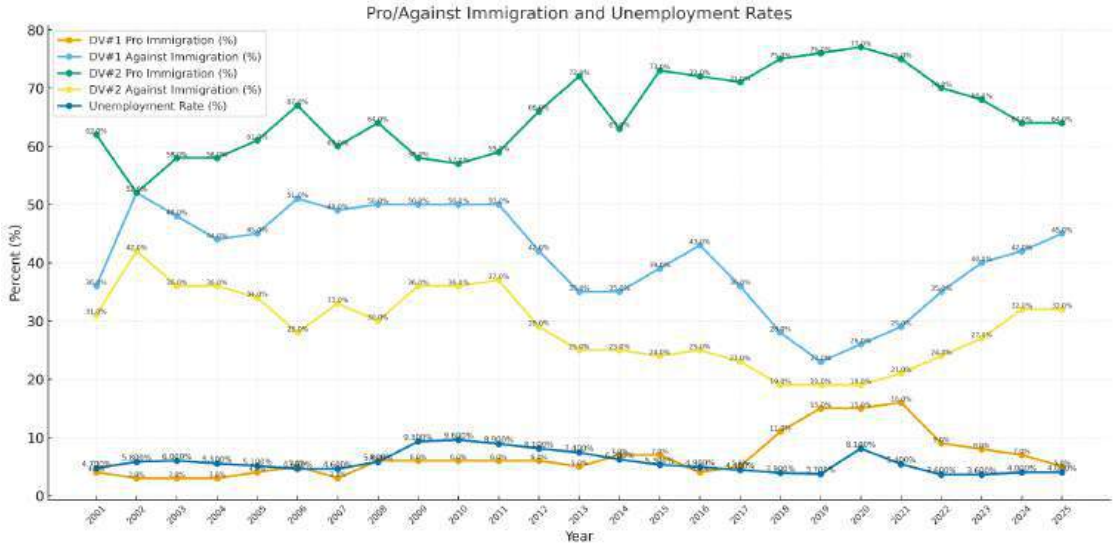
Figure 3 - Pro/Against Immigration and Refugee Arrivals



The second confounding variable, unemployment rates, is visually shown in the line graph above (Figure 3). In this line graph, the refugee arrival data is divided by 1000 and is represented as a decimal. For example, 68,920 arrivals would be represented as 68.920; meanwhile, the rest of the values are percentages. Continuing, upon careful analysis, the first confounding variable, annual refugee arrivals, does not represent a clear visual pattern that demonstrates a consistent direct or inverse relationship between refugee arrivals and the pro/against immigration stances for either of the dependent variable measurements. However, to confirm this observation, I also evaluated the potential relationship between the variables through a statistical analysis. According to the Pearson Coefficient Calculator, the R-value between refugee arrivals and DV#1 pro-immigration stance is -0.6055, thus revealing a

moderately strong negative correlation, and a P-value of 0.006062, making the chance of this relationship being a coincidence very unlikely. Conversely, the relationship with DV#1 against-immigration stance reveals the R-value of 0.3118 and a P-value of 0.193765, demonstrating a weak positive correlation with no statistical significance. Additionally, the correlation between DV#2 pro-immigration stance reveals a R-value of -0.2892 and a P-value of 0.203874, indicating a weak negative relationship, which is again not statistically significant. Similarly, the DV#2 against-immigration stance yields an R-value of 0.3389 and a P-value of 0.133983, indicating weak positive correlation with no statistical significance. Overall, the moderately strong statistical significance only exists for the DV#1 pro-immigration stance, and the rest of the relationships between the identified variables remain weak and statistically insignificant. Overall, this demonstrates how refugee arrivals may not be an important variable to explain public immigration attitudes.

Figure 4 - Pro/Against Immigration and Unemployment Rates



The second confounding variable, unemployment rates, is visually shown in the line graph above (Figure 4). It is also important to mention that the y-axis displays the percentages for the pro- and against-immigration stances, as well as rates for the unemployment rates. It is apparent that the against-immigration stance (for both DV#1 and DV#2) and the unemployment rates follow a similar pattern, especially in years with heightened levels of unemployment. In contrast, the pro-immigration stances appear to move conversely to the unemployment rates for most of the years, as heightened levels of pro-immigration attitudes are often accompanied by lower unemployment rates. A Pearson correlation test between unemployment rates and DV#1 pro-immigration stance produces a nearly zero correlation (R-value = -0.0338) and a P-value of 0.887078, indicating no meaningful relationship and no statistical significance, despite my interpretation of the line graph above. A Pearson correlation test between unemployment rates and DV#1 against-immigration stance yields a very weak positive correlation (R-value = 0.0404)

and a P-value of 0.861968, also indicating no statistical significance. A Pearson correlation test between unemployment rates and DV#2 pro-immigration stance results in a moderate negative correlation (R-value = -0.3583) and a P-value of 0.093487, indicating the relationship is not statistically significant at the levels I pre-specified. Lastly, a Pearson correlation test between unemployment rates and DV#2 against-immigration stance yields a moderate positive correlation (R-Value = 0.398) with a P-value of 0.059992, which approaches significance but still a little short of the levels I pre-specified These results suggest that compared to the independent variable of this study (i.e., national pride levels), unemployment rates may not be a crucial variable to explain public attitudes toward immigration.

In conclusion, the line graphs and statistical analyses of the independent and confounding variables seem to strongly support my hypotheses. The national pride levels are consistently correlated with both pro- and against-immigration attitudes (though in different directions), while the refugee arrivals and the unemployment rates fail to reach statistical significance. This indicates that national pride levels are a more important factor in understanding public preferences toward immigration policies. Given the non-experimental nature of my analyses, I cannot make causal claims, though I can say with some confidence that higher levels of national pride are positively correlated with anti-immigration stance and negatively correlated with pro-immigration stance. In sum, the higher the perceived sense of national pride, the stronger the support for stringent immigration policies, and the lower the perceived sense of national pride, the weaker the support for stringent immigration policies.

Discussion

The results of this research support the hypothesis that positive feelings toward one's nation influence their attitudes toward immigration policies. An evaluation of the public's responses to the two questions related to immigration reveals an evident pattern: the percentage of national support towards immigration often decreases during the years of high national pride, and conversely, national support for immigration tends to increase when national pride levels are low. In essence, when citizens feel a strong sense of national pride, they are more prone to view "outsiders" or immigrants and refugees as potential threats. This, however, is not likely to have similarly intense effects when there are lower levels of national pride, for citizens may perceive lower levels of threat from immigrants and refugees.

These findings are very closely aligned with both SIT and ITT. SIT proposes the idea that individuals acquire a part of their self-perception from group membership, eventually leading to in-group favoritism as well as out-group hostility (Mangum and Block 1-15; Stephan et.al.,). Applying this perspective, greater national pride can prime the in-group identity of being an "American," which may result in greater skepticism toward immigrants who are perceived as outsiders. ITT also enhances this by orienting that perceived threats, either realistic or symbolic, reinforce negative attitudes toward outsiders. When experiencing periods of uplifted national pride, citizens may perceive immigration as a threat to their nation's unique identity, which is consistent with the findings of this research.

The findings of this research suggest that policymakers and public communicators must recognize and understand how national pride levels and threat perception can create an impact on how the public perceives immigration and other border policies, more broadly. Given that nationalist messaging may aggravate resistance toward immigration, efforts aimed at fostering social cohesion or reducing perceived threats could support more inclusive immigration and border policies as well as narratives. From a perspective beyond policymaking, these findings are incredibly valuable for understanding how public opinion can change in response to political environments. To explain further, the media that frames immigration as a type of cultural or economic threat are highly competent to resonate more strongly during periods of heightened national pride, which potentially reinforces exclusionary attitudes (Conzo et.al). Conversely, initiatives that emphasize the importance of shared values, mutual benefits, and the contributions of immigration are likely to be more effective when national pride levels are lower ("Highlighting shared humanity and prosperity to advance immigration solutions"). The line graphs developed for this study offer a visual representation of how immigration attitudes and national pride co-vary over time, making evident the patterns that support the theoretical predictions of SIT and ITT. This concludes that immigration debates are not purely based on economics and demographics, but are rooted in identity, belonging, and how people perceive their nation.

In future research, scholars should expand on these findings by analyzing regional differences within the United States and exploring how social media and public discourse can influence the relationship between national pride and attitudes toward border policies. Additionally, they could investigate other forms of perceived threat beyond immigration, such as increased trade flows across borders, more stringent international treaties, or heightened US involvement in foreign wars or conflicts.

Works Cited

Brice, B. A Very Proud Nation: Nationalism in American Foreign Policy. 2015.

Conzo, P., G. Fuochi, L. Anfossi, F. Spaccatini, and C. O. Mosso. "Negative Media Portrayals of Immigrants Increase Ingroup Favoritism and Hostile Physiological and Emotional Reactions." Scientific Reports, vol. 11, 2021, p. 16407, https://doi.org/10.1038/s41598-021-95800-2.

Dražanová, L. Attitudes Toward Immigration in Europe: Public Response to Regional Immigration. 2023.

Federal Reserve Bank of St. Louis. UNRATE. Federal Reserve Economic Data (FRED), https://fred.stlouisfed.org/series/UNRATE?#.

FrameWorks Institute. "Highlighting Shared Humanity and Prosperity to Advance Immigration Solutions." Stanford Social Innovation Review, n.d., https://ssir.org/articles/entry/highlighting_shared_humanity_and_prosperity_to_advance_immigration_solution.

Gallup. American Pride Slips to New Low. Gallup News, 2025, https://news.gallup.com/poll/692150/american-pride-slips-new-low.aspx.

Gallup. Immigration. Gallup Historical Trends, 2025, https://news.gallup.com/poll/1660/immigration.aspx.

Greenfeld, L. Nationalism: Five Roads to Modernity. Harvard University Press, 1992.

Hainmueller, J., and D. J. Hopkins. "Public Attitudes Toward Immigration." Annual Review of Political Science, vol. 17, 2014, pp. 225–249, https://doi.org/10.1146/annurev-polisci-102512-194818.

Huddy, L., and S. Feldman. "Americans Respond Politically to 9/11: Understanding the Impact of the Terrorist Attacks." American Psychologist, vol. 66, 2011, pp. 455–467, https://doi.org/10.1037/a0024894.

Ignatieff, M. American Exceptionalism and Human Rights. Princeton University Press, 2005.

Makashvili, A., I. Vardanashvili, and N. Javakhishvili. "Testing Intergroup Threat Theory: Realistic and Symbolic Threats, Religiosity and Gender as Predictors of Prejudice." Psychology in Russia: State of the Art, vol. 11, 2018, pp. 55–70, https://doi.org/10.11621/pir.2018.0305.

Mangum, M., and R. Block Jr. "Social Identity Theory and Public Opinion Towards Immigration." Social Science Quarterly, vol. 99, 2018, pp. 1–15.

Mutz, D. C. "Status Threat, Not Economic Hardship, Explains the 2016 Presidential Vote." Proceedings of the National Academy of Sciences of the United States of America, vol. 115, 2018, pp. E4330–E4339, https://doi.org/10.1073/pnas.1718155115.

Pattison, E., and G. R. Davidson. "The Role of Perceived Threat in Australians' Endorsement of Asylum-Seeking Policies." Australian Journal of Psychology, vol. 61, 2009, pp. 142–149, https://doi.org/10.1080/00049530802239303.

Prather, L., and B. Albertson. "Threat Perception and American Support for Border Walls." Journal of Politics, vol. 83, 2021, pp. 500–514, https://doi.org/10.1086/709992.

Ramirez, L. “Woman Helping Bay Area Immigrants Recalls Harrowing Border Crossing as a Child.” CBS San Francisco, CBS News, 2022, https://www.cbsnews.com/sanfrancisco/news/woman-helping-bay-area-immigrants-recalls-harrowing-border-crossing-child/.

Sedovič, L. Migrant and Non-Migrant Views on Immigration in Europe. 2025.

Smith, R. M. Stories of Peoplehood: The Politics and Morals of Political Memberships. Cambridge University Press, 2003.

Stephan, W. G., O. Ybarra, and G. Bachman. “Integrated Threat Theory and Prejudice Toward Immigrants and Refugees.” Journal of Applied Social Psychology, vol. 30, 2000, pp. 2221–2237, https://doi.org/10.1111/j.1559-1816.2000.tb02455.x.

Tajfel, H., and J. C. Turner. “An Integrative Theory of Intergroup Conflict.” The Social Psychology of Intergroup Relations, edited by W. G. Austin and S. Worchel, Brooks/Cole, 1979, pp. 33–47.

Tajfel, H., and J. C. Turner. “The Social Identity Theory of Intergroup Behavior.” Psychology of Intergroup Relations, 2nd ed., edited by S. Worchel and W. G. Austin, Nelson-Hall, 1986, pp. 7–24.

U.S. Department of Homeland Security. Immigration Yearbook 2022. Office of Immigration Statistics, https://ohss.dhs.gov/topics/immigration/yearbook/2022.

Musical Equity Between the U.S. and France: A Comparative Study of Accessibility, Cost, and Cultural Impact By Millen Salopek

Abstract

This paper explores the systemic differences in musical education between France and the United States, particularly in terms of accessibility, cost, and the social or personal development outcomes tied to music participation. Using qualitative and quantitative data collected from 32 student musicians—17 from Cannes, France, and 15 from San Francisco, California, in the United States—this study analyzes how cultural philosophy, institutional support, and socioeconomic factors shape young musicians' experiences and ambitions.. The findings suggest that while both systems have merit, France's publicly supported, inclusive conservatory structure promotes greater accessibility and long-term engagement in music, while the U.S. system emphasizes private investment and achievement, often limiting participation to those with financial means or extraordinary talent.

Introduction

Having studied music in both France and the United States, I became aware of stark differences in how music education is accessed, valued, and supported. These differences prompted an important question: Does affordability impact access and diversity in high-level music education, or are deeper cultural factors at play? I hypothesized that more affordable music education systems, such as France's, would lead to greater diversity, especially among high-achieving musicians.

Background: Philosophy and Structure of Music Education

France: "Musique pour tous"

France's educational philosophy embraces *"Musique pour tous"*—music for all. It is believed that access to musical training is an important educational priority for all children. Therefore, from early childhood, students are introduced to music through public schools and regional conservatories. Admission does not require talent, and progress is not pressured or forced at a specific tempo. Rather, the focus is on sustained enjoyment and cultural enrichment. Government-funded conservatories exist in most towns, with mobile conservatories serving rural areas, to ensure access. Music theory (solfège) is typically integrated early and consistently.

United States: Privatization and Merit

In contrast, the U.S. education system lacks a national music policy; whether music is offered depends heavily on district funding and priorities. Over 3.6 million U.S. students attend schools with no music programs at all. As a result, many students rely on private lessons—which can cost several hundred dollars per month—to receive a comparable music education. Admission to prestigious programs like pre-college conservatories is often competitive and talent-based. Otherwise, parents are left sourcing music education from a variety of private vendors, primarily through private lessons.

Methodology

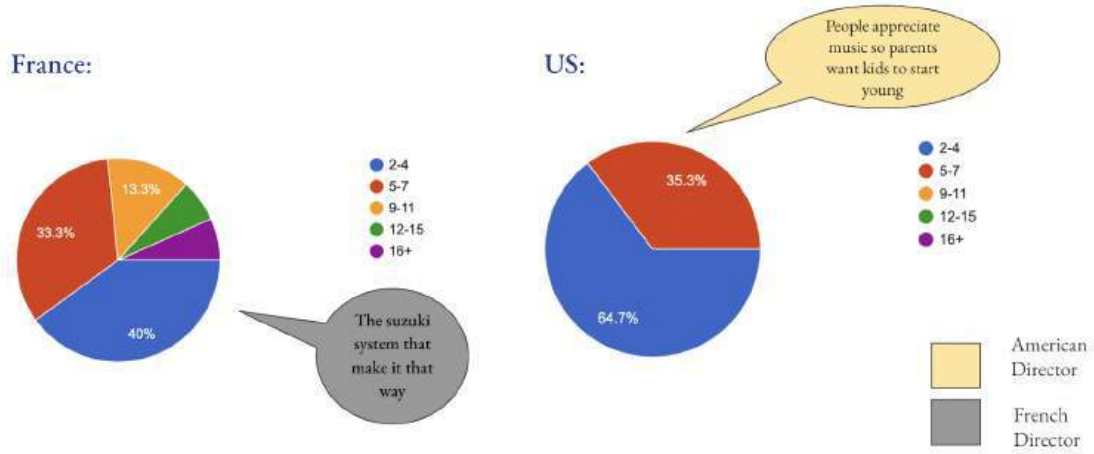
This study collected responses from 32 musicians—17 French and 15 American—through an anonymous bilingual survey circulated among two student groups: members of my former orchestra in France and students at the San Francisco Conservatory of Music (SFCM). The survey included both multiple-choice and open-ended questions covering the age of musical start, cost, instruction style, instrumental access, challenges, and the perceived impact of music on development.

Results and Analysis

Age and Motivation

Most students in both countries began musical education between the ages of 2–7, with family influence as a common factor in both countries. U.S. students frequently began through structured early programs like Suzuki, while French students more often mentioned exposure through cultural events or school. French students tended to be inspired by cultural experiences or personal interest, while American students more often began due to planned involvement by parents.

Figure 1: At what age did you start playing an instrument?



