



Violent & Valiant: Comparing the Portrayals of Vikings in the Medieval, Romantic, and Modern / Postmodern Eras through Analyses of Visual Media

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Abstract

Vikings have been represented in many different ways throughout history. By analyzing visual media about Vikings from different time periods, one can understand how they were portrayed while also learning about the different places and historical contexts in which the representations occur. Vikings have been represented both brutally and idealistically, but those representations have never been consistent. This lack of consistency in representation throughout history can also be applied to other social groups and cultures in general, including in our own time. Understanding the history of representation of one group is important because it helps to illuminate historical motivations for framing groups in different ways, specifically through visual media. Using mixed methods, this study examines how Vikings were portrayed in different visual media across three aesthetic periods: Medieval, Romantic, and Modern/Postmodern. Results show that patterns emerge with respect to how Vikings are portrayed within each time period. After taking into account the many categories from landscapes to style, Vikings were portrayed more brutally in the medieval era, more heroic in the romantic era, and more stereotypical in the modern era, but with much historical context to consider when generalizing about these overall representations. Art characteristics provide the basis of the data, which, when compared, show how the portrayals of Vikings evolved across the time periods. Overall, analysis of the data shows that the Romantic Era created the largest influence on the future time periods by focusing on cultural elements like mythology and beauty, and it was separated from the more brutal and political depictions of Vikings in the Medieval Era. Portrayals of Vikings have had a long and complicated history, and examining these portrayals can educate about the different ways artists can control people's perceptions of different social or cultural groups throughout time.

Keywords

Vikings; Art History; Visual Media; Stereotypes; Content Analysis

Introduction

What specific characteristics do people imagine when they think of Vikings? Although many have analyzed the evolution of the stereotypes of Vikings through literature (Nelson, 2003; Roylance, 2007), few have done so through other media such as visual art, music and film, with no studies comparing these representations through different time periods. Throughout these historical time periods, Vikings were often stereotyped. Scandinavian studies expert, Ellen Kythor (2020), describes how the stereotypes reveal both ideas related to Viking identity, and information about the regions and historical eras that contextualize the varying stereotypes (pp. 213-214). For example, a common stereotype of Vikings used in twenty-first century America represents Vikings as "a muscular man wearing medieval armor, with horns on his helmet" (Wilkins, 2019) which shows the current era's interest in escaping through fantasy in the 21st century. From my own discoveries, several articles including archeology professor, Anders Andren's, "Behind 'Heathendom'" (2005) and G. W. Dasent's Vikings of the Baltic (1875) provide insight on the literary and archeological elements depicting Vikings in different historical eras.



The Medieval Era: 500 to 1450 C.E.

In the Medieval Era, an abundance of art and music was based around Christianity. The Vikings lived in the Medieval Era roughly between 800 to 1050 C.E. Allen Mawer, a British philosopher from the early 1900s described in his book, *The Vikings* (1913), how the term “Viking” derives from the Old Norse language word, *vik*, meaning one who haunts a bay, creek, or fjord (p. 1). They had left their homes in Scandinavia in the 900s to assail European countries via ships. The Vikings during this period were portrayed as “Heathen,” a word to negatively describe someone who does not practice Christianity (Frank, 2007). Despite them not practicing Christianity, they had their own many ways of practicing religion. This included their own mythological beliefs surrounding their primary religion of Paganism (von Schnurbein, 2016).

Figure 1 shows an illustration from approximately 1100 C.E. called *Illustrations de la vie de Saint Aubin d'Angers*, which depicts a group of Viking warriors lined up in an organized section upon a ship.

Figure 1. *Illustrations de la vie de Saint Aubin d'Angers* (ca. 1100), Bibliothèque National de France.

They each carry a shield colored green or orange, and handcrafted long spears. They wear heavy layers of chainmail and metal helmets. The ship they stand upon is being carried by a multicolored, seemingly harsh wave adding an effect of intensity. These characteristics depicted in the painting represent how Vikings were not romanticized in works of art in the Medieval Era, but rather feared for their potential to raid European countries (Mawer, 1913, p. 12). A more common work of art, the embroidered Bayeux Tapestry, shown in Figure 2, depicts the Battle of Hastings between the Vikings and people of England (Britannica, 2026).

Figure 2. Bayeux Tapestry (1066), Bayeux Museum.

In the 70 meter tapestry created by the English after the attacks, Vikings are displayed upon horses charging at the people of England. They wear pointy helmets, and carry large shields with their golden swords. They also wear chain mail in this artwork, corresponding to the previously analyzed *Illustrations de la vie de saint Aubin d'Angers*. Deceased and injured villagers, soldiers, and horses are seen scattered across the ground. This signifies the impact the battle had on both the Vikings and English, as many people's lives were taken. The main purpose of this tapestry was to spread the concept to Englishmen that Vikings were not figures to be romanticized or idealized in their culture. These concepts were spread through more propaganda in art.

The Romantic Era: 1800 to 1910 C.E.

In the late 19th century, Vikings were romanticized for many reasons. A composer, Richard Wagner, is known for his operas that incorporate characters who are part of Viking groups. His operas were based upon old Norse folk and Nordic mythology tales which all portray Vikings (von Schnurbein, 2016). Specifically, in the four operas known as *The Ring Cycle*, there was a strong focus on old Norse mythology as it included characters who portrayed old Norse mythological figures like Wotan, Brunnhilde, Valhalla, and Siegmund (Larrington, 2023). Wagner, in fact, was the first artist to portray the Vikings as having horns on their helmets. From this point on, the stereotype continued. They were seen as a symbol of Norse power and to represent their barbaric characterization (Ward, 2001).

Along with music and operatic sequences, art also played a major role in the representation of Vikings in the Romantic Era. Many illustrations, paintings, engravings, and statues all depicted the Vikings wearing horned-helmets and carrying an abundance of armor (Langer, 2002). An illustration from 1839 C.E. (unknown artist) depicts a Viking character from the book *The Saga of Frithiof* with an idealized body and face shape, wearing a horned helmet and carrying hand-crafted shields with geometric patterns engraved (Langer, 2002). This creates a certain artistry that adds to the viewer's sense of



meaning in the illustration. Another example, shown in Figure 3, is a painting, Valkyrie, by Norwegian artist Peter Nicolai.

Figure 3. Valkyrie (1869), National Gallery of Norway.

This painting is an idealized portrait of a female Viking on a horse with a strong sense of power. Her facial features are depicted as ideal for the time, and her weapons are pointed neatly, unlike the depictions of their weapons in the Medieval Era. This can romanticize the feeling of power held by a female through the idealistic features characterised by her strong presence. The audience of this specific art style may feel more interested in the work by its unique romanticization of the Viking, hence the name of this era.

The Modern / Postmodern Era (1910-present)

Film was introduced as a new form of visual media during this time period, however the portrayal of Vikings through art and music continues. The 1958 film, *The Vikings*, was described as a film depicting Viking life very accurately (Pfeiffer, 2023). This film is a heroic portrayal of two half brothers competing for a princess during the Medieval Era. The attire of the Vikings, as well as the boats and tools used are some of the more accurate portrayals of the Vikings that can be seen during the Modern / Postmodern era. It does not lean in any specific direction towards a positive or negative portrayal. Some films, however, purposefully portray Vikings as either an enemy or a main character/protagonist. The film *The Secret of Kells* (2009), with art by Cartoon Saloon, is an Old Norse-based story displaying the lives of the Irish during the Viking invasions during Medieval Irish history (Buchelt, 2022). Vikings are portrayed as terrifying monsters, with fire around them, and hooded faces, along with prominent horns that are larger than their head. Cartoon Saloon uses art styles used during the medieval times to help portray the Vikings as violent and disruptive to the fairy-tail-like lives of the Irish.

An example of a film that portrays Vikings as kind and bubbly individuals is *How to Train Your Dragon* (2010). The main characters are all Vikings, and the story being told is not a Viking-specific tale. Some of the Viking characters are harsh, however they are portrayed in a style of animation that can apply to a broader audience. Carolyne Larrington (2023) performed a study examining how the old Norse myths influence current pop culture. She suggests that some of the portrayed masculine Gods and feminine Valkyries from the Medieval Era depict the gender ideals of the present time. This suggests that movies taking place during the time when Norse mythology influenced stylistic choices could even add to current controversial gender stereotypes. This is also true about works of art, books, and music videos. For example, the Thor comic books from the 1960s include the masculine qualities held by Thor, such as rippling muscles and angular jaw lines. Several other works of art portray this stereotypical characteristic as well.

Although several studies examine the stereotypes and representations of Vikings in specific time periods and with specific media, none of them analyze the evolution of these representations through historical time, or a comparison of how they are portrayed within the context of different eras and visual media.

Methods

Selection of the Works

Since this research project compares artworks that portray Vikings across three different time periods, my first task was selecting which artworks to analyze. Artworks have portrayed the Vikings through many different media: The selections I chose from the Medieval Era were artworks that come from tapestries, illuminated manuscripts, and stone carvings; from the Romantic Era, works include paintings, drawings, opera costumes, and book illustrations; and from the Modern / Postmodern Era, I chose film stills, drawings, music videos, and paintings. There are noticeably many more types of



media used in art during the Modern / Postmodern Era. I felt it necessary to represent a compilation of each artistic media as to not leave out portrayals that may only be seen in one type of media. For example, Vikings as superheroes became a dominant theme but are only portrayed through comic books and some films, not through paintings and sculpture. In order to represent all newer portrayals of Vikings, one must examine the newer types of media that opinions are portrayed through even though this choice lessens the homogeneity of the samples. Thus, both the content and the media reflect their respective eras. To do this comparison, I first selected and compiled nine works from each of these time periods, deciding on 27 works in total, and then used mixed methods, as outlined below, for the comparison. I found the items of analysis on many different museums' digital collections, including MoMA and the Metropolitan Museum of Art, as well as from web searches that used search terms related to real Viking kings, Norse mythology, artists, filmmakers, and composers from different eras.

To find what works of art, music, and film I am analyzing, I first had to gather plenty of context about the battles, leaders, folklore, and old religion surrounding the Viking culture. A video produced by the British Museum (2020), called Vikings Live provides a thorough overview on the most important topics to observe when researching Viking history. The video tours an art exhibition in the British Museum while providing detail on the lives of Vikings. The main figures that I looked for when collecting art were Ubba, the War Commander from the 8th century, Odin, the God of War, and any various battles caused by the Vikings' invasions during the Medieval Era (Niles, 2015). This led me to many connected works of art. For example, the artworks I found from the Romantic Era show a continuous portrayal of Odin, the God of War, while the art from the Medieval Era has been seen to focus more on the portrayal of specific real people and commanders during that era. The Romantic Era also provides a wide selection of Operas portraying Vikings. Continuing into the Modern/Post-Modern Era, there is more variation in the portrayal of Vikings, primarily because there are more past opinions that authors and artists can derive from, as well as a variety of media types and styles.

Mixed Method

For the analysis, I used a mixed method, including a qualitative thematic analysis and a quantitative content analysis, which were ideal for both qualitatively and quantitatively coming to new understandings about the characteristics present in a variety of artworks that portrayed Vikings. In a qualitative thematic analysis, researchers create thematic categories based on a thorough review of characteristics of the data, and in a quantitative content analysis, researchers count which of the chosen characteristics are present for each data point. In this study, the data is the chosen artworks. I learned about these methods from Langer (2021), Wansink et al. (2016), and Soldati & Illingworth (2020), as discussed below. There are many different characteristics portrayed through art by the artists, and each characteristic can represent different perspectives on the Vikings during the specific era. Different themes can express different emotions, aesthetics, and the artist or culture's impression of the Vikings.