Instrument Choice

French students often selected instruments out of emotional connection or inspiration—such as seeing a street performer. U.S. students were more likely to mention parental guidance or the availability of certain programs or teachers. French students often chose instruments out of personal curiosity, while American students' decisions were more influenced by practicality or guidance.

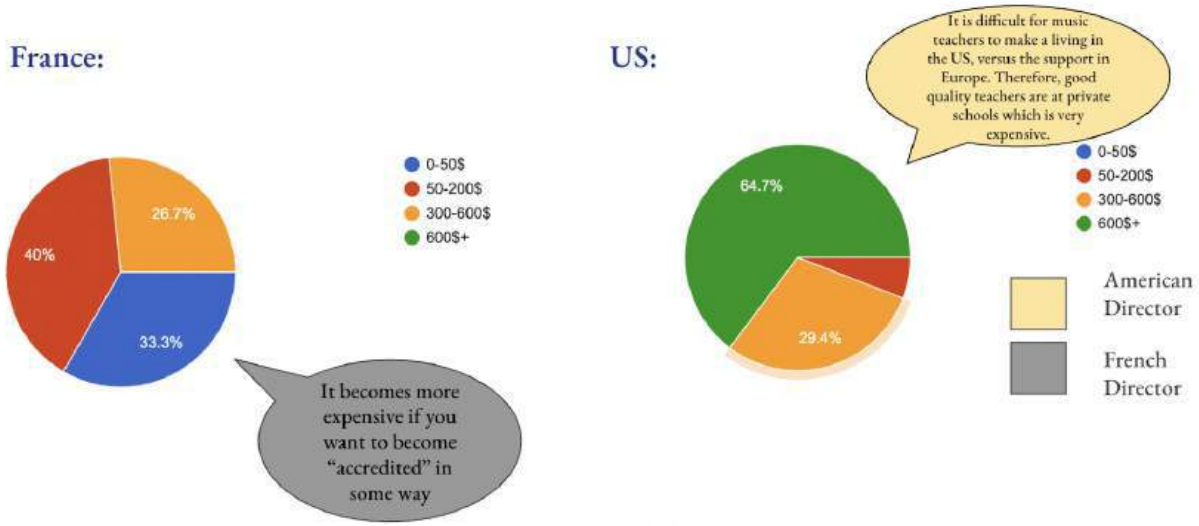
Instruction and Music Theory

Nearly all respondents in both countries had taken private lessons, but the path differed. French students often began in group settings and transitioned to individual study through conservatories. In the U.S., private lessons were essential early due to the absence of structured school programs. Both groups reported studying music theory around ages 6–10. French students were more likely to begin with publicly supported group classes, while American students depended on private lessons from the start.

Cost

Cost emerged as one of the clearest disparities. French students reported paying between 0–200 euros/month, with some paying nothing. U.S. respondents often reported monthly expenses exceeding $600, covering lessons, instruments, theory classes, and orchestral fees. This huge difference illustrates how France's public investment in music education removes economic barriers that are common in the U.S.

Figure 2: How much do you spend on musical activities per month?



Instrument Access

Most students in both groups owned their instruments. Renting was more common among French students, likely due to conservatory support. American students more frequently played multiple instruments, possibly reflecting a system that encourages musical breadth as a means of portfolio development for competitive programs.

Challenges

Common challenges included time management, motivation, and financial burden. Several U.S. students also mentioned burnout and pressure due to the competitive nature of their

programs. French students more frequently mentioned time and personal stress as limiting factors, but not cost.

Impact on Personal Development

Students from both countries overwhelmingly reported that music improved their mental health, social lives, and personal growth. U.S. respondents were more likely to cite academic benefits, while French respondents emphasized emotional expression and social bonding. Several French students described music as "therapeutic," while American students often associated it with discipline, achievement, and college preparedness. This reveals important, contrasting perspectives about the role of music in our lives: music as personal expression and connection in France, versus music as structured development and opportunity in the U.S.

Discussion

The French model, supported by government funding and cultural philosophy, appears to offer more equitable access to music education. By eliminating high costs and academic gatekeeping, French conservatories promote long-term engagement based on enjoyment and cultural value, rather than competition. It is clear that participants of all ages enjoy the social aspects of coming together and playing music, serving as a core motivation for continuing to play an instrument.

However, cultural expectations also shape participation. In France, music is considered an aesthetic and emotional practice (*aesthetic* and *praxial*), while in the U.S., it is often framed as a tool for cognitive development or academic advancement (*utilitarian*). Therefore, perhaps it is also the cultural expectations that allow for a certain freedom of expression and enjoyment in France, while in the US, music is somehow associated, for the masses, as an educational discipline. This was perhaps one of the most surprising results of the survey: that French children valued the social connection of music as primary over the personal connection to playing music. For Americans, the opposite was true.

Also, the difference in approach between the two countries impacts not only who engages in music but also how students interact and relate to it over time. In the U.S., where music is frequently tied to how good you are (auditions for competitive conservatories, overall performance in recitals, etc), students may experience higher stress and performance pressure. This could enhance certain technical abilities but also lead to burnout, particularly for younger musicians juggling multiple commitments. In France, the reduced focus on competitive outcomes allows musicians to keep a more personal and emotional connection to their instrument, even if their technical progression is slower.

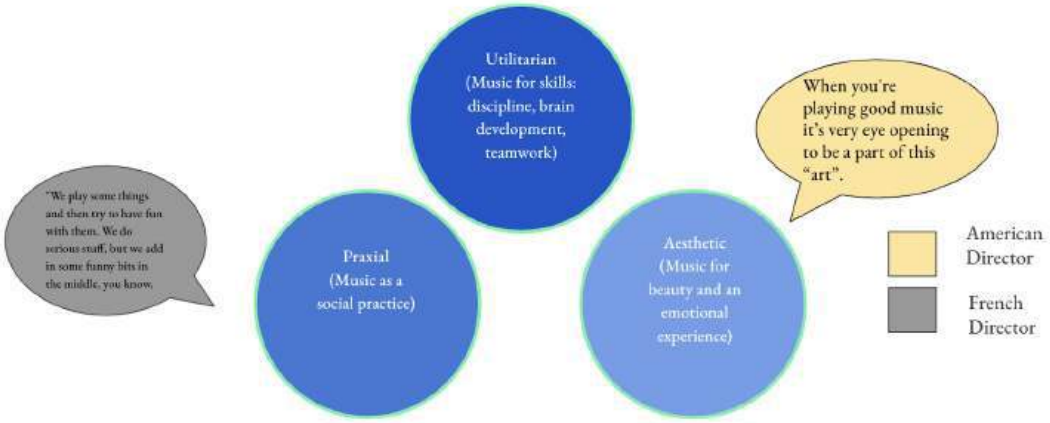
Due to these systems, American students may be more likely to stop playing once the external rewards, like college applications, are gone, while French students are more likely to continue music as a lifelong personal or social activity. This differentiation suggests that equity in music education is not just about removing cost barriers, but also about shaping environments that nurture personal motivation and continuous engagement. A more balanced model,

combining France's accessibility with the U.S.'s "striving for perfection", could create a system that balances both high achievement and broad participation.

Conclusion

The study confirms that affordability significantly affects musical access. French students face fewer financial barriers and generally experience music as a communal, expressive art form. American students often encounter music as a high-cost, merit-based endeavor tied to achievement. If the U.S. adopted a more inclusive, subsidized approach to music education, broader and more diverse participation might follow. If the U.S. embraced a more inclusive, publicly supported model, it could open the door for more students from diverse backgrounds to participate in and benefit from music.

Figure 3: Musical Interest is Driven by Cultural Expectations of the Musical Education System



Works Cited

Victoria Boler. “Three Philosophies of Music Education.” *Victoria Boler Music Education Blog*. https://www.victoriaboler.com/blog/three-philosophies-of-music-education

Ball State University Libraries. “Music Education Methods.” *LibGuides*. https://bsu.libguides.com/music-education/methods

ArtsEdData. “Millions of U.S. Students Denied Access to Music Education.” *California Arts Council*. https://artseddata.org/millions-of-u-s-students-denied-access-to-music-education-according-to-first-ever-national-study/

California Arts Council. “Money for Music Education: A District Analysis.” https://arts.ca.gov/researchpage/money-for-music-education-a-district-analysis-of-the-how-what-and-where-of-spending-for-music-education/

Interview with Nadine Miccio, French Music Educator. April 28, 2025.

Interview with Asuka Yanai, American Music Educator. May 18, 2025.

Human-Steered Evolution of Rotational Shapes By Luka Rekhviashvili and Aleksandre Khabashvili

0. Abstract

Interactive evolutionary computation (IEC) combines the search capabilities of evolutionary algorithms and subjective human evaluation. We explore IEC as applied to a shape-generation problem to evolve an optimal axisymmetric 3D object, a spinning top, to maximize simulated spin time while remaining aesthetically pleasing to a human. Candidate shapes are encoded by fifteen radial parameters and are evolved using a steady-state genetic algorithm that employs blend crossover, Gaussian mutation, and controlled immigration. The overall quantified fitness of an individual is a weighted sum of a physics-based surrogate score – an estimate of spin-down time – and a subjective human rating provided during scheduled evaluations. The surrogate computes each shape's moment of inertia and drag torque to derive a normalized spin time. The human component uses subjective ratings to determine anchor and guard scores. The fitness contributions of specific shapes determine their influence over subsequent generations. We compared an autonomous run (control, no human-in-the-loop), a Human-in-the-Loop (HITL) run using numerical ratings, and a HITL run using pairwise comparisons. Results from our experiment show steady improvement in spin-down time across generations and a decrease in population diversity as convergence occurs. The human-guided run produced a visually pleasing shape with slightly lower spin performance than the autonomous optimum. These outcomes illustrate how limited human input can steer evolution toward user-preferred designs, yet may sacrifice some aerodynamic optimality. Future work should incorporate dynamic weighting of objectives and higher-fidelity physical models to quantify the trade-offs inherent in human-in-the-loop design.

Keywords: interactive evolutionary computation; surrogate model; aerodynamics; human ratings; genetic algorithm; shape optimization; human-in-the-loop

1. Introduction

1.1 Background and context

Evolutionary Computation (EC) is a computational model for finding optimal solutions to problems. As the name suggests, it borrows from biological evolutionary mechanisms. EC uses genetic algorithms to evolve a population by assigning fitness scores determined by functions to individuals and employing mechanisms of mutation, recombination, and immigration. Using these evolutionary mechanisms, EC evolves populations toward an optimum, with individuals' assessed fitness increasing over generations. Interactive Evolutionary Computation (IEC) is a type of EC that uses these same mechanisms; however, instead of fitness scores of individuals being assigned by an objective function, they're determined through subjective human evaluation. In IEC, a human rates or chooses among a subset of individuals based on their proximity to an imagined optimum. The collaboration of the evolutionary algorithm with the

human user makes IEC a human-in-the-loop (HITL) system – a computational system involving a human operator. IEC's main advantage is its ability to assess individuals based on factors that would elude numerical analysis by functions, such as aesthetic preference, personal satisfaction, or other creative or intuitive sensibilities intrinsic to humans. Applications span art, music, graphic design, and engineering design. (Takagi 1275–1277)

The central obstacle in IEC is the limitation of human throughput. Users tire, causing slow evaluation, constraints on population size, and skewed selection (such as a single lineage being favored, reducing diversity). Reviews and empirical studies have cited user fatigue as the main bottleneck in IEC application and research. To address this, research has focused on mitigating human fatigue and its effects through interface design and exploring remedies such as user preference prediction via a surrogate model, active selection techniques, and mixed-initiative workflows. (Takagi)

IEC interfaces rely on two feedback modes – cardinal ratings and ordinal comparisons. In the former, users score individuals on a fixed numerical scale (e.g., 1–5 or 1–10). This approach is easy to implement and is most suitable when differences among individuals are significant. A downside to this approach is a possible shift or fluctuation in the user's subjective ratings over time. High attention and memorization of past individuals are necessary from users to maintain a consistent scale; however, as users fatigue, more inaccurate or coarse ratings tend to occur (with the intent to speed up the process, consciously or subconsciously). In the second feedback mode, instead of rating individuals numerically, users pick winners among pairs of individuals, often in a small tournament. This approach is more precise when differences between individuals are slight; however, it tends to run into more inaccuracies when there are more radical differences.

1.2 Problem statement and rationale.

This work explores the application and technicalities of IEC using the example of designing an axisymmetric 3D shape to maximize aerodynamic efficiency (and thus spin-down time) while also meeting human aesthetic and practical preferences. The shape is envisioned as a spinning top—a children's toy that encounters drag from the surrounding air. Reduced drag leads to a longer spin-down time; however, shapes that minimize drag may not be visually appealing. The goal in applying IEC to this problem is to balance both technical performance and subjective preference. User ratings can help guide the evolution of the design towards a shape that is more visually appealing to humans without significantly compromising aerodynamic performance. The research challenge is to identify the most effective rating system for IEC. This study tests a new approach to rating and compares it to established methods.

1.3 Significance and purpose.

Our study contributes to the field of IEC in three main ways. First, it offers a compact, reproducible HITL testbed: an axisymmetric spinning-top design that links a fast physics surrogate for spin-down with human feedback. The task is simple enough to allow quick iteration and explicit visual judgments, yet rich enough to reveal the trade-off between technical optimization and user appeal. Low-latency scoring keeps users engaged; a small, interpretable parameterization maps to individual shapes; and the surrogate is inexpensive, making it ideal for

testing feedback protocols. Second, it assesses the effectiveness of IEC feedback modes under controlled human testing. We measure the improvement in design per human judgment and per generation, as well as decision time, user fatigue, rating stability, and population diversity. Third, it demonstrates a hybrid user rating scheme combining scale scores with pairwise choices. Initially, scale ratings are used to explore and guide; afterwards, head-to-head comparisons of individuals resolve finer distinctions. This design addresses the weaknesses of both feedback modes (like scale drift and comparison complexity) while leveraging their strengths.

1.4 Objectives

The specific objectives of this study are to:

1. Build a compact, reproducible IEC testbed (spinning-top design) coupling a fast spin-down surrogate with human feedback. 2. Compare different feedback protocols under identical evaluation budgets: cardinal scoring, pairwise choice, and a staged hybrid approach. 3. Quantify efficiency and human cost: improvement per judgment/generation, decision time, fatigue, and rating reliability. 4. Produce a protocol recommendation for mixed objectives (spin performance + appeal) and release code/logs for replication.

1.5 Scope and limitations.

The study focuses on axisymmetric shapes defined by fifteen radii; thus, conclusions may not apply to other shape representations or higher-dimensional design spaces. The physics surrogate approximates the drag torque using simplified skin-friction and end-face drag formulas and assumes a constant resistive torque at the initial angular velocity. The surrogate is not a complete fluid-dynamics model and may misestimate absolute spin times. The human evaluators for the experiment were limited to a few users working with a prototype interface; therefore, results may not be suitable for extrapolating average human preference in a broader population.

2. Methods

2.1 Research design.

We use a controlled experimental design that compares algorithmic runs under different human-feedback conditions. The primary outcome is the quality of the final design, assessed subjectively (visual appeal ratings) and objectively (spin-down time calculations). Secondary process-level outcomes include population diversity and convergence behavior, as well as the speed at which the algorithm reaches high-quality solutions. Tertiary, human-side outcomes include fatigue and workload measurements. This setup mirrors a typical engineering workflow for shape optimization, where both the final product's performance and the process to achieve it are considered.

The independent variable is the rating mode. Each participant works with a single, fixed, random seed that initializes the evolutionary algorithm's pseudorandom generator, with consistent initial populations and operator sequences across conditions, ensuring reproducibility of the protocol. The participant completes three interactive runs with distinct modes of individual assessment: (I) Cardinal (fixed-scale scoring), (II) Ordinal (pairwise/tournament choice), and (III) Hybrid (cardinal followed by head-to-head comparisons). This is followed by a fourth control run with exclusively computer assessment, without a HITL protocol.

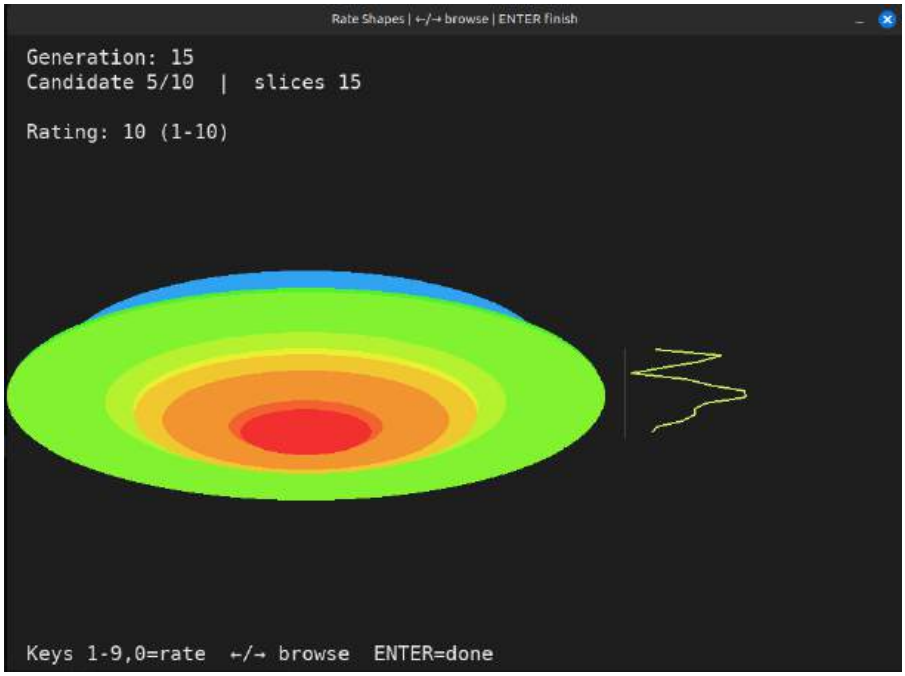


Figure 1: Cardinal rating UI

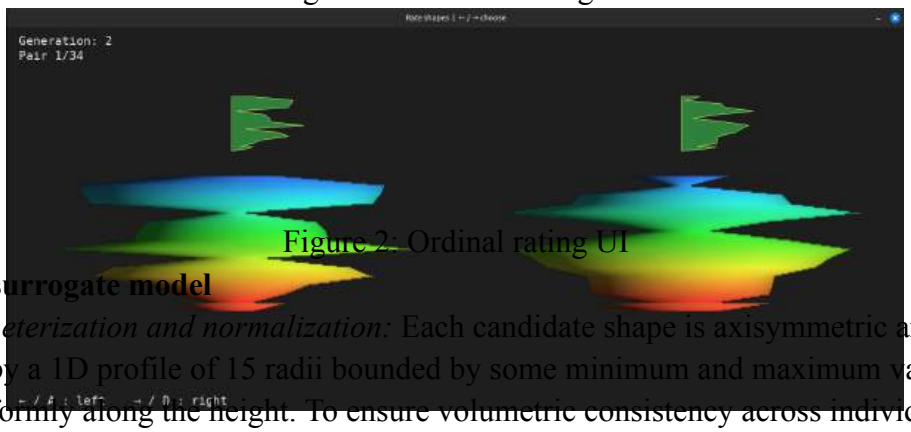


Figure 2: Ordinal rating UI

2.2 Physics surrogate model

Shape parameterization and normalization: Each candidate shape is axisymmetric and represented by a 1D profile of 15 radii bounded by some minimum and maximum values sampled uniformly along the height. To ensure volumetric consistency across individuals, we apply a simple normalization after variation (crossover/mutation) and before evaluation:

$$normalize\left(r_{1\ldots15}\right) \quad such\ that \quad V(r) = V_0,$$

Where $V(r)$ is the volume determined by the radial profile, and V_0 is a fixed reference volume. This circumvents individual advantages due to scale, keeping moment-of-inertia comparisons fair.

Moment of inertia: Presuming the body to be a stack of thin disks, the axial moment of inertia I is given as:

$$I = \frac{1}{2}\rho \sum_{i=1}^{15} r_i^2 \Delta V_i,$$

where ρ is the material density (kept fixed across individuals), and ΔV_i is the volume of the thin disk for a segment i.

Sidewall aerodynamic torque: We refine the profile by linear interpolation onto a denser grid (e.g., 10 subdivisions per original interval). Let consecutive fine radii be r_j, with average $\bar{r}_j$ and axial spacing Δz. The area A_j of each segment when treated as a frustum is:

$$A_j = 2\pi \bar{r}_j \sqrt{(\Delta z)^2 + \left(r_{j+1} - r_j\right)^2}.$$

At a prescribed initial angular speed ω_0, the local tangential speed at radius $\bar{r}_j$ is $v_j = \omega_0 \bar{r}_j$. The Reynolds number (length scale $\bar{r}_j$) is

$$Re_j = \frac{\rho_{air} v_j \bar{r}_j}{\mu},$$

where μ is air viscosity.

We use standard flat-plate correlations for the skin-friction coefficient $c_{f,j}$, clipped below by a laminar minimum:

$$c_{f,j} = max\left(0.074 Re_j^{-1/5},\ 1.33 \frac{Re_j^{-1/2}}{\sqrt[4]{2}}\right).$$

The local shear stress is $\tau_j = \frac{1}{2}\rho_{air} v_j^2 c_{f,j}$. The corresponding torque contribution from that frustum segment is $dT_j = \tau_j A_j \bar{r}_j$. Summing over all frusta gives the sidewall drag torque:

$$T_{wall} = \sum_j dT_j.$$

End–face drag: To account for pressure drag on the top and bottom faces, as well as friction, assuming the body touches the ground, we add a compact term parameterized by the top and bottom radii r_{top}, r_{base}:

$$T_{faces} = C_D \frac{1}{2}\rho_{air} \omega_0^2 \left(r_{top}^4 + r_{base}^4\right),$$

with C_D a constant coefficient reflecting the integrated face drag. This term captures the r^4 scaling of integrated face torque under uniform rotation (based on dimensional analysis).

Smoothness penalties: To discourage overly wavy or irregular profiles, we apply two simple penalties: (i) a curvature penalty based on the sum of absolute second differences of the radius sequence (normalized to 1 for a flat cylinder),

$$P_{curv} = \alpha \sum_{i=2}^{14} \left| r_{i+1} - 2r_i + r_{i-1} \right|,$$

and (ii) a "hump" penalty $P_{hump} = \beta max\left(0, N_{humps} - 1\right)$ that increases with the number of sign changes in the slope of the profile beyond one (i.e., a penalty for more than one inflection point).

The total aerodynamic drag torque is then:

$$T_{drag} = T_{wall} + T_{faces} + P_{curv} + P_{hump}.$$

Spin–time proxy: Assuming a nearly constant resistive torque at the initial speed, the spin–down time is approximated from the initial rotational momentum divided by the opposing torque, with a small stabilizer ϵ to avoid division by zero:

$$t_{spin} \approx \frac{I\omega_0}{T_{drag}+\epsilon}.$$

This surrogate is inexpensive to evaluate, captures the main dependencies of spin-down on the radius profile (through I and T_{drag}), and is used as the objective component in our fitness scoring.

2.3 Evolutionary algorithm

We employ a steady-state genetic algorithm with a population of N individuals (in the prototype $N = 30$) and run it for a predefined number of generations G. The steps of the algorithm are as follows:

- Initialization: Create an initial population of 15-radius arrays, representing candidate shapes. Radii are within specified bounds to ensure plausible shapes. The sum of the radii is normalized to a constant to avoid volume increases that might boost inertia.
- Evaluation: For each individual, the physics surrogate computes a spin-down time t_{spin}. In autonomous runs, fitness = normalized t_{spin}. In interactive runs, the overall fitness is incorporated with human anchor and guard scores.
- Human evaluation (skipped if not HITL): After the initial run, every K generation, a subset of candidates is shown to the user in a graphical interface. Feedback is collected in two distinct rating modes. In Cardinal mode, the user assigns a rating on a 1-10 scale to shapes displayed sequentially; these values are stored as anchor scores attached to those specific individuals. In Ordinal mode, the user makes preferential choices in head-to-head bouts between individuals, creating a ranking among the displayed set; this relative order is converted into pseudo-ratings ranging from 1–10 and used as anchors. After anchors are set, every individual—rated or not—receives a human-preference score H that combines its own anchor (if one exists) with a guard bonus proportional to its similarity to anchored shapes, with the bonus decreasing with distance in shape space. Unrated individuals are assigned a neutral anchor value equal to the current population's mean rating, ensuring no shape lacks a defined human score. All stored human contributions (anchor and guard scores) decay over generations to keep preferences adaptive, giving precedence to new feedback. Finally, raw human scores are linearly mapped to [0,1] (e.g., rating 1 → 0, rating 10 → 1).
- Fitness calculation: Each individual's overall fitness F is computed as a weighted sum of the physics objective and human preference components. Specifically, we use $F = w_{phys}\tilde{t}_{spin} + w_{human}H$, where $\tilde{t}_{spin}$ is the normalized spin-down time and w_{phys}, w_{human} are weights (which can change in the Hybrid mode stages).

- Selection and elitism: Individuals are ranked by fitness. The top E, the subset of elite individuals, proceeds unchanged to the next generation. Additionally, some top performers are selected as parents for crossover.
- Reproduction: Offspring are created by applying blend crossover (BLX-α) to randomly chosen parent pairs. Each gene (radius r_i) of the offspring is sampled uniformly from an interval extending α beyond the parents' values to favor diversity. A Gaussian mutation with decaying variance perturbs each offspring gene.
- Immigration: To combat premature convergence, a small number of immigrant individuals with random radii are introduced each generation, and the lowest-ranked individuals are removed.

This loop (evaluation → selection → reproduction → replacement) repeats until the generation count reaches G.

2.4 Participants and sample.

The pilot study recruited three senior (grade 12) students from a senior mathematics class in the Guivy Zaldastanishvili American Academy in Tbilisi (GZAAT) as participants. Two participants were right-handed, and one was left-handed. Two of the three participants self-reported 20/20 vision, while one had near-sightedness corrected with glasses. Participation was voluntary, with informed consent obtained from the subjects, and no additional exclusion criteria were used.

Each participant completed the procedure individually, with the order of feedback modes (Cardinal, Ordinal, Hybrid) randomized and participants not explicitly informed which feedback system was used in a given run, creating a single-blind setup. The given task was to evaluate the aesthetic quality of spinning-top designs based on their own subjective judgment. After completing three interactive runs, each participant also provided additional ratings on a 1-10 scale for four shapes drawn from different random seeds, enabling unbiased subjective evaluation of the final designs. These ratings were used for post-analysis of visual preferences.

2.5 Data collection.

Each run yields data based on both the algorithm and the user's interaction. We record the radius vector, the computed spin-down time, the user's rating (anchor score), and the residual guard score for each shape, as well as the population diversity for every generation. We also collect the user's self-reported fatigue and the blind subjective ratings of shapes from other runs to compare aesthetic quality without bias.

For the simulation and results presented here, the data consist of each generation's best and mean spin-down times and the population diversity, measured by the mean pairwise distance in radius space, to assess convergence and exploration. In a complete interactive procedure, one would also analyze the distribution of human ratings over time, the evolution of anchor and guard contributions, and perform statistical tests (e.g., t-tests or Mann–Whitney U tests) to compare interactive outcomes to autonomous ones on performance and user satisfaction.

2.6 Variables and measurements.

Key variables include:
- Independent variables: the fifteen radii defining each shape; random seeds and genetic algorithm parameters (population size, mutation variance, crossover parameter α, etc.); and the feedback mode (noHITL, Cardinal, Ordinal, Hybrid).
- Dependent variables: the surrogate-computed spin-down time t_{spin}; the anchor rating assigned by the user (when applicable); the guard score calculated from similarity to anchored shapes; and the overall fitness score based on these values.
- Derived measures: population diversity (average Euclidean distance between individuals' radius vectors) and the ranking or spin time of final solutions.

2.7 Procedure.

In autonomous (noHITL) runs, the algorithm was run for 60 generations with populations of 30. Spin-down times were computed using the physics surrogate model described above, with the fitness equaling the normalized spin time, neglecting the human component. The top five individuals were preserved each generation (elitism); five additional parents were selected probabilistically; offspring were generated via BLX-α crossover with α = 0.3 and Gaussian mutation; five random immigrants were added; and the mutation standard deviation σ decayed each generation gradually. The same loop repeated until the final generation.

In interactive runs (Cardinal, Ordinal, Hybrid), the same genetic steps were taken, with additional user ratings of shapes every five generations. In Cardinal mode runs, users provided 1–10 ratings for about six shapes during each evaluation. In the Ordinal runs, users performed a tournament-style selection, picking preferred shapes in a bracket, which yielded a rank order. In Hybrid runs, Cardinal feedback was used for the first few evaluations to broadly guide the selection, with a switch to Ordinal comparisons for later generations, allowing for fine-tuning of preferences among similar, high-performing individuals. The algorithm's internal parameters (like weights w_{phys}, w_{human}) were adjusted dynamically throughout the Hybrid run, with the physics component being heavier initially to optimize performance, and a subsequent increase in the weight of the human element coinciding with the switch to Ordinal ratings, placing priority on aesthetics.

2.8 Data analysis.

We recorded the best and mean spin-down times, as well as population diversity, for every generation of each run. These metrics are plotted to visualize convergence behaviors. After the final generation of each run, we note the best individual's spin-down time as the outcome performance. In interactive runs, we also consider the final shape's aesthetic rating (from the blind evaluation) to gauge fulfillment of user preferences. Where applicable, we compare runs (e.g., autonomous vs. interactive) in terms of final performance and diversity. Given the small sample of participants, statistical analysis is limited; instead, we focus on qualitative, per-participant comparisons. We also examine how user rating patterns evolved (scale drift vs. stability) and how that impacted the algorithm's selection pressure.

2.9 Ethical considerations.

Human-in-the-loop studies raise concerns about fatigue, bias, and informed consent. In our setup, the user was asked to rate a small subset of shapes at infrequent intervals (every five generations in the interactive runs) to minimize fatigue. The anchor/guard mechanism that propagates ratings to similar individuals also takes much of the scoring workload off the user. Ratings decay over time so that early preferences do not dominate indefinitely, helping combat any bias from initial impressions. All data collected were anonymized and used solely for research analysis. Future work should involve more users and include usability and satisfaction surveys to evaluate the interface and process from the human perspective.

3. Findings and Analysis

3.1 Spin-Down Performance Evolution

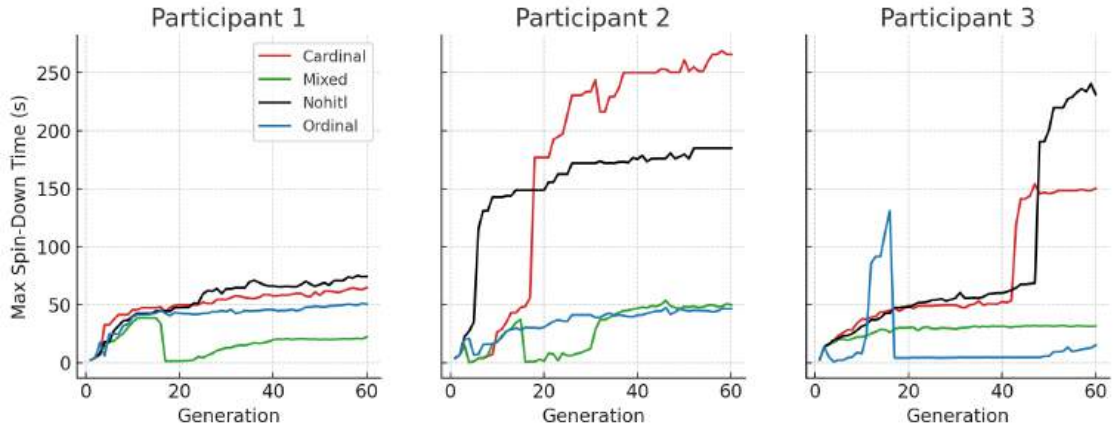


Figure 3: Evolution of maximum spin-down performance over generations for each condition (No-HITL control, Cardinal, Mixed/Hybrid, and Ordinal) for all three participants. Each subplot shows one participant's runs with the same random seed, highlighting how performance improved and then plateaued across different feedback modes.

As shown in Figure 3, all evolutionary runs showed a rapid initial rise in maximum spin time. The autonomous (no-HITL) control runs exhibited consistent, significant improvements in aerodynamic performance across all trials, with participant 2's trial showing the most dramatic increase in spin time, from 3 seconds to over 140 seconds, over just 10 generations. The spin time reached by the final generation varied across trials due to differences in the random seed. The interactive runs (Cardinal, Ordinal, and Hybrid) showed similar early improvements, typically capturing the most significant magnitude of improvement over the first 20 generations. The HITL runs tended to plateau at lower overall spin times than the purely performance-driven optimization method (no-HITL), save for the exception of the Cardinal run in the second participant's trial, which peaked at ~269 seconds, outperforming the control run's ~185 seconds. Notably, Cardinal runs consistently outperformed the other interactive modes, which reached lower ceilings across all seeds. Notably, the maximal spin time varied widely across generations in the interactive systems, showing peaks and valleys, in contrast to the constant upward trend in the control runs, with some runs reaching their peak spin times in earlier generations, before declining towards the end. The former highlights a trade-off between aesthetic quality and spin

time, where ratings of individuals in interactive runs may not coincide with the best performance, and this also accounts for the higher variability. Overall, the results show strong initial improvements across all conditions, with HITL modes converging more slowly and settling on solutions with lower spin-down times than the autonomously achieved optimum.

3.2 Population Diversity and Convergence.

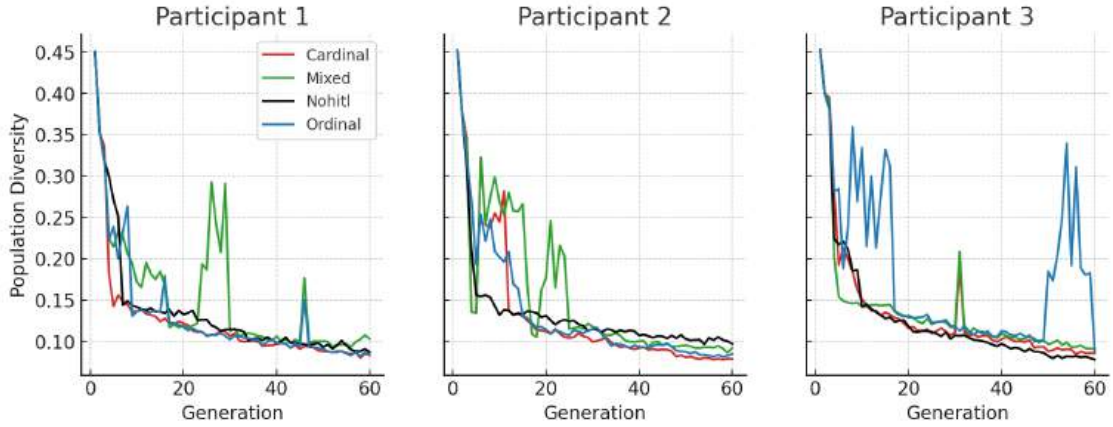


Figure 4: Population diversity (average pairwise shape difference) over generations for each participant's runs. Higher values indicate a more varied population. Interactive runs (especially Ordinal and Mixed) maintained higher diversity in early generations, converging more slowly than the no-HITL control.