Johnni Langer (2021), a professor with a PhD in Viking Age Archeology and Old Norse Religion, does an analysis of old Norse Religion and how its stereotypes are portrayed among Vikings. Different themes are given for comparison like behavior, society, nationalism, and environment. Next to each theme, there is a description of how the portrayed Norse Religion represents that characteristic or stereotype, either positively or negatively. Another study uses a similar methodology to examine different foods seen throughout paintings in different places. Brian Wansink et al. (2016) are professors at various universities in the United States who do a thematic, then quantitative analysis of the different foods found in art in their study, "Food Art Does Not Reflect Reality: A Quantitative Content Analysis of Meals in Popular Paintings." A third example of this mixed method can be seen in Arianna Soldati and Sam Illingworth's (2020) study on the perception of volcanoes through poetry. The two European researchers found the major categories that emerged from their thematic coding of the poems. Next, using these five categories, they were able to perform an unbiased quantitative



analysis with the correct variables. This gave them the data they needed to provide a visual and statistical representation of the portrayals of volcanoes in poetry. This study matches and validates my methodology precisely as it provides a meticulous way to properly analyze visual characteristics of portrayal, which can be difficult to represent given that art can be perceived differently by separate individuals.

For my own project, the thematic analysis involved selecting the primary characteristics from each of the 27 artworks that best depict the notable changes in the portrayal of the Vikings over time. These characteristics form the code book so I can begin the quantitative content analysis, which shows the frequency of each characteristic of art across all three time periods (Medieval, Romantic, Modern / Post-Modern). In the code book, I used a “1” if the artwork displayed the characteristic in question, and a “0” if it did not, as shown in Appendix B. This quantitative analysis of a variety of characteristics will go further than just a “positive” or “negative” portrayal of Vikings in each era. Examining a plethora of characteristics allows the study to more deeply analyze the context and importance of the outcome of each characteristic and how it relates to the overall portrayal of Vikings from that era. The total counts show which characteristics emerge as dominant in each era, with the help of graphs and charts as visualizations of the data from the code book.

After all of the data is compiled, the final comparison of Viking portrayals from the three eras can occur. According to my hypothesis, each time period will have a different portrayal of Vikings through art, music, and film.

Results and Discussion

Selected Works

The art chosen for this analysis consists of paintings, drawings, illuminated manuscripts, tapestries, sculptures, opera scenes/costumes, comic strips, films and music videos all depicting Vikings/Viking culture. Each artwork chosen is listed in Tables 1, 2, and 3 depending on the time period, and a comprehensive list is also in Appendix A.

Table 1. Artworks chosen from the Medieval Era.

Artwork	Media
A depiction of Ivar and Ubba setting forth to avenge their father, Lodbrok (ca. 1430)	Drawing/Illuminated Manuscript
Miscellany on the life of St. Edmund (ca. 1130)	Drawing/Illuminated Manuscript
Lives of Saints Edmund and Fremund (ca. 1430)	Drawing/Illuminated Manuscript
Miscellany on the life of St. Edmund MS M.736 fol. 10r (ca. 1130)	Drawing/Illuminated Manuscript
Miscellany on the life of St. Edmund MS M.736 fol. 9v (ca. 1130)	Drawing/Illuminated Manuscript
Viking Domesday stone (ca. 800s)	Sculpture
Illustrations de la vie de saint Aubin d'Angers (ca. 1100)	Drawing/Illuminated Manuscript



Bayeux Tapestry Scene 52 (ca. 1000)	Embroidered Tapestry
A fifteenth-century depiction of the murder of Loðbrók by Bjørnc (ca. 1400s)	Drawing/Illuminated Manuscript

Table 2. Artworks chosen from the Romantic Era.

Artwork	Media
Wagner Costumes/Scenes (late 1800s)	Opera Costumes/Scenes
Wotan takes leave of Brunhild (1892)	Drawing
The Wild Hunt of Odin (1872)	Painting
Mårten Eskil Winge (1866)	Painting
Frithjof Kills Two Ocean Trolls (1826)	Painting
Frithjof's wooing (1907)	Drawing
Sittende Viking I Kystlandskap (1840)	Painting
Nicholas Roerich, Guests from Overseas (1901)	Painting
Valkyrie, by Peter Nicolai Arbo (1869)	Painting

Table 3. Artworks chosen from the Modern / Postmodern Era.

Artwork	Media
How to Train Your Dragon (2010)	Film
The Secret of Kells (2009)	Film
The Vikings (1958)	Film
Thor Comic Strip (1960s)	Comic Strip
Amon Amarth - We Rule The Waves (2025)	Music Video
Wardruna - Lyfjaberg (Healing-mountain) (2020)	Music Video
The Norseman: Frank Frazetta (1972)	Painting
Lagertha as imagined in a lithography (1913)	Drawing
Irish Gael attack a Viking raiding party (ca. late 1900s)	Drawing

Thematic and Content Analyses

Several characteristics came into focus when examining these diverse media across three different historical time periods. After completing a qualitative thematic analysis, 45 characteristics placed in six different thematic groupings arose as suitable for my content analysis, as shown in Table 4. There are five to 11 different characteristics within each thematic grouping.



Table 4. Thematic groupings and characteristics.

Thematic Grouping	Characteristics
Weapons and Armor (11)	Swords, Axes, Spears, Circular Shields, Heater Shields, Shields with Banners/Devoted Patterns, Bow/Arrows, Chainmail, Armor, Horned/Winged Helmets, Other Helmets
War and Violence (7)	Fighting, Dead Valkyries, Dead Vikings, Dead Non-Vikings, Blood, Horses, Fire
Clothing and Style (9)	Beards, Braids, Face Paint, Men with Long Hair, Bare Feet, Sandals, Clothing from Animal Fur, Women in Gendered Clothing, Muscular Physiques
People/Characters (8)	Vikings, Non-Vikings, Men, Women, Children, Valkyries/Other Mythological Characters, Armies, Portrait of One or Two
Landscape Characteristics (5)	Mountains, Open Oceans, Shore, Big Birds, Villages
Miscellaneous Viking Characteristics (5)	Flags/Banners, Color Themes, Viking Ships, Nordic Art Symbolism, Patterned Grouping in Armies

After gathering all of these characteristics, I was able to perform my quantitative content analysis, the comprehensive results of which are shown in Figure 4 and Appendices A and B.

Figure 4. Clustered Bar Chart Showing Total Counts of Each Characteristic, As Dispersed Amongst Three Historical Eras.

Figure 4 shows different types of variation of portrayal of Vikings in each category. This is the overview of all of my results compiled onto a bar graph. To examine how often each characteristic appears in each era, one would use the x axis to find the category, and analyze the amount of works of art in which the characteristic appears. For example, big birds are seen mostly during the Romantic era (red), partially during the Medieval Era (green), and barely at all during the Modern / Postmodern (blue). The characteristic of face paint barely appears in the Medieval Era, and doesn't appear in any other pieces of media I collected from the following eras.

Discussion

When examining the results, different patterns emerge. A characteristic may be abundant in the Medieval Era but rare in the Romantic and Modern/Postmodern Eras and its opposing characteristic may be abundant in the Romantic and Modern/Postmodern Eras but rare in the Medieval Era. An interesting example of this scenario is the results provided from the Bare Feet and Sandals characteristics. After observing the Vikings' footwear in every artwork from every era, I discovered that despite the Vikings primarily wearing no footwear in the Medieval artworks, they suddenly were depicted wearing sandals through the other two eras, as shown in Figure 5.

Figure 5. Percent of artworks with sandals.

A similar pattern, when a characteristic increases over time, is also seen with clothing made of animal fur as well as horned/winged helmets, as shown in Figures 6 and 7.

Figure 6. Percent of artworks with animal fur as clothing.



Figure 7. Percent of artworks with winged / horned helmets.

This pattern of increasing frequency occurred mainly because of the influential operas done by Wagner. The most well known example of this is horned / winged helmets which, interestingly, was not the most prominent of this type of variation and ideology amongst these many other characteristics. Once Vikings were seen in a new, romanticized, and idealized way in the theater, many artists took after that same portrayal to enhance the romanticism within their art. Some more of the results that give evidence to this concept are depiction of muscular physiques, fire, beards on Vikings, and male Vikings with long hair.

A different type of pattern I discovered in my content analysis is the dominance of a certain characteristic in just one era. This happens within each era, all with different characteristics. The displaying of Valkyries/other mythological characters appears mostly within the Romantic Era, as shown in Figure 8, with 75% of the works displaying a mythological character. This is due to the idealism and glorification of post-Renaissance heroic legends occurring during the Romantic Era (Stanford University, 2016).

Figure 8. Percent of artworks with valkyries / other mythological characters.

The Greco-Roman mythological rediscoveries of the Renaissance Era, after the Medieval Era, lingered into the Romantic Era but stayed behind as there was a multitude of types of media in the Modern Era so all types of portrayals were broken down into smaller groupings (Bernstock, 1993). This ideology is demonstrated by Valkyries and other mythological characters in my content analysis.

This dominance of a particular characteristic with the Romantic Era can also be observed with the mountains depicted in each work. In the Romantic Era, 63% of works displayed mountains whereas the Medieval Era had 0% mountain display and the Modern/Postmodern Era had 22% mountain display. This proves the romanticism ideology of the Romantic Era portraying nature more sublimely and dramatically in the hopes of providing a sense of intensity and heroism to the observer (Galitz, 2004). Frequent depiction of chainmail, circular shields, large birds, and seashores in the Romantic Era also give evidence to this ideology.

Another pattern that emerged was when characteristics decreased in abundance across the three eras. Examples are shields with banners/flags, bow/arrows, regular helmets, the death of non-vikings, and Nordic art symbolism. These characteristics are common in the Medieval Era, but rarer in the Romantic and Modern / Postmodern Eras. This is due to the characteristics' lack of portrayal within the very influential Wagner's operas and the deep desire to create intense and deep emotions from a piece of art.

This dominance of certain characteristics in the Medieval Era is evident in the depictions of patterned grouping in armies, as shown in Figure 9. Medieval art styles tend to be much more geometric and sharp than later art styles.

Figure 9. Percent of artworks with patterned groupings of armies.

This is generally the style of all scenes throughout this era. In addition to this, the organization of the subjects within a piece of art tells the audience that the artist has a dramatic intent. This style may also give one a sense of threat and forbidding due to the intense order within the work. Heater shields, the triangular-like shields shown in Figure 1, are also confirmation of a more geometric and orderly approach to the styles in the Medieval Era, along with the thematic color schemes of Vikings' clothes.

This differentiation in shield shape created another interesting comparison across historical eras, as shown in Figures 10 and 11.

Figure 10. Percent of artworks with heater shields.



Figure 11. Percent of artworks with circular shields.

Heater shields, which are the shields whose shape is defined by a point at the bottom, are confirmation of a more brutalist portrayal of Vikings during the Medieval Era. A contrasting style seen through comparison is the more circular shields (Figures 3 and 12) that developed during the Romantic Era and lingered into the Modern / Postmodern Era. The circular shields presented a more toned, natural, and graceful style of Vikings in art. The portrayal of the circular shields was another aspect of Romantic Era portrayal that originated from Wagner's Operas. The costumes included Valkyries carrying round shields with pointed spears at the center. This trait came from one of Wagner's intentions to portray Vikings more powerfully and valiantly than they have been in prior eras.

One important point to note is the absence of characteristics in certain time periods. A primary example can be seen through the data displaying shield shape depiction. Circular shields, for example, are not depicted in the Medieval Era, which could be a result of many different factors. After taking into consideration the context and the background of each characteristic's representation, one might make the assumption that circular shields were not yet invented or just not commonly used. However, depictions in art do not always represent reality. Later, the heater-shaped shields' depiction is absent from the Modern / Postmodern Era. This fallout of a once popular characteristic being replaced with an emerging and opposing one can be an explanation for many of the absences of attributes that can be seen in all of the data. Another example of this concept can be seen with the Clothing from Animal Skins characteristic. The Medieval Era has an absence of this characteristic. Again, a similar point can be made that this may just be a way they are portrayed, but not how they really were since archeologists have found animal skins and fur in Viking graves (Kirkinen et al, 2020).

Figure 12. Costume design for Waltraut, *Der Ring des Nibelungen* (1889).