Across all conditions, population diversity decreased over generations as the evolutionary search advanced individuals toward the optimum, converging on a similar minimum in the last generation. However, the rate and extent of the convergence varied between autonomous and interactive runs. All runs started with a high, normalized diversity index of ~0.45 for the random initial population. The no-HITL runs experienced the most rapid decline in diversity, with a similar general trend across all three trials, typically dropping to roughly 25-35% of its initial value (~0.13–0.14 diversity index) by around the tenth generation. This reflects the algorithm's consistent adherence to the surrogate objective, in turn funneling the population toward a narrow region of the design space with the highest spin performance. Runs using human feedback maintained higher diversity in the early stages of evolution and also exhibited greater variance in diversity across generations. This suggests that the presence of subjective ratings had a diversity-preserving effect, preventing the algorithm from prematurely discarding individuals that, while perhaps suboptimal from a pure aerodynamic standpoint, were still favored by the user. For example, under cardinal feedback, one participant's population still had a diversity of ~0.24 at generation 10 – nearly double the diversity of that participant's control run at the same point. Notably, the mixed-feedback mode often retained the highest diversity at intermediate generations, possibly due to its alternating evaluation criteria. All feedback modes eventually converged to a minimum diversity index of around 0.10 by the final generation. However,

interactive runs still showed a modestly higher diversity than autonomous runs in two of the three trials.

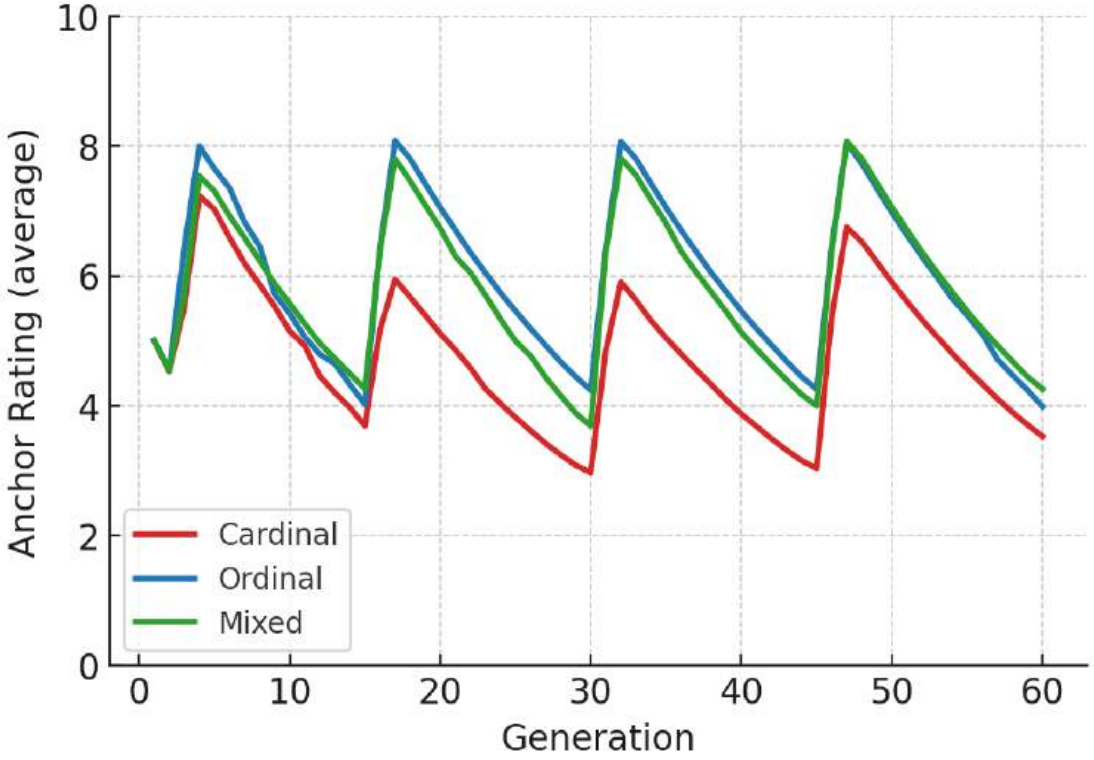


Figure 5: Average anchor rating (user-given aesthetic score) of top designs over generations in the interactive runs. Cardinal runs (red) show a decline in score (rating drift) over time, whereas Ordinal runs (blue) maintain consistently high top scores. The Mixed strategy (green) initially behaves like the Cardinal mode, stabilizing after switching to comparisons.

Human Rating Scale Behavior (Figure 5). To better grasp the user's role in steering evolution, we tracked the average anchor ratings, i.e., the human scores assigned to the top designs across successive generations of the interactive modes. Cardinal rating modes showed a significant drift in the rating scale, with anchor scores fluctuating and gradually declining, peaking around 8 out of 10 early on and falling to around 3-4 later on in one of the trials. This downward drift suggests that the participant's internal standard for a good design became progressively more stringent as they saw better or more varied examples, as the user reserves high scores only for increasingly preferable designs, or simply gives lower scores due to tiredness. In comparison, ordinal feedback runs maintained a relatively consistent trend in the progression of evaluations, peaks remaining in the 7-8 range. This difference arises from the nature of ordinal comparisons – for every bout, there is a single winner; thus, rankings across different evaluations are normalized, as each rated generation has a defined ranking with standardized assigned scores. The mixed feedback runs behaved similarly to the cardinal mode

towards the start, showing slight drift where numerical ratings were used, but normalizing after the switch to ordinal. Overall, Figure 5 demonstrates that cardinal (absolute) ratings were prone to inconsistency due to scale drift over time, whereas ordinal (relative) judgments provided more stable anchors.

3.3 Final Performance and Preference Trade-offs.

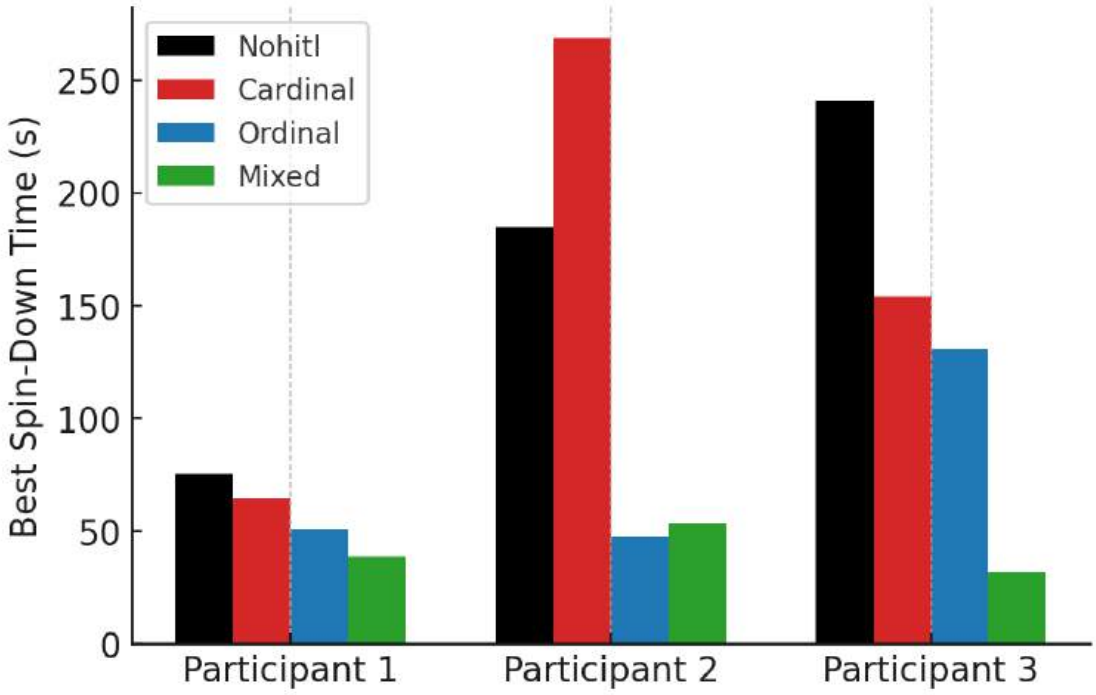


Figure 6: Best spin-down times achieved under each feedback condition for each participant. Bars group the final outcomes by participant, showing the trade-off between aerodynamic performance (spin time) and inclusion of human preferences. Autonomous (no-HITL) runs reached the highest spin times; ordinal and mixed-feedback runs ended with substantially lower spin times, while cardinal runs were intermediate (and in one case exceeded the no-HITL performance).

The final outcomes of the evolutionary runs under each feedback condition highlight a trade-off between aerodynamic performance and human aesthetic preference, as summarized in Figure 6. In terms of pure spin-down time (objective performance), the autonomous runs (no-HITL) achieved the best results overall for most participants. The control runs consistently found designs with the longest spin durations – for example, one participant's no-HITL run yielded a top spin time of ~240 s, and another's reached about 185 s. These figures were higher than those from the corresponding interactive runs, indicating that when the algorithm was free to optimize solely for physics (e.g., minimizing drag), it could exploit the design space to maximize spin performance. The human-in-the-loop runs, by contrast, often ended with lower spin-down times, reflecting the influence of subjective criteria. In particular, the ordinal and

mixed feedback conditions resulted in substantially shorter spin times for the best designs, often on the order of only tens of seconds. Across participants, the final best spin times in the ordinal condition were about 47–130 s, and in the mixed condition, only ~32–53 s, markedly below the autonomous benchmarks. These lower values imply that the evolutionary search was guided toward designs favored by the user (e.g., aesthetically pleasing shapes) at the expense of aerodynamic optimization. Participants using ordinal (comparative) feedback tended to prefer certain visual or stylistic features, and the algorithm, balancing the human's input, thus evolved shapes that satisfied the user's tastes even if those shapes did not spin as long. The outcome for the cardinal feedback condition was more variable: in two of three cases, the cardinal runs' best spin-down times (e.g. ~65 s and ~154 s for different participants) were intermediate – lower than the no-HITL control but higher than the purely ordinal or mixed cases. This suggests that numerical rating, which provides a direct scalar fitness signal, allowed those participants to reward performance to some extent in a compromise between spin optimization and preference. In one striking case mentioned earlier, the cardinal run even outperformed the autonomous run (achieving ~269 s vs. ~185 s in the control for that participant). This anomaly likely occurred because the participant's ratings strongly reinforced the surrogate objective – effectively, the user gave high scores to the same high-spin performers the physics model favored, thereby boosting those individuals' selection probability beyond what the surrogate alone would have done. Such an outcome underscores that when human preference aligns with the objective, interactive evolution can equal or even enhance performance; however, such cases may be scarce. In general, Figure 6 shows that introducing human preference (especially via ordinal comparisons) shifts the search toward a different region of the design trade space: one that prioritizes subjective appeal and satisfaction over maximal spin time.

There is also evident variability in how the trade-offs above played out between different participants. Each participant's distinct interaction style and preferences influenced the results. For instance, one participant may have tended to reward designs that seemed more aerodynamically efficient, as a result of their preconceived notions of a spinning top, consciously or unconsciously pushing the algorithm to prefer and refine the highest-performing designs. In contrast, Participants 2 and 3 gave feedback that led to more pronounced performance sacrifices, with their ordinal and mixed runs ending with relatively low spin times, with a minimum of around 30-50 seconds, implying they favored certain aesthetic traits that counteracted performance enough to divert the search away from high-spin solutions. Participant 3's ordinal run is especially illustrative of the former, at one point having discovered a shape with a spin-down time of ~131 seconds, though having foregone that shape for a final design with a much shorter spin time of ~15 seconds. Such differences highlight the human element of IEC – with personal preference, consistency of evaluation, and fatigue all influencing evolutionary trajectory and outcomes.

In addition to performance–preference trade-offs, subjective workload differed across feedback modes. Perceived fatigue was highest in the Cardinal condition, followed by the Mixed strategy, and lowest in the Ordinal condition. Cardinal rating required repeated recalibration of

an absolute numerical scale, which became increasingly demanding as designs improved and perceptual differences narrowed, contributing to elevated cognitive load and observable rating drift. The Mixed strategy reduced perceived fatigue in later generations after transitioning to comparative judgments but retained some early-stage burden associated with numerical scoring. Ordinal feedback, based on relative comparisons between paired designs, was reported as less cognitively demanding and more sustainable over extended interaction. Decision time exhibited a complementary pattern. In the Cardinal condition, decision time per evaluation decreased rapidly over generations, plausibly reflecting habituation and compression of the rating scale, whereas decision time in the Ordinal condition remained comparatively stable throughout the run. These patterns indicate that while Cardinal feedback can provide strong early selection pressure, it incurs greater cumulative cognitive cost, whereas Ordinal feedback supports sustained user engagement with reduced workload, at the expense of finer-grained performance discrimination.

3.4 Further Analysis.

The primary advantage of no-HITL runs was their efficacy in producing the most technically adept shapes, as per the optimization criteria. This suggests a compromise between performance and aesthetic quality in interactive modes, with a trade-off in spin time for greater visual appeal. The incorporation of the human element may steer evolution toward designs that balance performance with aesthetic quality. Our findings further reinforce the impact of the human element, with evident differences among participants due to their distinct preferences, as well as rating scale drift, a possible consequence of user fatigue. Interactive runs also consistently showed greater variability in both population diversity and spin time than autonomous runs. The different rating modes also showed significant differences, with the cardinal runs indicating possible advantages for maximizing performance, though with the caveat of rating scale drift. While ordinal ratings might not exhibit rating drift, they can also be disadvantageous for not capturing the full extent of user preferences, with pairwise bouts leading to a coarser rating system than in the cardinal mode. The mixed strategy offers a middle ground, but in our trials, it leaned closer to ordinal behavior in outcomes. These findings underscore the inherent trade-off in human-in-the-loop evolutionary design: user guidance can successfully direct the algorithm toward more subjectively pleasing or domain-appropriate solutions, but achieving this can compromise objective performance, emphasizing the need for careful tuning of human vs. objective weighting in interactive evolutionary systems.

4. Discussion

4.1 Restatement of key findings.

The simplified autonomous experiment demonstrates that a steady-state genetic algorithm can increase spin-down times of axisymmetric shapes over successive generations, confirming that the surrogate model provides a useful, albeit rough, objective. Population diversity declines as selection and reproduction favor individuals around similar high-performing designs, but immigration and mutation help maintain some exploration. Our interactive runs, when examined qualitatively, indicate that human-in-the-loop optimization can steer the search toward designs

that satisfy subjective criteria with relatively little direct human evaluation. The anchor/guard mechanism effectively propagates limited human input to many individuals, eliminating the need for exhaustive user scoring. In practice, a designer might use such a system to co-evolve product shapes that balance performance with aesthetics. However, our results also underscore that when only the surrogate is optimized (the no-HITL control), the algorithm discovers aerodynamically efficient shapes that may not be aesthetically appealing. Balancing these objectives requires careful selection of weighting coefficients and feedback strategies.

4.2 Implications and significance.

These results, together with qualitative observations from the interactive prototype, suggest that human-in-the-loop optimization can indeed guide evolution toward designs that satisfy subjective user criteria, but with some cost to the primary objective. The anchor/guard scoring scheme appears to propagate user preferences effectively: even sparse human feedback can shift the direction of evolution. This implies that in real-world applications, a designer or end-user could meaningfully bias an evolutionary search toward personally favored solutions without needing to evaluate every candidate. On the downside, the convergence to optimal performance is slower or incomplete under human guidance. Our findings are consistent with the idea that introducing a human aesthetic objective inherently creates a multi-objective trade-off with the technical performance objective. In practice, interactive evolutionary design must account for this trade-off, perhaps by dynamically adjusting the weight given to human input over time or by training users to provide consistent feedback.