Figure 12 shows a Valkyrie costume design for one of the four operas in Wagner's Ring Cycle. This kind of circular shield hadn't been seen previously, which was found in my data that did not find any circular shields in the Medieval Era. Shield shape, then, is one example of how the Romantic Era strays from realistic portrayals of Vikings and leads into more idealistic portrayals, which influenced many of the portrayals of Vikings in the Modern / Postmodern Era.

The Modern Era resulted in diverse portrayals of Vikings. Due to the overwhelming amount of media types, there were many different ways in which Vikings were portrayed. Overall, they were alternately portrayed as harmful, frolicsome, and heroic. This era also shows an exaggeration of certain male gendered characteristics such as beards and muscular physiques, as shown in Figures 13 and 14.

Figure 13. Percent of artworks with beards.

Figure 14. Percent of artworks with muscular physiques.

Given that the Modern Era contains several types of media that strayed from the previous media seen in the Romantic and Medieval Eras, such as music videos, live-action films, cartoons, and comic books, it was very difficult to choose a sample that captured the most valuable representation of how Vikings were portrayed during this time period. A mixture of all of these media ended up being included in the Modern / Postmodern Era sample of works. This also offered the variation of intended audience in the sample, from children seeking light-hearted content, to adults hoping for a realistic to moderate portrayal of history, also seeking education. Despite this difference in audience, the sample of works I chose provides results that capture a combination of all portrayals of Vikings. The results show that many of the Modern / Postmodern content percentages are about halfway in between of the other two eras, sometimes functioning as an average between the two other eras. A specific example of this is the appearance of Vikings dressed in armor. Forty-four percent of Medieval works show Vikings in armor, 100% of Romantic works show Vikings in armor, and 78% of Modern / Postmodern works show



Vikings wearing armor. Seeing as 78% is very close to the mean between the 100% in the Romantic Era and the 44% in the Medieval Era, the idea that the Modern / Postmodern Era can show a variation and combination of the previously seen portrayals of Vikings is distinctly proven.

Each pattern that emerged in my analysis has a historical explanation. The primary explanatory factors responsible for the variations in portrayals of characteristics have a strong correlation within each category giving structure to my results. After taking into account the many categories from landscapes to style, Vikings were portrayed more brutally in the medieval era, more heroic in the romantic era, and more stereotypical in the modern era, but with much historical context to consider when generalizing about these overall representations.

Limitations

One of the limitations that appeared in the process of performing the quantitative content analysis was having to decide whether or not a given characteristic appears without the help of other individuals' opinions. I sometimes had to choose "0" or "1" in ambiguous situations. For example, the characteristic of men with long hair was one of the more vague qualities to analyze. Whether or not a hair length is categorized as long or short would have been easier to decide with the perception of another individual to provide variation that would be combined into an ultimate choice. Having two or more co-authors would have helped in unclear situations like this one.

Seeing as there are many more artifacts available to examine from the Modern / Postmodern Era, and only nine works are collected from each era, a smaller ratio of media is being taken out of the selection. Although it is valid to have a persistent number of works being analyzed from each era, the change in amount of media available to be analyzed also changes the extent to which the era is represented. A smaller percentage of artworks are being selected from the era's artistic offerings. Additionally, the nine chosen works from the Medieval and Romantic Era have much less variation in media due to the minimal materials, in comparison to the Modern / Postmodern era, that were used for art. The exponential growth of art forms in the 20th and 21st century provided much more media to be analyzed, so the Modern / Postmodern sample has much more fluctuation in the types of media considered. This also creates a difference in the amount by which each era's portrays; of Vikings through art is being represented.

The works selected offer a very wide differentiation of regional background and perspectives. Although this increases variation in culture, standards of what's considered aggressive, and extent of exaggerated portrayal, it also makes it difficult to provide even more context on each artwork. Without proper examination of the intentions in each region's development of artistic expression and perspectives, there is potential for misrepresentation of local intentions.

Another limitation that appeared was during the selection of pieces of media prior to the thematic analysis. It was a difficult process to put together a single sample of works that fully represented the portrayal of Vikings during that specific era. A potential solution to this problem could be to increase the sample size to 30 or more pieces of media per era and gather one to two works that represented a multitude of that type of work seen within a sample.

Conclusion

Before performing this analysis, I hypothesized that the Medieval Era would have a negative portrayal of Vikings, the Romantic Era would have a positive portrayal of Vikings, and the Modern / Postmodern Era would have a mixture of both positive and negative portrayals. After performing this analysis, I have found that this hypothesis was a very vague description of my final results. The results I collected examine the details of each portrayal to allow for a greater level of complex understanding for this topic. For example, the Romantic Era does not simply portray Vikings positively, but it focuses on the influence of Viking mythology and Valkyries, which do ultimately create an idealized portrayal of Vikings, but doesn't equate to simply being "positive." Future studies may want to examine more artwork and could look at specific samples or these portrayals. It may be a useful addition to the body



of knowledge surrounding the topic of portrayals of Vikings to examine how they were depicted in a specific region, such as only in French art or only in Irish art, or through other historical eras like the Renaissance, which my research showed had very few Viking portrayals. It may also be interesting to do a deeper analysis on the comparison of how they are portrayed through literature across time, seeing as language provides a different lens than other art forms.

In this study, a significant amount of data was collected that creates a credible comparison of portrayals of Vikings through art, music, and film throughout the Romantic, Medieval, and Modern / Postmodern Eras. The characteristics of the art provided for an analysis of the portrayals of Vikings in each era. Not only did the data collected quantitatively provide for the individual analyses in each era, but it allowed for the comparison of each era's representation of Vikings throughout time. These comparisons show how the portrayals of Vikings evolved across the time periods. Overall, analysis of the data shows that the Romantic Era created the largest influence on the future time periods by focusing on cultural elements like mythology and beauty, and it was separated from the more brutal and political depictions of Vikings in the Medieval Era. Portrayals of Vikings have had a long and complicated history and examining these portrayals can educate about the different ways artists can control people's perceptions of different social or cultural groups throughout time.