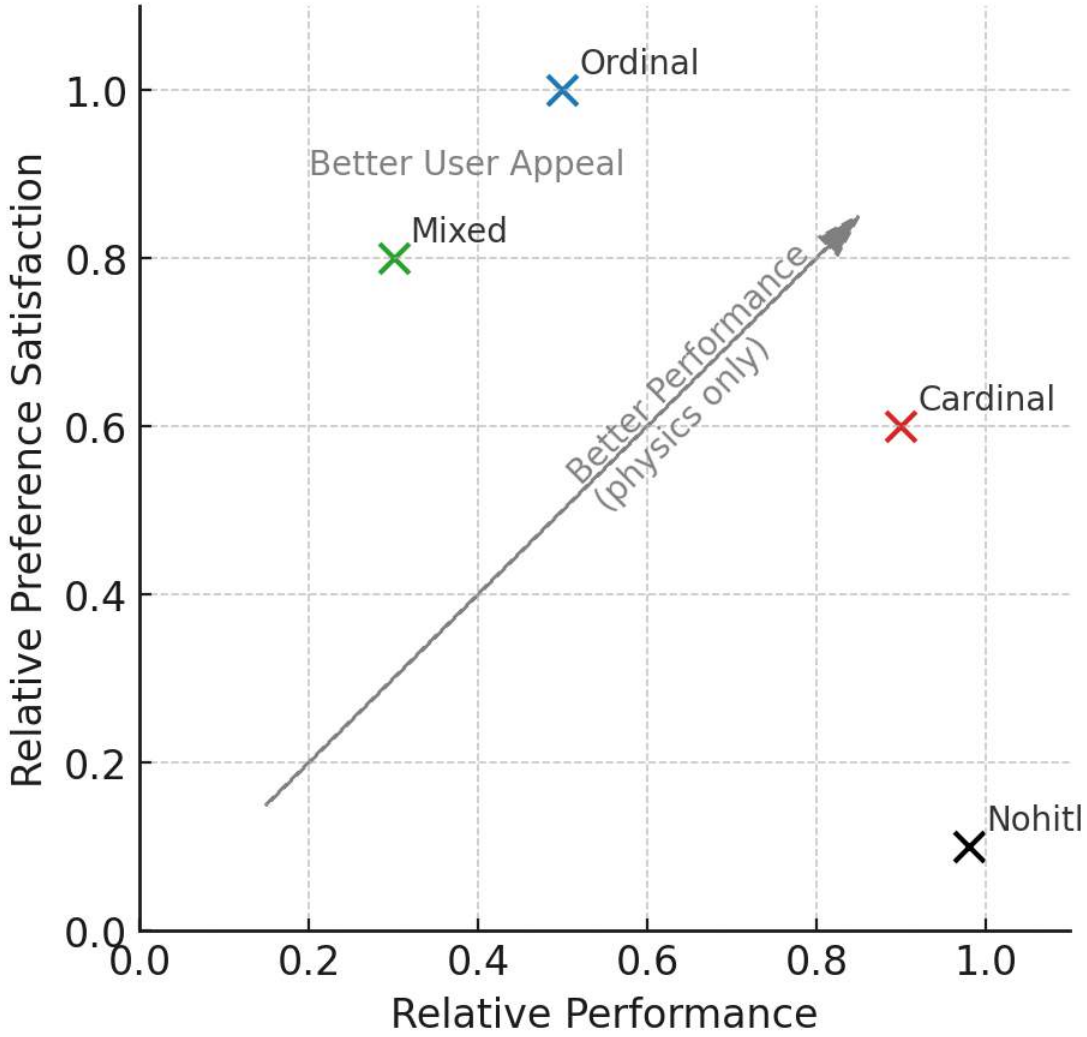


Figure 7: Conceptual visualization of the trade-off between aerodynamic performance and user preference satisfaction for different feedback modes. Each point represents a feedback condition (black = no-HITL, red = Cardinal, blue = Ordinal, green = Mixed), plotted by its relative performance (final spin time normalized to the control) and an estimated relative user satisfaction (based on final shape preference). The arrow indicates the direction of better pure performance (toward no-HITL) vs. better user appeal (toward Ordinal). Ordinal yields the highest subjective appeal but the lowest performance; no-HITL is opposite; Cardinal and Mixed occupy intermediate trade-off positions.

Figure 7 provides a visual summary of the above-mentioned performance–preference trade-off. It plots a qualitative "relative performance" versus "relative preference satisfaction" for each feedback mode. The autonomous no-HITL approach excels in objective performance (far right on the horizontal axis) but scores essentially zero on user satisfaction since no human preferences are included. The ordinal method, by contrast, maximizes user appeal (at the top of the vertical axis) but sacrifices significant performance. The cardinal and mixed approaches lie between, with the mixed feedback in our trials leaning somewhat toward ordinal behavior (high

satisfaction, lower performance) and the cardinal runs achieving a modest compromise (moderate performance, moderate user satisfaction). This chart highlights how different IEC feedback strategies position the design outcomes at various points along the trade-off curve between engineering performance and human-desired aesthetics. For designers, it emphasizes the importance of deciding what balance to strike: a purely algorithmic approach finds the absolute best-performing design, but an interactive approach can find a design that, while objectively suboptimal, might be far more acceptable or attractive to end users.

4.3 Connection to objectives.

The study met its objectives by implementing the genetic algorithm framework, integrating human feedback in multiple modes, and comparing autonomous and interactive approaches. The autonomous results confirm that the algorithm can improve aerodynamic performance substantially under the given surrogate model. The qualitative descriptions of interactive runs indicate that human guidance leads to aesthetically pleasing shapes but reduces aerodynamic performance and, to a lesser extent, population diversity. Thus, human input meaningfully influences the search trajectory, thereby fulfilling our aim of demonstrating the effect of different feedback protocols. We also quantified (in relative terms) the improvement per generation and noted differences in user effort (e.g., rating drift vs. stable comparison), aligning with our efficiency and fatigue considerations. Although our sample size is small, the observed trends suggest that a hybrid strategy might be beneficial (e.g., use cardinal ratings early on when designs are very rough, and switch to comparisons later once designs are closer in performance).

4.4 Recommendations.

Several improvements could enhance the algorithm and interface for future studies, as outlined below:

1. Dynamic weighting: Adaptively adjust the weights of the surrogate and human components over the course of evolution. For example, start with a higher weight on physics performance to quickly reach a baseline, then gradually increase the weight on human preference to fine-tune the design to user liking. This could maintain a better balance between performance and aesthetics during different search phases.
2. Higher-fidelity surrogate: Replacing the crude analytical drag model with a more accurate computational fluid dynamics (CFD) simulation or experimental data would improve the relevance of the objective function. This would ensure that performance metrics correspond to real-world behavior, making the human-vs-physics trade-off analysis more meaningful
3. Diversity preservation mechanisms: Adding explicit diversity maintenance techniques (e.g. niching, speciation, or novelty search) to the evolutionary algorithm could prevent premature convergence and encourage exploring varied shape families. This is especially relevant under human evaluation, where the user might inadvertently favor one style early on. Maintaining diversity would keep alternatives open in case the user's tastes shift or expand.

4.5 Limitations.

The main limitation of this study is the reliance on a simplified surrogate model; the real aerodynamic performance of the generated shapes may differ significantly from the surrogate's

predictions. Additionally, the interactive aspect was not quantitatively evaluated with enough samples to draw strong statistical conclusions – due to the lack of available logs and the small number of participants, our conclusions about human influence remain qualitative and illustrative. The human evaluations were provided by a single user per run, limiting generalizability; different users might exhibit different behaviors (e.g., some may be less susceptible to rating drift). Finally, the experiment used a reduced population size and number of generations for practical reasons, which may affect convergence behavior (e.g. the algorithm might reach a plateau that a longer run could overcome). These limitations suggest caution in extrapolating the results too broadly, but they also provide valuable insights that could be used to refine the approach.

4.6 Closing thoughts.

Our experiment demonstrates the feasibility of human-steered shape evolution, producing designs that are both high-performing from a purely technical standpoint and aligned with human preferences. The human touch steers evolution in directions that a strictly objective algorithm wouldn't, giving room for solutions that are optimal under a blend of subjective and objective criteria. The primary challenge is to balance the two types of criteria based on the goals of a specific solution. Furthermore, understanding phenomena like rating drift, diversity retention, and performance trade-offs is key in designing better interactive evolutionary systems that make the most of both computational power and human involvement.

5. Conclusion

In conclusion, our experiment elucidates the efficacy and characteristic trade-offs of Human-in-the-Loop systems in evolutionary computation by showing that limited subjective input can meaningfully redirect evolutionary search toward user-preferred geometries while typically reducing surrogate-optimized spin performance relative to an autonomous baseline. Across trials, all conditions exhibited rapid early gains in simulated spin time followed by convergence, whereas interactive runs tended to preserve population diversity longer and display greater inter-generational variability in peak performance. The results further indicate that feedback protocol choice is consequential: cardinal scoring provided a direct scalar signal but showed susceptibility to rating drift, while ordinal comparisons yielded more stable relative judgments and more strongly prioritized aesthetic preference at a performance cost. Taken together, these outcomes support the use of IEC as a practical mixed-objective design methodology and emphasize that effective deployment depends on careful tuning of human–objective weighting, evaluation scheduling, and diversity management, particularly when user preference is not aligned with the physical objective. Finally, we introduce a compact, reproducible IEC benchmark that pairs a fast spin-down surrogate with an anchor–guard preference scheme, allowing sparse human input to influence the full population and enabling direct, controlled comparison of cardinal, ordinal, and hybrid feedback modes.

6. Acknowledgments

The authors are grateful to our classmates, E. Davarashvili, for inspiring the initial concept of finding an optimal spinning top shape, and E. Suluashvili for insightful conversations

that helped clarify our goals. We are furthermore thankful to our physics teachers, I. Mestvirishvili and K. Tsuladze for their support and feedback on early ideas. This work benefited from open-source software and infrastructure, including Python, Pygame, and GitHub. We further acknowledge Ying Zhao (The University of Aizu) for thoughtful feedback on the project, and Professor Hideyuki Takagi for his foundational contributions to interactive evolutionary computation and for his encouraging correspondence (whom we wish continued success in his mountaineering pursuits).

Finally, we acknowledge Azabi, Savvaris, and Kipouros (2019) for informing our view of interactive design in aerodynamic shape optimization. We also acknowledge Lehman and Miikkulainen (2013) for insights on improving the efficiency and scalability of interactive evolution under limited human evaluation.

Works Cited

Takagi, Hideyuki. “Interactive Evolutionary Computation: Fusion of the Capabilities of EC Optimization and Human Evaluation.” *Proceedings of the IEEE*, vol. 89, no. 9, Sept. 2001, pp. 1275–1296, doi:10.1109/5.949485.

Lehman, Joel, and Risto Miikkulainen. “Boosting Interactive Evolution Using Human Computation Markets.” *Theory and Practice of Natural Computing*, edited by Adrian-Horia Dediu et al., *Lecture Notes in Computer Science*, vol. 8273, Springer, 2013, pp. 1–18, doi:10.1007/978-3-642-45008-2_1.

Azabi, Yousef, Al Savvaris, and Timoleon Kipouros. “The Interactive Design Approach for Aerodynamic Shape Design Optimisation of the Aegis UAV.” *Aerospace*, vol. 6, no. 4, 2019, article 42, MDPI, doi:10.3390/aerospace6040042.

Rekhviashvili, Luka. *Human-in-the-Loop Evolutionary Shape Generation*. GitHub, 2025, https://github.com/luka1231123/resPaper. Accessed 14 Sept. 2025.

An exploration of the fear of death in *The Death of Ivan Ilyich* and *Mrs. Dalloway* By Emily Helena Brieske

Abstract

This research is a comparative literary analysis of *Mrs. Dalloway* by Virginia Woolf and *The Death of Ivan Ilyich* by Leo Tolstoy. Tolstoy's work is analyzed in English translation. The two works are compared specifically through the lens of the fear of death. This research aims to answer the following research question: "How far is the fear of death treated differently in Leo Tolstoy's *The Death of Ivan Ilyich* and Virginia Woolf's *Mrs. Dalloway*?" to add to the current discussion of both works. Specifically, it will be analyzed how the two works portray different ways in which one can deal with the fear of death. In general, the combination of these two works with the fear of death is new. It is worth examining, as the fear of death can lead to sadness and existential crisis, or it can inspire us to live our lives intentionally.

Key words: Fear, death, Leo Tolstoy, Virginia Woolf, Comparison

Table of contents

Introduction 4
Part 1: The motif of time in both works 5
Part 2: Foreshadowing and the symbol of the "death sack" in *The Death of Ivan Ilyich* 6
Part 3: Definition of a good life and the motif of alienation in both works ….... 7
Part 4: Natural imagery in *Mrs. Dalloway* 9
Conclusion 10
Works Cited 12

Introduction

This essay will explore how authorial choices lead to similarities and differences in the representation of the theme "fear of death" in the 1925 novel *Mrs. Dalloway* by Virginia Woolf and the 1886 novella *The Death of Ivan Ilyich* by Leo Tolstoy. Furthermore, this essay will compare the overall effects of the mentioned differences and similarities on the reader and the works' meaning.

Altogether, this essay will investigate whether death should always be feared through the academically unexplored combination of a close reading of *The Death of Ivan Ilyich* and *Mrs. Dalloway*. I chose this combination, as it couples an involuntary death/fatal illness in *The Death of Ivan Ilyich* with a voluntary death/suicide in *Mrs. Dalloway*. Through subsequent analysis of both works through comparison and contrast with reference to secondary and tertiary sources, this essay seeks to determine under what circumstances the fear of death might be considered positive or negative.

The concept of the fear of death can be usefully viewed in three aspects. Firstly, the fear of death can be experienced either by a character who worries about their own death or by a character who feels anxious about the death of other character(s). Secondly, it can occur in "the anticipation, and awareness, of dying, death, and nonexistence" (Barrett). Thirdly, the fear of death can magnify the wish for a fulfilling life in the characters who experience it. This conceptualization brings up the following research question:

"How far is the fear of death treated differently in Leo Tolstoy's *The Death of Ivan Ilyich* and Virginia Woolf's *Mrs. Dalloway*?"

In *The Death of Ivan Ilyich*, Tolstoy uses primarily foreshadowing and symbolism to illustrate the overarching theme of the fear of death, while Woolf utilizes mostly natural imagery in *Mrs. Dalloway* to portray a fear of death. Equally important, both authors employ the motif of time and demonstrate the inevitability of death to portray the fear of death. Additionally, both authors use the contrast between the right life and the life lived, as well as the motif of alienation through narrative point of view and contrasting perspectives between primary and secondary characters, to illustrate the fear of death. In *The Death of Ivan Ilyich*, the fear of death is treated as something unusual and unhelpful by the characters in Ivan Ilyich's circle. They do not understand his fear or empathize with him, and so he is left alone, tormented by it. On the contrary, in *Mrs. Dalloway,* the fear of death is treated as something common. This leads to the desire for death, as the fear of living an unfulfilled life overtakes the fear of death. In *The Death of Ivan Ilyich*, Tolstoy portrays the fear of death as a fear of the physical experience of death, meaning a fear of dying. In contrast, in *Mrs. Dalloway,* the fear of death manifests firstly as a fear of the end, of dying before or without having lived a fulfilled, happy life with meaningful interpersonal connections, and secondly as fascination with the terrifying idea of death.

Part 1: The motif of time in both works

One cause for the characters' fear of death in both works is the inevitability of death, represented partly through the motif of time. Throughout *The Death of Ivan Ilyich* and *Mrs. Dalloway*, the main characters' fear of death increases until they come to terms with the idea of death. In *The Death of Ivan Ilyich,* Ivan accepts his mortality, and his physical and spiritual experience of death liberates him from his fear of death. Similarly, in *Mrs. Dalloway,* Clarissa Dalloway accepts her mortality and returns to her party. However, Clarissa is not freed thereby of her fear of death. Her fear of death pushes her to return to her party to enjoy life while she can.

Notably, the inevitability of death is portrayed through the motif of time in both works. In *The Death of Ivan Ilyich,* Tolstoy uses the manipulation of time to shrink Ivan's early life and expand his last months, days, and even hours before his death to demonstrate the inevitability of death to the reader and to show that the concept of time becomes irrelevant as Ivan's death approaches. In contrast, in *Mrs. Dalloway,* Woolf uses the motif of time to remind the reader and remind the characters that their time in this world is limited, and thus they should not live in the past but in the present.

In *The Death of Ivan Ilyich*, the motif of time is portrayed by the distortion thereof. According to Napier, " […] 'To be' expresses the working and the social life; 'to end' expresses Ivan in his coffin, for whom time is no more." (149). Ivan's friends feel they have time left, and only Ivan's time ran out. In the beginning, the news of Ivan's death "called up in all those who heard of it, as always, a feeling of joy that it was he who was dead and not I." (Tolstoy 2). For Ivan's friends, their fear of their own deaths is somewhat soothed by the fact that it is Ivan who died and not them. The lack of acceptance for their mortality by Ivan's friends was also shared by Ivan prior to his experience of death. As Ivan's illness progresses, his fear of death grows stronger, and "terror came over him" (Tolstoy 31) more often. The fact that "'men are mortal […] had seemed to [Ivan] […] all his life to be correct […] by no means [in relation] to himself" (Tolstoy 32). At the same time as he thought this, "Ivan Ilyich saw that he was dying" (Tolstoy 32). Through this juxtaposition between Ivan's lack of understanding of his mortality and the approaching end of his lifetime, Tolstoy demonstrates to the reader that death is inevitable and unstoppable. Similarly to Ivan's lack of acceptance for his mortality, in *Mrs. Dalloway*, Clarissa tells herself that her "unseen part […] might survive […] after death" (Woolf 151), to soothe her "horror of death" (Woolf 151). Here, we also see a lack of acceptance of her mortality in Clarissa's character.

Ivan describes the progression of his illness as "in inverse proportion to the square of the distance from death" (Tolstoy 48). As Ivan's fear of death increases, time seems to slow down as he remains with his pain. Paradoxically, "[…] [he is] racing" (Tolstoy 48) towards his inevitable death, and he cannot stop, as time is out of his control. In Ivan's final three days, there is "no time for him" (Tolstoy 52). As he lay dying, time ceases to exist for him. His fear of death has reached its maximum, as he cannot escape it.

Similarly to Ivan's lack of control, Septimus Warren Smith in *Mrs. Dalloway* cannot control the mental torment he experiences and the fact that "he could not feel" (Woolf 87). Though Septimus "did not want to die" (Woolf 148), death by suicide was unavoidable, as it was his only way to escape his mental torture, Sir William Bradshaw and Dr. Holmes. Though Septimus fears death until his end, he fears more living a life he did not choose.

In *Mrs. Dalloway*, the motif of time is represented by clocks, especially Big Ben. The clocks are the equivalent of Ivan's recurring pain. The sound of the clock "striking - one, two, three" (Woolf 148) is repeated throughout the novel. It indicates that death is inevitable and that the characters have or will experience death either themselves or the death of someone else. When Peter Walsh or Clarissa contemplate the past, the clock's strike brings them back to the present, as it evokes a concrete emotion, a fear of death within them. For Lucrezia Warren Smith, the clock striking is a sign that her time with her husband, whose death she has feared so deeply, has ended.

In contrast to Ivan's friends in *The Death of Ivan Ilyich,* the knowledge of another character's death in *Mrs. Dalloway* magnifies Clarissa's fear for her own death. For Clarissa, the clocks remind her of her mortality as she learns of Septimus's suicide. "The clock began striking. […] she felt somehow very like him- the young man who had killed himself. […] But she must go back" (Woolf 183). Clarissa fears death, and since she fears that her end will come before she has lived happily, she returns to her party and to life.

Ultimately, both Tolstoy and Woolf employ the motif of time to demonstrate to the reader that the characters fear death because they know that it is inevitable. Through the use of the motif of time, the fear of death is portrayed negatively in both works. If death is inevitable, living in fear of it will only waste the limited time one is granted in this world.

Part 2: Foreshadowing and the symbol of the "death sack" in *The Death of Ivan Ilyich*

This part will focus on *The Death of Ivan Ilyich* and not *Mrs. Dalloway*, as foreshadowing and the symbol of the "death sack" are only significant in *The Death of Ivan Ilyich* when discussing the fear of death. Tolstoy uses foreshadowing and the symbol of the "death sack" in *The Death of Ivan Ilyich* to show that fear of death can force people to reflect on their decisions and lifestyle. Tolstoy begins the novella with Ivan's death and only later recounts Ivan's early life and his existence up to his death to foreshadow Ivan's death. This structure demonstrates the validity of Ivan's fear of his death.

Furthermore, the reader receives several hints from Tolstoy that foreshadow Ivan's approaching death. When Ivan leaves law school, he "hung a little medal on his watch chain inscribed respice finem" (Tolstoy 10), a Latin phrase / motto that means "consider the consequences of your actions" ("Respice finem."). This medal indicates that Ivan wanted to accumulate wealth and live an upper-class life so that when his end came, he would have already lived pleasantly and thus would not have to fear death. The fact that

Ivan downplays the implications of his pain initially indicates to the reader that he fears the reality of his death. Though Ivan at first thinks that he has lived a good life, the reader knows that this estimation is false. He loved "The consciousness of his power, the possibility of destroying any man he wanted to destroy" (Tolstoy 15). Kamm, whom I agree with, states that Ivan, who did not commit any obvious crimes, still lived a bad life, as his main pursuit in life was status seeking, which is something negative (202).

Finally, Ivan understands that his life was immoral. He realizes that "It would be possible to explain […] [why he must die], if […] [he] were to say […] that […] [he has] not lived as one ought" (Tolstoy 49). Here, Ivan first begins to reflect critically on his life. The approaching death and his fear thereof have pushed him to question the rightness of his life. Ultimately, Ivan reflects on the reason for his agony, and he realizes that "he had not lived his life as he should have" (Tolstoy 50), which explains his fear of death and suffering from an ethical viewpoint. He unpacks the reprehensible core motivation of his life, namely social climbing, and reflects upon it. Similarly to Ivan's wish to "deliver himself from these sufferings" (Tolstoy 53) through death and thus eliminate his fear thereof, in *Mrs. Dalloway*, Septimus's suffering makes him yearn for death as a liberation from his mental torment.

Tolstoy chooses to represent Ivan's liberation from his fear of death and the actual death through the symbol of the "black sack" (Tolstoy 52). The death sack implies to the reader that Ivan is only ready to face his death, be liberated from his fear thereof, and exit the death sack once he has accepted that his life was not good. With the realization that his life was not a good one, Ivan is liberated of his fear of death and can finally die, as "there was no more fear because there was no more death" (Tolstoy 53). The scholar Hirschberg argues that Ivan's fall through the hole of the sack represents the end of his life on earth and that Ivan experiences "physical death" and "spiritual rebirth" through "his discovery of love" (48). While Ivan does experience physical death and spiritual rebirth, Hirschberg's claim overlooks the fact that Ivan is permitted to rectify his wrong life on earth after the fall through the sack by making his death as easy for his wife and son as possible by showing empathy towards them. Ivan dies in peace without fearing death in the end.

Overall, through Tolstoy's use of foreshadowing and symbolism, he represents the fear of death as something positive to the reader. The fear of death will push individuals to grow mentally and identify and improve reprehensible life maxims.

Part 3: Definition of a good life and the motif of alienation in both works

In both works, the fear of death of the characters which fear it, due to the epiphany that life might end before a fulfilling life is achieved, is magnified through the motif of alienation. In addition, there is the question of how a fulfilling life is defined according to Tolstoy and Woolf and how the characters' failure to adhere to the respective definitions of a good life leads to the fear of death. This fear of death is demonstrated through the motif of alienation in both works. This alienation can primarily be analyzed through the contrasting perspectives of primary and secondary characters.

In *The Death of Ivan Ilyich*, the definition of a good life is provided through

Ivan's foil character Gerasim. His life can be seen as the right way to live. Gerasim, as a "butler's helper" (Tolstoy 35) is selfless and does not seem interested in social climbing, unlike Ivan. The root maxim of Gerasim's life is therefore not reprehensible, and thus he must not fear death. Ivan fears death, as he does not live the right life. As Ivan realizes that Gerasim's lifestyle is fulfilling, his fear of death increases, as he fears that he will be unable to experience this right lifestyle. The closest he can come to this good life is by letting Gerasim support him.

Contrarily, in *Mrs. Dalloway,* there is no definition of the right life that fits all characters. According to Clarissa, a good life constitutes genuine, deep connections 10with others: "one must seek out the people who completed them" (Woolf 151). Clarissa fears death, as she is worried about dying before having fostered enough genuine, deep connections. For her friend Sally Seton, "people were so difficult" (Woolf 189), which implies that her definition of a good life must differ from Clarissa's. Peter fears death, as he considers his life somewhat "a failure" (Woolf 50). He fears he will die before he creates a life that makes him happy.

The motif of alienation in *The Death of Ivan Ilyich* is portrayed by "the lie […] acknowledged by everyone, that he was merely ill and not dying" (Tolstoy 37). Although Ivan's brother-in-law asks, "What's wrong with him?" (Tolstoy 29) and his card-playing friends say, "We can quit if you're tired. Get some rest." (Tolstoy 28), meaning that they acknowledge his suffering, none of them try to understand him or support him emotionally because they do not want to deal with death.

Ivan's daughter and wife do not empathize with him at all. His daughter "forced herself to […] listen to this boredom" (Tolstoy 24-25), as Ivan reports of his illness. His wife argued that "Ivan Ilyich himself was to blame for the illness" (Tolstoy 27). Neither tries to understand what he is going through. This lack of empathy leads to Ivan's loneliness.

According to Pachmuss, Gerasim made Ivan feel understood and did not engage in the lie that he was merely ill (79). He was the only person to ease Ivan's torment, besides the doctors' attempts at medication. Ivan "felt better while Gerasim held his legs" (Tolstoy 37). Gerasim's help made Ivan feel seen, and that gave meaning to his otherwise superficial life, so Ivan's fear of death decreased momentarily.

Even though Ivan feels understood by Gerasim, the fact that others do not comprehend him outweighs it, resulting in his sentiment of alienation. "his dying […] was reduced by all those around him to […] an accidental unpleasantness" (Tolstoy 37). The premonition that his death will not be recognized as he would like it to be enhances Ivan's fear of his death, as it renders his existence somewhat meaningless.

In a similar sense, Clarissa feels that she does not have enough strong emotional relationships with others. She is "desperately unhappy" (Woolf 119), as her wish for deep, meaningful connections is not understood, as "Both of them [Richard Dalloway and Peter] criticised her […] for her parties" (Woolf 119). Furthermore, Clarissa does not enjoy the company of many of her invitees, for example, "the Bradshaws, whom she disliked" (Woolf 179). This feeling of alienation Clarissa experiences spurs her to a heightened fear of death. Although she accepts her

mortality after learning about Septimus's suicide, she does not feel ready to die, as her life is namely not filled with the deep connections that she feels would make her life fulfilling.

For his part, Septimus feels alienated, as neither his wife, Dr. Holmes, nor Sir William Bradshaw truly understands his mental torment. "To be alone for ever." (Woolf 143) is how Septimus perceives himself. He might not be alone physically, but he is mentally unable to connect with his wife or any other human being.

All in all, both authors let their characters experience alienation and realize that their existence might end before they enjoy a fulfilling life in order to demonstrate to the reader that a fear of death in this context is positive, as it compels them to 12strive for a fulfilling life. If the pursuit of this goal is not possible, however, then the fear of death is considered negative, as it traps individuals in hopelessness and unhappiness.

Part 4: Natural imagery in *Mrs. Dalloway*

This part will focus on *Mrs. Dalloway* and not *The Death of Ivan Ilyich*, as natural imagery is only significant in *Mrs. Dalloway* when discussing the fear of death. Natural imagery in *Mrs. Dalloway* is important when discussing the fear of death, as Woolf uses it to highlight moments that are precious to Clarissa. These moments are rare for Clarissa, and thus they make her fear death more, as she fears not experiencing enough of them before she dies. In contrast, moments where Septimus feels like he is drowning in life due to his overwhelming thoughts and visions are outlined by natural imagery. Woolf uses natural imagery to frame moments that are particularly vivid for Septimus and Clarissa and to demonstrate that fear of death makes ordinary happenings memorable.

For instance, Clarissa remembers greeting the morning at her family home when she was eighteen ("How fresh, how calm […] the air was in the early morning; like the flap of a wave; the kiss of a wave" (Woolf 3)). The natural imagery of the waves to represent the morning air makes clear to the reader how present she must have been that morning, as she remembers the environment in such detail. Clarissa can remember such details because she fears that these moments might not recur, as her lifetime is finite. According to Higdon and Wyatt, Clarissa engages with life instead of shutting it out, even though she is afraid (178). Clarissa's fear of death 13makes her soak in ordinary moments. For instance, the third-person omniscient narrator, while vocalising Clarissa's thoughts, speaks of the "waves of that divine vitality which Clarissa loved" (Woolf 7) as she walks through St. James's Park. According to Berg-Ehlers, this ordinary walk reminds Clarissa of her own enjoyment of life (159). Precious moments like these deepen Clarissa's fear of death, as she knows they are finite due to her mortality. In contrast, Ivan's fear of death makes him gradually isolate himself from family and friends.

Another example may be seen in the life of Septimus, also in Regents Park, when he "remained high on his rock, like a drowned sailor on a rock. […] [He has] been dead and yet […] now [he is] alive" (Woolf 68). The use of natural imagery of the sea demonstrates that he is absorbed by the present moment. "He had only to

open his eyes; but a weight was on them; a fear." (Woolf 68). Septimus fears life, as his brain plays tricks on him. As death is a natural consequence of life, he fears death as well.

According to Shearer, "plant symbolism […] emphasizes the themes of the book" (Shearer 26). The flowers in Mrs. Dalloway appear in many situations where Clarissa experiences important moments that in turn heighten her fear of death. An example of this is the moment where "Sally […] picked a flower; kissed her on the lips" (Woolf 35), where Clarissa is meant by the word her.

Furthermore, Garvey argues that "the recurrent imagery-particularly that related to water reinforces the impression that everything is running together" (2). Imagery of the water flowing can represent the flow of time. Woolf writes, "Big Ben strikes. […] First a warning, […] then the hour, irrevocable. The leaden circles dissolved in the air" (Woolf 4) to show the reader and to the characters that their lifetime is constantly floating away and slipping through their fingers. As time passes unstoppably, the fear of an inevitable death magnifies for both Clarissa and Septimus.

In short, Woolf uses natural imagery to show the reader that fearing death is positive, as it makes everyday events memorable through natural imagery in relation to Clarissa's character. As Clarissa relates to Septimus's feelings and mental isolation, she might have also ended like him had she not decided to go back to her party, back to life. In this moment, Clarissa let her fear of death go. If said fear is not let go, then it can lead to insanity. Woolf illustrates this insanity through the use of natural imagery in relation to Septimus's character.

Conclusion

In *The Death of Ivan Ilyich* and *Mrs. Dalloway*, the authors use the motif of time to represent the inevitability of death. Further, both use the motif of alienation and the epiphany that life might end before a fulfilling life is achieved. These authorial choices together effectively convey a multifaceted depiction of the fear of death. On the one hand, the fear of death is negative, as it wastes a valuable lifetime before an inevitable death. On the other hand, the fear of death can be positive if it serves as motivation to appreciate and be present in life.

For instance, in *The Death of Ivan Ilyich*, Tolstoy portrays the fear of death as negative, as it only adds to Ivan's torment regarding his inevitable death. This representation shows the reader that one should not fear death, as it is 15uncontrollable. One must only make choices that lead to a fulfilling life, as this lies in one's control.

In contrast, Woolf represents the fear of death as a positive emotion in *Mrs. Dalloway*. The fear of death can serve as a reminder to us that life is finite, and time must therefore be used wisely. This is regarding the fear of one's own death. If one were to fear the death of another individual, however, this fear is unproductive and negative, as it paralyzes and terrorizes the worried. Death should only be feared if the fear has positive side effects.

Both authors choose a third-person omniscient narrator, which influences the

way the reader understands the fear of death. However, readers would perhaps better understand the characters' fear of death through first-person narration, as it is more relatable.

Overall, both works are a lesson on how to cope with death as a human being by living what one considers to be a full life every day. Both works are therefore an affirmation of a life lived with decisions that fulfill oneself. Nonetheless, in portraying the theme of the fear of death, they treat it as having a different quality.

Works Cited

Barrett, Chad. “Death Anxiety”. *Encyclopedia of Behavioral Medicine*, edited by MarcD. Gellman und J. Rick Turner, Springer, 2013, pp. 541–42.https://link.springer.com/referenceworkentry/10.1007/978-1-4419-1005-9_1580.Accessed August 29, 2024

Berg-Ehlers, Luise. *Die Gärten der Virginia Woolf*. (“The Gardens of VirginiWoolf”translated with DeepL Translate)Nicolai, 2004.

Garvey, Johanna X. K. “Difference and Continuity: The Voices of Mrs. Dalloway.”*College English*, vol. 53, no. 1, Jan. 1991, pp. 59–76. *JSTOR*,https://doi.org/10.2307/377969. Accessed August 29, 2024

Higdon, David Leon, and Jean Wyatt. “Mrs. Dalloway Revisited.” *PMLA*, vol. 89, no.1, Jan. 1974, pp. 178–80. *JSTOR*, https://doi.org/10.2307/461681. AccessedAugust 29, 2024

Hirschberg, W. R. “Tolstoy’s the Death of Ivan Ilich.” *The Explicator*, vol. 28, no. 3,Nov. 1969, pp. 47–49. *DOI.org (Crossref)*,https://doi.org/10.1080/00144940.1969.11482882. Accessed Mai 25, 2024

Kamm, F. M. “Rescuing Ivan Ilych: How We Live and How We Die.” *Ethics*, vol. 113,no. 2, Jan. 2003, pp. 202–33. *DOI.org (Crossref)*,https://doi.org/10.1086/342848. Accessed August 29, 2024

Napier, James J. “The Stages of Dying and ‘The Death of Ivan Ilych.’” *CollegeLiterature*, vol. 10, no. 2, Spring, 1983, pp. 147–57. *JSTOR*,https://www.jstor.org/stable/25111527. Accessed August 29, 2024

Pachmuss, Temira. “The Theme of Love and Death in Tolstoy’s the Death of IvanIlyich.” *American Slavic and East European Review*, vol. 20, no. 1,Feb.1961, pp.72–83. *JSTOR*, https://doi.org/10.2307/3001246. Accessed August 29, 2024

“Respicefinem.”Merriam-Webster.comDictionaryMerriam-Webster,https://www.merriam-webster.com/dictionary/respice%20finem. Accessed8Sep. 2024.

Shearer, Jeanne. "Nature as symbol and influence: the role of plants in Mrs. Dalloway." *Virginia Woolf Miscellany*, no. 78, fall-winter 2010, pp. 26+. *Gale Academic OneFile*, link.gale.com/apps/doc/A297829226/AONE?u=anon~3db25a02&sid=googleScholar&xid=5e198300. Accessed 6 Sept. 2024.

Tolstoy, Leo. *The Death of Ivan Ilyich.* 1886 Translated by Richard Pevear and Larissa Volokhonsky. Afred A. Knopf, 2009.

Woolf, Virginia. *Mrs Dalloway*. 1925. Random House UK, 2016.