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References

- Andrén, A. (2005). Behind "Heathendom": Archaeological studies of old Norse religion. *Scottish Archaeological Journal*, 27(2), 105–138. <http://www.jstor.org/stable/27917543>
- Bernstock, J. E. (1993). Classical mythology in twentieth-century art: An overview of a humanistic approach. *Artibus et Historiae*, 14(27), 153-183. <https://www.jstor.org/stable/1483450>
- Britannica. (2026). Viking. In Britannica online encyclopedia. Retrieved February 10, 2026, from <https://www.britannica.com/topic/Viking-people/The-Carolingian-empire-and-France>
- The British Museum. (2020, May 27). Vikings live: A tour from the British Museum [Video]. <https://youtu.be/NuL0Q0tsid4?si=cxDUNnE6qQuk2WpN>
- Buchelt, L. C. (2022). 'One beetle recognizes another': Translation, transformation, transgression in Cartoon Saloon's film *The Secret of the Kells*. In M. C. Conner, J. Grossman, & R. B. Palmer (Eds.), *Screening Contemporary Irish Fiction and Drama*. Palgrave Studies in Adaptation and Visual Culture, Palgrave Macmillan. https://doi.org/10.1007/978-3-031-04568-4_7
- Dasent, G. W. (1875). *The Vikings of the Baltic: A tale of the north in the tenth century*. Chapman and Hall. <https://babel.hathitrust.org/cgi/pt?id=nyp.33433074951264&seq=7>
- Frank, R. (2007). Terminally hip and incredibly cool: Carol, Vikings, and Anglo-Scandinavian England. *Representations*, 100(1), 23–33. <https://doi.org/10.1525/rep.2007.100.1.23>
- Galitz, K. C. (2004, October 1). Romanticism. Met Museum. <https://www.metmuseum.org/essays/romanticism>
- Kirkinen, T., Vajanto, K., & Björklund, S. (2020). Animal hair evidence in an 11th century female grave in Luistari, Finland. *Archaeological Textiles Review*, 62, 109–125. <https://doi.org/10.7146/atr.62.166829>
- Kythor, E. (2020). Stereotypes in and of Scandinavia. In A. Lindskog & J. Stougaard-Nielsen (Eds.), *Introduction to Nordic Cultures* (pp. 210–224). UCL Press. <http://www.jstor.org/stable/j.ctv13xprms.20>
- Langer, J. (2021). Horned, barbarian, hero: The visual invention of the Viking through European art (1824-1851). *Scandia Journal of Medieval Norse Studies*, 4, 131-180.



https://www.researchgate.net/publication/356086493_Horned_barbarian_hero_the_visual_invention_of_the_Viking_through_European_art_1824-1851_Scandia_Journal_of_Medieval_Norse_Studies_vol_4_2021_pp_131-180_Dossier_Norse_Myths_in_the_artistic_reception
 Larrington, C. (2023, March 16). Why old Norse myths endure in popular culture. University of Oxford. <https://www.english.ox.ac.uk/article/why-old-norse-myths-endure-in-popular-culture>
 Mawer, A. (1913). *The Vikings*. Cambridge University Press.
<https://archive.org/details/vikings00mawe>
 Nelson, J. L. (2003). Presidential address: England and the continent in the ninth century: II, the Vikings and others. *Transactions of the Royal Historical Society*, 31, 1-28.
<https://www.jstor.org/stable/3679244>
 Niles, J. D. (2015). The myth of the feud in Anglo-Saxon England. *The Journal of English and Germanic Philology*, 114(2), 163–200. <https://doi.org/10.5406/jenglgermphil.114.2.0163>
 Pfeiffer, L. (2023, April 28). The Vikings. *Encyclopedia Britannica*.
<https://www.britannica.com/topic/The-Vikings>
 Roylance, P. J. (2007). Northmen and Native Americans: The politics of landscape in the age of Longfellow. *The New England Quarterly*, 80(3), 435–458. <http://www.jstor.org/stable/20474556>
 Soldati, A., & Illingworth, S. (2020, March 26). In my remembered country: what poetry tells us about the changing perceptions of volcanoes between the nineteenth and twenty-first centuries. *Geoscience Communication*, 3, 73–87. <https://doi.org/10.5194/gc-3-73-2020>
 Stanford University. (2016). 19th century romantic aesthetics. In *Stanford Encyclopedia of Philosophy*. Retrieved April 25, 2026. <https://plato.stanford.edu/entries/aesthetics-19th-romantic/>
 von Schnurbein, S. (2016). Germanic neopaganism – A Nordic art-religion? In *Norse Revival: Transformations of Germanic Neopaganism* (pp. 298–350). Brill.
<http://www.jstor.org/stable/10.1163/j.ctt1w76v8x.17>
 Wansink, B., Mukund, A., & Weislogel, A. (2016). Food art does not reflect reality: A quantitative content analysis of meals in popular paintings: a quantitative content analysis of meals in popular paintings. *Sage Open*, 6(3). <https://doi.org/10.1177/2158244016654950>
 Ward, E. I. (2001). Viking pop culture on display: The case of the horned helmets. *Material Culture Review*, 54(1), 6-20. <https://journals.lib.unb.ca/index.php/MCR/article/view/17894/19169>
 Wilkins, K. (2019). Horns: Vikings, adaptation, evolution. In K. Fugelso (Ed.), *Studies in Medievalism XXVIII: Medievalism and Discrimination* (pp. 133–148). Chapter, Boydell & Brewer.
<https://www.cambridge.org/core/books/abs/studies-in-medievalism-xxviii/horns-vikings-adaptation-evolution/032C730A0EC99E985B7CC81EE3637A9D>

Authors

Cora Gillespie is going into her senior year at Sachem North High School and has interests in music, art, design, and history. She is a dedicated violinist and enjoys hiking and visiting museums in her free time. She hopes to travel to several new places in the future to discover the many wonders the world has to offer.

Appendix A.