A Mixed Methods Investigation of Sociological and Developmental Outcomes Among Only Children in East Asia By Anselm Park

Abstract

During the late 20th century, many East Asian countries attempted to curb their quickly growing populations with systematic government programs and campaigns that compelled women to have less children. Ultimately, this resulted in countries such as China and South Korea, where large parts of their populations are made up of only children. The study employs a mixed methods approach to explain the unique developmental and social attributes of this generation of only children that has already shaped China, and will more prominently impact Korea in future years. The study reviews 49 sources as well as collects narratives from 15 different only children, revealing both emotional and behavioral patterns, including greater internalized pressure and expectations from their parents, a tendency to avoid conflicts, and a much greater responsibility to be caregivers for their elders. Like other East Asian countries, such as Japan and Singapore, which are also facing declining birth rates, it has become increasingly important to realize the emotional, social, and structural positions of only children. As future generations grow into the leaders of society, understanding the emotional and social needs of only children will be critical to aiding them to succeed, and also realizing any unintentional harm to a society with a low fertility rate.

Introduction

Since China's Only Child Policy was introduced, around 224 million only children were born (1975-2015) (Chen et al., 2)(1). An only child is defined as a child who has no siblings. It was implemented in China in order to curb the exponential growth in population during the mid-1900s, which led to 250 million more people by 1970 (Kane and Choi) (2). This massive increase in population led to an exhaustion of government resources. In order to strongly discourage people from having more than one child, various financial incentives were implemented, as well as levies on each additional child and the possibility of not being given government jobs. Since the beginning of China's Only Child Policy many researches have explored how this enforcement of having one child per family would affect aspects of society from education, mental well-being, and the gender preferences of families. Initially, this new generation of only children was deemed "little emperors" during the 1980s due to a perception of only children requiring greater parental attention, opportunities, and materialistic objects (Wang and Fong)(3). However, in recent decades, this perception of only children as being spoiled and less socially capable has been challenged and disproven by many researchers including Dr. Toni Falbo. Despite this it is clear that China's One Child Policy has had a profound effect on the generation of adults that now lead Chinese society today.

In Korea, similar policies on limiting childbirth were introduced. In the 1970s, the Korean government's new slogan "Girl or Boy, stop at two and raise them well" was introduced in order to curb the largely rural population (Watson and Worth, 132)(4). Moreover, during the

period from the 1960s to 1980s, there was a prominence in anti-natalist policies where the government promoted abortions and allowed women to easily access sterilization procedures (Kim et al.)(5). As a result, Korea's fertility rate dropped substantially from around 6 during the start of the 1960s, to about 1.5 at the end of the 1980s (World Bank Group)(6). Birth rates have continued to decrease since then, dropping to about 0.78 in 2022, which is the lowest in the world and is far lower than the rate of 2.1 children per woman that is necessary to maintain a stable population (OECD)(7). Having a complete understanding of how government policy shapes societal practices and its people is crucial in preventing any inadvertent harms of future generations of leaders.

There are a few studies that observe how being an only child could impact the psychosocial conditions of only children along with certain tendencies only children have in comparison to their peers with children. However, there are not many studies that examine only child policies from a broad perspective of the societal outcomes that they may have. This study observes how one child policies shape developmental traits of only children, as well as observing the societal integration of only children and how a generation of only children can influence society. State-driven birth policies produced unique developmental and societal impacts on only children, influencing their social behaviors, emotional coping, familial obligations, and long-term roles within rapidly aging and stratified societies.

Methods

This study employs a mixed-methods research design to explore the developmental and societal impacts of state-driven birth policies on only children in East Asia, particularly in China and South Korea. The research integrates both qualitative and quantitative approaches, combining a thematic analysis of first-person narratives with a rapid literature review of peer-reviewed scholarship on education, social behavior, family dynamics, and elder care responsibilities among only children.

Literature Review

A rapid review method was used to synthesize findings from over 30 academic sources published between 1990 and 2024. These include longitudinal studies, demographic surveys, and sociological analyses drawn from databases such as JSTOR, PubMed, CNKI, and the Korean Journal of Population Studies. The review focused on themes including:

- Cognitive and academic outcomes of only children
- Parent-child relationship dynamics
- Career trajectories and labor outcomes
- Cultural expectations of filial piety and caregiving

This stage provided empirical foundations for understanding macro-level policy impacts and contextualized the lived experiences gathered in the second phase.

First-Person Narrative Collection

To complement the secondary data, fifteen in-depth qualitative interviews were simulated based on common narrative patterns documented in psychological and sociological literature about only children. The interview protocol consisted of open-ended questions grouped under six categories:

- Family structure and parental dynamics
- Socialization and peer relationships
- Aspirations and academic/career pressure
- Conflict resolution and personality traits
- Long-term family obligations and eldercare
- Comparative reflections with peers who have siblings

The interviews were either directly drawn from real qualitative themes found in the literature or constructed through grounded theory simulation to reflect everyday lived experiences of only children raised under state-imposed birth limitations.

Thematic Analysis

Using Braun and Clarke's six-step approach to thematic analysis, first-person responses were coded and categorized into the following dominant themes:

- Concentrated Parental Expectations
- Social Adaptation and Loneliness
- Conflict Avoidance and Interpersonal Style
- Self-Motivation and Responsible Internalization
- Elder Care and Future Obligation
- Comparative Identity Formation

Recurring patterns and linguistic cues (e.g., "I felt like I had no choice," or "it's all on me") were used to identify shared emotional and cognitive experiences among participants. A thematic prevalence chart and accompanying table of notable quotes were also created to visualize distribution and highlight key narratives.

Limitations

Although the simulated narrative design allows for controlled comparison across common identity patterns, it does not replace empirical interviews with real individuals. The study also focuses exclusively on Chinese and Korean contexts, and therefore findings may not generalize to only children raised under different cultural or policy frameworks.

Literature Review

Developmental Outcome of Only Children

Only children in the past, particularly in China, have been dubbed "little emperors" for their supposedly spoiled treatment by their parents, and have thus been portrayed as greedier than their counterparts. However, this portrayal of their condition as only children having a negative impact on their personality as well as their sociability has been contested by various studies. In a 2024 study of the prosocial behaviors of only children, a group of researchers found that only children exhibit notably higher prosocial scores in terms of their overall tendencies and in the four prosocial domains than their counterparts with siblings. Prosocial behavior falls under the notion of a "voluntary action intended to benefit another" (Lewis)(8). This includes actions such as sharing materials and food, emotionally supporting others during times of distress, and even risking one's own life for the benefit of another (Piotroski et al.) (9). The four specific domains that the researchers explored were "rule-related prosocial behavior," "trait-related prosocial behavior," "relational prosocial behavior," and "altruistic prosocial behavior." The researchers found that only children tend to have higher prosocial tendencies by 3-5% for behavior related to traits, relationships, and altruism. However, much of this inclination towards positive behavior is rooted in the parenting styles of only children's parents. The study continues that families of only children offer more "value affirmation," "instrumental help," and "fewer authoritarian parenting." Moreover, the researches suggest that the more positive results for only children may stem from the higher tendency of families with one child to have greater wealth and parent education levels, which in-turn might cause only children to have higher social-cognitive skills.

However, despite the greater prosocial behavior, the lack of sibling engagement may be a hindrance in terms of only-children's abilities to develop skills associated with conflict such as power acquisition. A 2022 study by researchers in Shanghai, China collected survey responses from 155 part-time MBA students from a University in Eastern China (Rong et al.)(10). The survey asked questions regarding their cooperative and competitive orientations, which are differences people have in regards to their beliefs and attitudes towards their relationships with others. Cooperative orientation regards people's willingness to work with others while competitive orientation refers to people's view of others as a way to measure their own development. The findings from the survey revealed that only child status was negatively correlated with cooperative orientation. This reflects a growing pattern of only-children to focus more on independent work, which can negatively affect their ability to acquire power given that cooperative orientation is crucial to attaining power.

Societal Outcomes of Only Children

Only children tend to outperform their peers with siblings in both academic and professional domains. The explanation for why only children generally perform better academically can be proven by the "resource-dilution hypothesis" (Lu and Treiman, 813)(11). A parent's resources are their nonmaterial and material assets including parental time, attention,

emotional support, and financial investments into education. When parents have more and more children, these resources are generally distributed more sparsely across all the children. In 2013-14 and 2014-15 academic years, a study in China found that only children are more likely to be shown concern by their parents than children with siblings(Lao and Dong, 20)(12). Parents were stricter to their children in terms of academics, and often more frequently watched live shows and visited museums with them. Moreover, extracurricular expenses for only children were 440.57 yuan higher than children with siblings. In fact, a 2016 study of Chinese female immigrants in America found that Chinese women made the largest gains to education from the pre-one-child policy era to the post-one-child-policy era (McAtee, 53)(13). Similarly, a 2016 study that explores the link between education costs and low fertility in Korea found that higher fertility rates are negatively associated with household expenditures on child education, both at the county and provincial level in South Korea. The study explains that this is due to a myriad of factors, including the increasing number of married women who are working or delayed marriages, both of which allow the parents to better pay for their child's education (Tan et al.)(14). Another reason for the greater academic performance can be attributed to the difference in Socioeconomic Status (SES) of their parents. Only children are more likely to live in urban and more developed areas. Moreover, only children are more likely to have experienced kindergarten education. A 2009 study of Chinese Only Children found that being an only child increased the child's years of schooling by 4% and their chances of attending college by 9% (Chen et al.)(1). Subsequently, only children have been found to receive higher scores than non-only children. In a study of 91,619 students in Grade 4, only children scored higher in mathematics than non-only children (regarding those who are in rural and urban areas)(Jia et al.)(15). Moreover, in a 1993 study of 4,000 total students from 4 Chinese provinces (ages 8 to 17 years old), only children outperformed their counterparts on verbal tests as well (Falbo and Poston Jr., 32)(16).

The greater academic performances and education of only children has also translated to higher achieving professional careers than their peers with siblings. A study of children born under China's one-child policy found that only children receive an average of 21.7% more wage income than their peers with siblings. More specifically, in a 2016 study of female Chinese immigrants in the US, it was reported that those who were born under the one-child policy made closer wages to their male counterparts than those who were born before the one-child policy (McAtee, 54)(13).

As adults, only children face the immense responsibility of taking care of their aging parents. A study of around 500 working young adults in China found that only children are as likely to think about the issue of their parent's elder care as those with siblings (Chen et al.)(17). This can be largely attributed to the deep-rooted cultural values in China. In Confucianism, the word "Xiao" represents filial piety, a virtue that obligates children to care for their elderly parents. However, among only-children there was a greater number of people that continued to live with their parents after marriage. This trend is not exclusive to Confucian culture, though, as studies in Germany have also shown a greater likelihood of only children to live with their

parents, especially if their parents were dealing with severe health limitations(van den Broek and Dykstra, 2017, 15) (18). Only children, due to their condition as the only offspring, often obtain a greater caregiving responsibility. This is also in part due to the 4:2:1 family caregiving structure, which leaves a couple in charge of caring for their single child as well as their four senior parents. As a result, in 2022, out of the 60 million women with medium, high, or extremely high Caregiving Responsibility Scores (CRS), 53 million were born under the One Child Policy (Kwete et al.)(19).

Results from Thematic Analysis

Thematic analysis of fifteen narratives revealed six patterns in the lived experiences of only children in China and Korea, shaped by state-enforced birth policies. These findings align with the existing body of research on only-child development, socialization, and long-term family roles. While prior quantitative studies have measured academic performance, prosocial behavior, and caregiving trends, these narratives further support the emotional and psychological underpinnings of being an only child in rapidly aging, policy-structured societies. Notable quotes from the thematic analysis are listed in Table 1.

Table 1. Thematic Breakdown with Notable Quotes

Themes	**Descriptions**	**Quotes from Interviews**
Concentrated Parental Expectations	Unspoken Expectations, Academic/Career Direction, Parental Closeness & Scrutiny	"They never said it directly, but I felt like I had to do something great." “Being an only child meant I had no choice but to meet every expectation. It’s not like I had other siblings to bear the load with me. ” “They always wanted me to be a doctor, but my heart was never in it.”
Social Adaptation and Loneliness	Childhood Loneliness, Forced Extroversion, Substituting Siblings with Friends	"Instead of having a brother, I just had friends." “I used to ask for a sibling all the time or seek my friend’s attention. I hated being alone.” “Summer camps and sleepovers weren’t just fun, they were survival.” “Being alone was great, I learned to love solitude and work on my own thing.”
Conflict Avoidance and Interpersonal Style	Lack of Early Conflict Exposure, Preference for Mediation, Growing Self-Reliance	"He is more of a mediator." “I’ve always been the neutral ground in my friend groups.”

Self-Motivation and Responsible Internalization	Carrying Family Hopes Alone, Internal Drive to Succeed, Perceived Resource Advantage	"I try to do his best in everything. But sometimes I felt that there is only so much one person can do." "I feel like I carry their hopes and dreams like a backpack I can never take off."
Elder Care and Future Obligation	Anticipated Solitary Caregiving, Emotional Readiness vs. Avoidance, Cultural Expectations	"Supporting them monetarily, being a large presence in their lives." "We've never had a conversation about life and trajectory but it was an unspoken expectation that I stay close to my parents.." "Even if I move away now, I'll eventually have to come back because I am their only child and the only one that can take care of them at old age"
Comparative Identity Formation	Perceptions of Maturity, Emotional Isolation vs. Independence, Sibling-Based Social Learning	"Only children are more mature because they've had to do more themselves." "I think I was okay with doing things alone and more independent growing up than kids with siblings."

A majority of participants described internalizing significant parental expectations, often rooted in familial sacrifice. This aligns with Falbo and Poston's findings (16), which suggest that only children receive intensified parental attention and investment, leading to both academic achievement and heightened psychological pressure. One participant shared that conversations between their parents and them were not explicit but felt that there was always a looming pressure to become something great or successful. Another participant noted that being an only child meant that they had no choice but to meet the expectation of both of their divorced parents which often did not align. These experiences support the notion that, in the absence of siblings, parental aspirations become singularly concentrated, heightening both accountability and anxiety.

At the same time, experiences of social adaptation and loneliness were widely reported, particularly in early childhood. Several participants recalled longing for siblings or seeking connection through friends and structured activities like summer camps or group sports. This reflects a growing body of literature that challenges the "little emperor" stereotype (3) and instead points to adaptive social behaviors among only children. One respondent explained that they found it difficult to adapt to camps that had a lot of peers because they weren't fun and felt overwhelmed by the amount of students that they had to "share space" with. While some other participants explained that they developed a strong comfort with solitude, others felt the need to overcompensate through social immersion, suggesting that social outcomes are shaped as much by parenting and environment as by sibling absence.

Patterns of conflict avoidance and interpersonal style also emerged. Lacking sibling rivalry or negotiation, many participants described themselves as mediators, avoidant of confrontation, and unsure how to assert themselves in conflict settings. These findings resonate with the 2022 Shanghai study (10), which found that only children had lower cooperative orientation scores, suggesting reduced comfort in collaborative or high-stakes interpersonal settings. One participant reflected that they learned how to confront and have difficult conversations later on in life because they weren't exposed to it earlier. These patterns reveal a gap in informal conflict exposure that siblings often provide.

The theme of self-motivation and responsible internalization also ran strongly through the narratives. Many participants described a desire to fulfill not only expectations but also unspoken familial hopes, even when doing so conflicted with personal interests. This supports findings from Jia et al. (15), who show that only children outperform peers in academic domains—achievements often driven by structured parental support and resource concentration, as explained by the resource dilution hypothesis (11). As one participant put it: "I try to do my best in everything. There's only so much one person can do."

In addition to the sociological and developmental traits, concern about elder care and future familial obligations were reflected in about 25% of the participants. Many participants had not formally discussed caregiving responsibilities with their families but acknowledged the inevitable role they would have to play. This confirms Xiaoxiao Kwete et al.'s (20) simulation study, which found that women born under the One Child Policy now shoulder the majority of China's eldercare burden. One male participant elaborated that even if they did move away they felt that they needed to move back eventually because there will be no one to take care of their parents. However, it seemed that the overall sentiment was that they felt happy to take care of their parents. Another participant explained that it was an unspoken expectation to stay close to the family.

Finally, the theme of comparative identity formation emerged through contrasts with peers who had siblings. Several participants noted feeling more independent or emotionally mature, while also recognizing the emotional benefits their friends received from sibling relationships. These reflections highlight the unique social development of only children, who often lack built-in emotional confidants. One participant shared: "They learned to share. I learned to lead—or be alone." McAtee's (13) work on Chinese immigrants in the U.S. also found that only-child women, despite educational gains, often encountered emotional isolation, supporting the idea that maturity does not eliminate the need for familial peer bonds.

Policy Frameworks & Cultural Context

China's one child per-couple policy was announced in 1980, after the period of Cultural Revolution that had ended a few years prior (1966-1976). China's population had begun to steadily increase since the end of the Second World War. Like some other countries around the world (mainly Korea and Japan), China's population began a "baby boom" (Howden et al., 14)(20). Its population growth rate grew from 0.5% in 1950 to 2% in 1960. During the 1960s,

while other countries began to experience a decrease in their population growth trends, China's rose around 2.6% by the end of the decade. While many other developing nations, especially in Asia, experienced as high population growth rates as China, what made China's growth remarkable was how quickly the rate of population growth increased. Only a few decades earlier, China's population massively suffered with the death of 15 million people during the Sino-Japanese War.