I. Key for Analyzed Artworks

MEDIEVAL:

1. [British Library Harley 2278](#)(ca. 1430s)
2. [Miscellany on the life of St. Edmund](#)(ca. 1130)
3. [Lives of Saints Edmund and Fremund](#)(ca. 1430s)
4. [Miscellany on the life of St. Edmund MS M.736 fol. 10r](#)(ca. 1130)
5. [Miscellany on the life of St. Edmund MS M.736 fol. 9v](#)(ca. 1130)
6. [Viking Domesday stone](#)(ca. 800s)
7. [Illustrations de la vie de saint Aubin d'Angers](#)(ca. 1100)
8. [Bayeux Tapestry Scene 52](#)(ca. 1000)
9. [British Library MS Yates Thompson 47, folio 34r](#)(1400s)

ROMANTIC:

10. [Wagner Costumes/Scenes](#)(late 1800s)



11. [Wotan takes leave of Brunhild](#)(1892)
 12. [The Wild Hunt of Odin](#)(1872)
 13. [Mårten Eskil Winge](#)(1866)
 14. [Frithjof Kills Two Ocean Trolls](#)(1826)
 15. [Frithjof's wooing](#)(1907)
 16. [Sittende Viking I Kystlandskap](#)(1840)
 17. [Nicholas Roerich, Guests from Overseas](#)(1901)
 18. [Valkyrie, by Peter Nicolai Arbo](#)(1869)
- MODERN / POSTMODERN:
19. [How to Train Your Dragon](#)(2010)
 20. [The Secret of Kells](#)(2009)
 21. [The Vikings](#)(1958)
 22. [Thor Comic Strip](#)(1960s)
 23. [Amon Amarth - We Rule The Waves](#)(2025)
 24. [Wardruna - Lyfjaberg \(Healing-mountain\)](#)(2020)
 25. [The Norseman: Frank Frazetta](#)(1972)
 26. [Lagertha as imagined in a lithography](#)(1913)
 27. [Irish Gael attack a Viking raiding party by Angus McBride](#) (ca. late 1900s)

II. Key for Color Codes of Themes

Weapons and Armor
War and Violence
Clothing and Style
People/Characters
Landscape Characteristics
Miscellaneous Viking Characteristics

Appendix B.

I. Complete Code Book for Artworks Chosen from the Medieval Era

Work #: (See Appendix A-I)	1	2	3	4	5	6	7	8	9	Total
Swords	1	0	1	1	0	1	0	1	0	5
Axes	1	0	1	0	0	0	0	1	0	3
Spears	1	0	1	1	1	0	1	1	0	6
Circular Shields	0	0	0	0	0	0	0	0	0	0
Heater Shields	0	0	0	1	1	0	1	1	0	4
Shields with Banners/Devoted Patterns	0	0	0	1	1	0	0	1	0	3
Bow/Arrows	0	1	0	1	0	0	0	0	0	2
Chainmail	0	0	0	0	0	0	1	1	0	2
Armor	1	0	1	0	0	0	1	1	0	4
Horned/Winged Helmets	0	0	0	0	0	0	0	0	0	0
Other Helmets	1	0	1	1	1	0	1	1	0	6
Fighting	1	1	1	1	0	1	0	1	1	6
Dead Valkyries	0	0	0	0	0	0	0	0	0	0



Dead Vikings	0	0	0	0	0	0	0	1	0	1
Dead Non-Vikings	0	0	1	1	0	0	0	1	0	3
Blood	0	0	1	1	0	0	0	1	0	3
Horses	0	0	0	0	0	0	0	1	0	1
Fire	0	0	1	1	0	0	0	0	0	2
Beards	1	0	0	0	1	0	0	0	1	3
Braids	0	0	0	0	0	0	0	0	0	0
Face Paint	0	0	0	0	0	0	1	0	0	1
Men with Long Hair	0	0	0	0	0	0	0	0	0	0
Bare Feet	0	1	1	1	1	1	0	1	0	6
Sandals	0	1	0	0	0	0	0	0	0	1
Clothing from Animal Skins	0	0	0	0	0	0	0	0	0	0
Women in Gendered Clothing	0	0	0	0	0	0	0	0	0	0
Muscular Physiques	0	0	0	0	0	0	0	0	0	0
Vikings	1	1	1	1	1	1	1	1	1	9
Non-Vikings	1	1	1	1	0	0	0	1	1	6
Men	1	1	1	1	1	1	1	1	1	9
Women	1	0	0	1	0	0	0	0	0	2
Children	0	0	0	1	0	0	0	0	0	1
Valkyries/Other Mythological Characters	0	1	0	0	0	0	0	0	0	1
Armies	1	1	1	1	1	1	1	1	0	8
Portrait of One or Two	0	0	0	0	0	0	0	0	1	1
Mountains	0	0	0	0	0	0	0	0	0	0
Oceans	1	0	0	0	1	0	1	0	0	3
Shore	0	0	1	0	0	0	0	0	0	1
Big Birds	0	0	0	0	0	0	0	1	1	2
Villages	0	0	1	1	0	0	0	0	0	2
Flags/Banners	1	0	1	0	0	0	0	0	0	2
Color Themes	1	1	1	1	1	0	1	1	0	7
Viking Ships	1	0	1	0	1	0	1	0	0	4
Nordic Art Symbolism	0	1	0	0	1	0	1	1	1	5
Patterned Grouping in Armies	0	0	1	1	1	1	1	1	0	6

II. Complete Code Book for Artworks Chosen from the Romantic Era

Work #: (See Appendix A-I)	10	11	12	13	14	15	16	17	18	Total
Swords	1	0	1	1	0	1	0	0	0	4
Axes	0	0	0	0	0	0	1	0	0	1
Spears	1	1	1	0	1	0	0	0	1	5
Circular Shields	1	0	0	1	1	1	0	0	1	5