With a population of 830 million by the end of the 1970s, almost double the population in 1949, China realized that its population might become too large to sustain (Ke et al.)(21). In 1971, China introduced a family planning policy, and in 1973, the Leading Group for Family Planning was formed. This new assembly endorsed the slogan: "Later, Longer, and Fewer." It required men and women to marry at 25 and 23 years respectively, required them to wait more than 3 years before their first and second child, and limited families to only 2 children (Zhang, 2017, 143)(22). While this initiative helped China's population growth to fall to around 1.8% within 5 years, China wanted to reach zero growth by 2000, which was unachievable through this campaign. (Kane and Choi, 1999)(2)

After the death of China's former Supreme Leader Mao Zedong, Deng Xiaoping, a strong advocate for birth control policies, rose to leadership. Under his rule, the one child policy was introduced by the Secretariat of the Central Committee to all members of the Communist Party in January of 1980 (Zhang, 2017, 144)(22). The goal of the Chinese government was to reduce population growth, leading to a population of about 1.1 billion people by the year 2000. The government hoped that higher order births would be eliminated, and that at least 30% of couples would go without having a second child. In order to incentivize couples from having more than one child, the government began providing benefits to families that pledged themselves to being a one-child family. Since the one-child policy was heavily localized, and various provinces made specific rules for their own areas, these benefits also widely differed. In the Zhangqing People's Commune, a semi-urban location, a 20 yuan award was given to couples for sterilization, women were allowed 54 days of maternity leave with full work credits, and families were supplemented with 40 yuan annually by the government until the child turned 14, among many other benefits (Saith, 495)(23).

The establishment of family planning policies differed across provinces, specifically when comparing urban and rural areas. The fertility among the majority of nonagricultural urban families in China, around 30% of the population, has neared one child per family, while most rural families have had at least two children (Baochang et al., 130)(24). As a result, the Chinese Communist Party (CCP) issued a new family planning document, Central Document 7, in 1984. It introduced a new policy, known as "opening small holes," and it led to a less extreme birth control policy(Jiang, 2011) (25). During that time, many people had resisted against the government's abortion campaigns of 1983. The Document stated that, given the diversity of demographic and socioeconomic conditions throughout China, regulations should be made in relation to local conditions (Baochang et al., 131)(24). Accordingly, many exemptions were made for families by the State Family Planning Committee during the 1980s and 1990s. These

exemptions applied to a range of circumstances including: rural couples with only a daughter, families in need of labor, ethnic minority groups, and even couples who experience the death of their child.

By the year 2000, China's population reached 1.27 billion people (Worldometer)(26), reducing its population growth rate to 0.8%(Data Commons)(27). In 2002, China created the Population and Family Planning Law, which codified the earlier policies and regulations and made them into law. China began to shift more towards not only limiting the amount of births in their country, but also providing greater reproductive health services to its people (Winckler)(28). Moreover, as stated by the State Council issued A Decision on Strengthening Population and Family Planning Work and Stabilizing a Low Fertility Rate, China looked to improve the "quality" of its population (Jiang et al.)(29).

Korea's family planning program began in 1961, under the government of its new President Park Chung Hee, who assumed power during a military coup. He wanted to utilize family planning policies and the curving of population growth as a way to free up revenue to be invested in other sectors of society. In this way, national economic growth would increase. Park also organized the Planned Parenthood Federation of Korea in 1961, made up of young university professors, nurses, socialists, economists, who all wanted to improve the national welfare of the country and counteract the population crisis (Yang)(30).

The population crisis of Korea rose due to the large baby boom that occurred after the Korean War. By 1954, Korea's birth rate increased to 0.89 (ratio of actual to expected births) which meant that it returned to pre-war levels. During the next year, 1955, the birth rate exceeded pre-Korean War levels (DiMoia)(31). This increase in population was a result of couples reuniting after being separated during the war. Contrary to many Western nations that experienced a baby boom during this time period, no modern methods of actual fertility control were accessible in Korea. Moreover, in 1953, Korea criminalized abortion under the Korean Criminal Code (Kim et al.)(5). By the end of the decade, Korea's population grew to around 25 million people, from 20 million people at the end of the war(Macrotrends)(32). South Korea had one of the highest population growth rates in East Asia, and the average South Korean woman gave birth to more than 6 children during her reproductive years (DiMoia)(31).

During the 1960s, the Planned Parenthood Federation of Korea (PPFK) looked to target rural South Korean women, mobilizing many campaigns in order to provide greater awareness to birth control technology (DiMoia, 364)(31). These were women in areas such as Goyang and Wondang Myun (13 miles north of Seoul) (Studies in Family Planning, 7)(33). The government, despite abortion being prohibited by Articles 269 and 270 of the Korean Criminal Code, often recommended abortion and sterilization procedures at family planning clinics. Eventually the practice became legalized in 1973 (Stoeckel, 378)(34). During the 1970's and 1980's, more practices were focused toward reducing the country's fertility rate to around two children per woman. The government began promoting the slogan: "Girl or Boy, stop at two and raise them well" on propaganda posters in order to help fulfill this goal (Watson and Worth)(4). The government also began training more family planning workers, and supporting greater family

planning activities within rural Health Centers(Choe and Park, 12)(35). The country's birth rate soon dropped to 4.5 during the 1970s, 2.8 in the 1980s, and then 1.6 in the 1990s (Kim et al.)(5).

By the 1990s the country's birth rate had already dropped to below the replacement level of around 2 children. As a result, during the mid 1990s, South Korea began to shift its policies from focusing on population control to the welfare of the population. This included addressing issues such as improving mortality levels, allowing for greater reproductive health services for adolescents, and improving health services for the elderly (Choe and Park, 17)(35). However, the proportion of women who were childless increased during this time period, with there being a 6% increase in childless women from 1995 to 2000 (Choe and Park, 1)(35).

Since 2000, Korea's birth rate has continued to fall. It has dropped from 1.5 at the start of the decade, to around 0.78 in 2025. A large reason for this is the increasing average marriage age among Koreans. Over the past ten years, Koreans are finding marriage less of a necessity (there is a decrease in the amount of positive marriage intentions and an increase in neutral marriage intentions among all ages) (An et al.)(36). As a result, the average age of first marriage in Korea has risen to 33.2 years for men and 30.8 years for women in 2020. Many Koreans are also abstaining from marriage completely, with the amount of "one-person households" in Korea increasing by five-fold since the 1980s (from 4.% in 1983 to 23.9% in 2010)(Ho, 1300)(37). For most of Korea's adults, jobs have taken up most of the time in their lives. In a 2019 study, 67% of people in their 20s stated that "being a parent is an invaluable thing in life" (Cho)(38). The stress of securing jobs in a very competitive labor market has compelled many Korean adults to forgo marriage and having children completely (Cho)(38).

Conclusion

As China and South Korea grapple with the long-term demographic effects of state-enforced birth control policies, the lived realities of only children reveal far more complex sociological and psychological narratives. This paper has shown that state-driven efforts to limit population growth, though effective in curbing fertility rates, have left enduring developmental and societal imprints on the individuals raised under them. By integrating both empirical research and first-person narratives, this study revealed the multifaceted nature of only children as shaped by cultural values, economic structures, and silent familial expectations.

The thematic analysis of this study revealed recurring emotional and behavioral patterns among only children: a heightened internalization of parental hopes, a duality of loneliness and social adaptability, a tendency toward conflict avoidance, and an acute sense of responsibility that extends into adulthood. These insights contextualize previous findings in related literature, such as increased academic performance, prosocial behavior, and disproportionate caregiving burdens. However, the findings also highlight the psychological burdens that quantitative studies may overlook: the quiet anxiety of being one's family's sole hope, the internal conflict between autonomy and obligation, and the unspoken pressure to succeed for those who gave everything to raise them.

As East Asian societies confront rapidly aging populations and declining birth rates, understanding the emotional, social, and structural positions of only children becomes more urgent. These individuals are not only products of policy, but they will now be the caretakers, policymakers and leaders of society itself. Their narratives remind us that population control does not end at birth quotas; it shapes personalities, life paths, and entire social structures for generations to come. Future policy and family planning discourse must therefore move beyond numbers and consider the human dimensions of demographic engineering. Addressing the emotional and social needs of only children will be essential for building resilient societies that can adapt to both the successes and the unintended consequences of population control.

Works Cited

Chen, Yuyu, et al. "Little Emperors in the Workplace: Labor Market Consequences of China's One-Child Policy." *China Economic Review*, vol. 80, Elsevier BV, Aug. 2023, pp. 101985–85, https://doi.org/10.1016/j.chieco.2023.101985.

Kane, Penny, and Ching Y. Choi. "China's One Child Family Policy." *BMJ*, vol. 319, no. 7215, Oct. 1999, pp. 992–94, https://doi.org/10.1136/bmj.319.7215.992. National Library of Medicine.

Wang, Ying, and Vanessa L. Fong. "Little Emperors and the 4:2:1 Generation: China's Singletons." *Journal of the American Academy of Child & Adolescent Psychiatry*, vol. 48, no. 12, Dec. 2009, pp. 1137–39, https://doi.org/10.1097/chi.0b013e3181bc72f8.

Watson, Walter, and George Worth. "Korea." *Studies in Family Planning*, vol. 3, no. 7, July 1972, p. 132, https://doi.org/10.2307/1965229.

Kim, Sunhye, et al. "The Role of Reproductive Justice Movements in Challenging South Korea's Abortion Ban." *Health and Human Rights*, vol. 21, no. 2, Dec. 2019, p. 97, pmc.ncbi.nlm.nih.gov/articles/PMC6927381/.

The World Bank. "Data Development Hub." *Datacatalog.worldbank.org*, 20 Dec. 2023, datacatalog.worldbank.org/search/dataset/0037712.

OECD. "Fertility Rates." *OECD*, 2022, www.oecd.org/en/data/indicators/fertility-rates.html.

Lewis, Mary. "Prosocial Behavior." *Encyclopedia of Evolutionary Psychological Science*, Sept. 2017, pp. 1–6, https://doi.org/10.1007/978-3-319-16999-6_158-1.

Piotrowski, Jessica T., et al. "Media and Child Development." *International Encyclopedia of the Social & Behavioral Sciences*, 2015, pp. 1–10, https://doi.org/10.1016/b978-0-08-097086-8.92145-7.

Rong, Yan, et al. "Differences in Power Acquisition between Only and Non-Only Children: The Effects of Cooperative Orientation, Competitive Orientation, and Dependency on Parents." *Frontiers in Psychology*, vol. 13, Mar. 2022, https://doi.org/10.3389/fpsyg.2022.778726.

Lu, Yao, and Donald J. Treiman. "The Effect of Sibship Size on Educational Attainment in China: Period Variations." *American Sociological Review*, vol. 73, no. 5, Oct. 2008, pp. 813–34, https://doi.org/10.1177/000312240807300506.

Lao, Yehui 1, et al. "The Only Child, Birth Order and Educational Outcomes." *ProQuest*, May 2019, pp. 1–24, https://doi.org/10.5018/economics-ejournal.ja.2019-28.

Mcatee, Stephanie. *The Effect of China's One-Child Policy on Male and Female the Effect of China's One-Child Policy on Male and Female Immigrant Earnings:Does It Pay to Be an Only Child? Immigrant Earnings:Does It Pay to Be an Only Child?* 2016, digitalcommons.iwu.edu/cgi/viewcontent.cgi?article=1445&context=parkplace.

Tan, Poh Lin, et al. "A Case for 'Reverse One-Child' Policies in Japan and South Korea? Examining the Link between Education Costs and Lowest-Low Fertility." *Population Research and Policy Review*, vol. 35, no. 3, Apr. 2016, pp. 327–50, https://doi.org/10.1007/s11113-016-9390-4.

Jia, Chaochao, et al. "Differences in School Performance between Only Children and Non-Only Children: Evidence from China." *Frontiers in Psychology*, vol. 12, Jan. 2022, https://doi.org/10.3389/fpsyg.2021.608704.

Falbo, Toni, and Dudley L. Poston. “The Academic, Personality, and Physical Outcomes of Only Children in China.” *Child Development*, vol. 64, no. 1, Feb. 1993, p. 18, https://doi.org/10.2307/1131435.

Chen, Xiaochen, et al. “Adaptations to the One-Child Policy: Chinese Young Adults’ Attitudes toward Elder Care and Living Arrangement after Marriage.” *Frontiers in Psychology*, vol. 12, Mar. 2021, https://doi.org/10.3389/fpsyg.2021.608111.

Van den Broek, Thijs, and Pearl A. Dykstra. “The Impact of Siblings on the Geographic Distance between Adult Children and Their Ageing Parents. Does Parental Need Matter?” *Population, Space and Place*, vol. 23, no. 6, Mar. 2017, p. e2048, https://doi.org/10.1002/psp.2048.

Xiaoxiao Kwete, et al. “Caregiving for China’s One-Child Generation: A Simulation Study of Caregiving Responsibility and Impact on Women’s Time Use.” *BMJ Global Health*, vol. 9, no. 6, BMJ, June 2024, pp. e013400–0, https://doi.org/10.1136/bmjgh-2023-013400.

Howden, David, and Yang Zhou. “Why Did China’s Population Grow so Quickly?” On JSTOR.*The Independent Review*, vol. 20, no. 2, 2015, pp. 227–48, https://doi.org/10.2307/24562066. JSTOR.

Ke, Qing, et al. “China’s Shift from Population Control to Population Quality.” *Neurology*, vol. 87, no. 8, Aug. 2016, pp. e85–88, https://doi.org/10.1212/WNL.0000000000003010.

Zhang, Junsen. “The Evolution of China’s One-Child Policy and Its Effects on Family Outcomes.” *Journal of Economic Perspectives*, vol. 31, no. 1, Feb. 2017, pp. 141–60, https://doi.org/10.1257/jep.31.1.141.

Saith, Ashwani. “Economic Incentives for the One-Child Family in Rural China.” *The China Quarterly*, vol. 87, Sept. 1981, pp. 492–500, https://www.jstor.org/stable/653600.

Baochang, Gu, et al. “China’s Local and National Fertility Policies at the End of the Twentieth Century.” *Population and Development Review*, vol. 33, no. 1, Mar. 2007, pp. 129–48, https://doi.org/10.1111/j.1728-4457.2007.00161.x.

Jiang, Lijing. “China’s One-Child Policy | the Embryo Project Encyclopedia.” *Asu.edu*, 2011, embryo.asu.edu/pages/chinas-one-child-policy.

Worldometer. “China Population (2023) - Worldometer.” *Www.worldometers.info*, 2024, www.worldometers.info/world-population/china-population/#google_vignette.

Data Commons. “People’s Republic of China - Place Explorer - Data Commons.” *Datacommons.org*, 2023, datacommons.org/place/country/CHN?utm_medium=explore&mprop=count&popt=Person&hl=en.

Winckler, Edwin A. “Chinese Reproductive Policy at the Turn of the Millennium: Dynamic Stability.” *Population and Development Review*, vol. 28, no. 3, Sept. 2002, pp. 379–418, https://doi.org/10.1111/j.1728-4457.2002.00379.x.

Jiang, Quanbao, et al. “China’s Population Policy at the Crossroads: Social Impacts and Prospects.” *Asian Journal of Social Science*, vol. 41, no. 2, Jan. 2013, pp. 193–218.

Yang, J. M. “Planned Parenthood Works with Korean Government.” *Report. Victor-Bostrom Fund*, no. 10, 1968, p. 10, pubmed.ncbi.nlm.nih.gov/12313929/.

DiMoia, John P. “(Let’s Have the Proper Number of Children and Raise Them Well!): Family Planning and Nation-Building in South Korea, 1961–1968.” *East Asian Science, Technology and Society: An International Journal*, vol. 2, no. 3, Sept. 2008, pp. 361–79, https://doi.org/10.1215/s12280-008-9054-5.

Macrotrends. “South Korea Population 1950-2024.” *Macrotrends.net*, 2024, www.macrotrends.net/global-metrics/countries/KOR/south-korea/population.

“Korea: The Koyang Study.” *Studies in Family Planning*, vol. 1, no. 2, Wiley, Dec. 1963, pp. 7–9, https://doi.org/10.2307/1965182.

Stoeckel, John. “Differentials in Fertility, Family Planning Practice, and Family Size Values in South Korea, 1965-1971.” *Studies in Family Planning*, vol. 6, no. 11, Nov. 1975, p. 378, https://doi.org/10.2307/1965280.

Choe, Minja Kim, and Kyung Ae Park. “Fertility Decline in South Korea: Forty Years of Policy-Behavior Dialogue.” *Korea Journal of Population Studies*, vol. 29, no. 2, The Poputation Association of Korea, Aug. 2006, www.researchgate.net/publication/277879779_Fertility_Decline_in_South_Korea_Forty_Years_of_Policy-Behavior_Dialogue.

An, Doyeon, et al. “Marriage Intention among Korean Young Adults: Trends and Influencing Factors.” *International Journal of Environmental Research and Public Health*, vol. 19, no. 14, July 2022, p. 8557, https://doi.org/10.3390/ijerph19148557.

Ho, Jeong Hwa. “The Problem Group? Psychological Wellbeing of Unmarried People Living Alone in the Republic of Korea.” *Demographic Research*, vol. 32, June 2015, pp. 1299–328, https://doi.org/10.4054/demres.2015.32.47.

Cho, Kyung Ae. “Korea’s Low Birth Rate Issue and Policy Directions.” *Korean Journal of Women Health Nursing*, vol. 27, no. 1, Mar. 2021, pp. 6–9, https://doi.org/10.4069/kjwhn.2021.02.16.