Heater Shields	0	0	0	0	0	0	0	1	0	1
Shields with Banners/Devoted Patterns	1	0	0	0	0	0	0	1	0	2
Bow/Arrows	0	0	1	0	0	0	0	0	0	1
Chainmail	1	0	1	1	1	1	0	1	1	7
Armor	1	1	1	1	1	1	1	1	1	9
Horned/Winged Helmets	1	1	1	0	0	0	0	0	1	4
Other Helmets	0	0	0	1	1	1	0	1	0	4
Fighting	1	0	1	0	0	1	0	0	1	4
Dead Valkyries	1	0	0	1	0	0	0	0	0	2
Dead Vikings	1	0	0	0	0	0	0	0	0	1
Dead Non-Vikings	1	0	1	0	0	0	0	0	0	2
Blood	0	0	0	1	0	0	0	0	0	1
Horses	1	0	1	0	0	0	0	0	1	3
Fire	1	1	0	0	0	0	0	0	0	2
Beards	1	1	1	1	1	0	1	1	0	7
Braids	1	1	0	0	0	0	0	0	0	2
Face Paint	0	0	0	0	0	0	0	0	0	0
Men with Long Hair	1	0	1	1	1	1	0	0	0	5
Bare Feet	0	0	1	0	0	0	0	0	1	2
Sandals	1	1	0	1	0	1	1	0	0	5
Clothing from Animal Skins	1	0	1	1	0	0	1	0	0	4
Women in Gendered Clothing	1	1	1	0	0	1	0	0	0	4
Muscular Physiques	0	1	0	1	0	1	1	0	0	3
Vikings	1	1	0	0	0	1	1	1	0	5
Non-Vikings	1	0	0	0	0	1	0	0	0	2
Men	1	1	1	1	1	1	1	1	0	8
Women	1	1	1	0	0	1	0	0	1	5
Children	1	0	0	0	0	1	0	0	0	2
Valkyries/Other Mythological Characters	1	1	1	1	1	1	0	0	1	7
Armies	1	0	1	0	1	0	0	1	0	4
Portrait of One or Two	0	1	0	1	0	0	1	0	1	4
Mountains	1	0	1	1	0	0	1	1	0	5
Oceans	1	0	0	0	1	0	0	0	0	2
Shore	1	0	0	1	0	0	1	1	0	4
Big Birds	1	0	1	1	0	0	0	1	1	5
Villages	1	0	0	0	0	0	0	1	0	2
Flags/Banners	0	0	0	0	1	0	0	1	0	2
Color Themes	0	0	0	0	0	0	0	1	1	2
Viking Ships	0	0	0	1	1	0	0	1	0	3



Nordic Art Symbolism	0	1	0	1	1	0	0	1	0	4
Patterned Grouping in Armies	0	0	0	0	0	0	0	0	0	0

III. Complete Code Book for Artworks Chosen from the Modern / Postmodern Era

Work #: (See Appendix A-I)	19	20	21	22	23	24	25	26	27	Total
Swords	1	1	1	0	1	0	0	0	1	5
Axes	1	0	1	0	1	0	0	0	1	4
Spears	1	0	1	0	1	0	1	1	1	6
Circular Shields	0	0	1	0	1	0	0	1	1	4
Heater Shields	0	0	0	0	0	0	0	0	0	0
Shields with Banners/Devoted Patterns	0	0	0	0	1	0	0	0	0	1
Bow/Arrows	0	0	0	0	0	0	0	0	0	0
Chainmail	0	0	1	0	0	0	0	1	1	3
Armor	1	1	1	1	0	0	1	1	1	7
Horned/Winged Helmets	1	1	0	1	0	0	1	0	0	5
Other Helmets	0	0	1	0	0	0	0	0	1	2
Fighting	1	1	1	1	1	0	1	1	1	8
Dead Valkyries	0	0	0	0	0	0	0	0	0	0
Dead Vikings	0	0	1	0	0	0	0	1	0	2
Dead Non-Vikings	0	1	1	0	0	0	0	0	0	2
Blood	0	1	1	0	0	0	0	0	0	2
Horses	0	0	1	0	1	0	0	0	0	2
Fire	1	1	0	1	1	1	1	0	0	6
Beards	1	1	1	1	1	1		1	1	8
Braids	1	0	0	0	0	1	0	0	0	2
Face Paint	0	0	0	0	0	0	0	0	0	0
Men with Long Hair	1	0	1	1	1	0	1	0	1	6
Bare Feet	0	0	0	0	0	1	0	0	0	1
Sandals	1	1	1	1	0	0	1	1	1	7
Clothing from Animal Skins	1	1	1	1	1	1	0	0	1	7
Women in Gendered Clothing	0	1	1	1	0	0	0	0	0	3
Muscular Physiques	1	1	1	1	1	0	1	0	1	7
Vikings	1	1	1	1	1	1	1	1	1	9
Non-Vikings	0	1	1	1	0	0	0	0	1	4
Men	1	1	1	1	1	1	1	1	1	9
Women	1	1	1	1	1	1	0	1	0	7
Children	1	1	0	0	1	0	0	0	0	3
Valkyries/Other Mythological Characters	1	1	0	0	0	0	1	0	0	3



Armies	1	1	1	0	0	0	0	1	1	5
Portrait of One or Two	0	0	0	1	0	0	1	1	0	3
Mountains	0	0	0	0	0	1	0	0	1	2
Oceans	1	1	1	0	0	0	0	0	0	3
Shore	0	0	0	0	0	1	0	0	1	2
Big Birds	0	0	0	0	0	0	0	0	1	1
Villages	0	1	1	1	1	0	0	0	0	4
Flags/Banners	0	0	0	0	0	0	0	0	0	0
Color Themes	0	1	1	0	0	1	1	0	1	5
Viking Ships	0	1	1	0	0	0	0	0	1	3
Nordic Art Symbolism	0	1	1	0	0	0	0	0	1	3
Patterned Grouping in Armies	0	1	0	0	0	0	0	0	0	1



Comparative Analysis of Conventional Antibiotics and Next-Generation Alternatives in Combating Antibiotic Resistance: Why Static Drugs Cannot Outpace an Adaptive Genome

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Abstract

Antibiotic resistance poses a threat to decades of clinical improvement and modern medicine, as antibiotics serve as the backbone of modern medicine, driven by a fundamental evolutionary mismatch: static antibiotics cannot outpace the rapidly adapting bacterial genome. Also, the development pipeline is stalled; antibiotic production carries a 90 percent failure risk, takes 10 to 15 years, and costs an estimated 1 billion dollars, so many major pharmaceutical companies have opted out of production. To address this crisis, this paper evaluates three next-generation alternatives, CRISPR-Cas9, bacteriophage therapy, and antimicrobial peptides (AMPs), against three criteria: genomic adaptability, evolutionary trade-offs, and durability against mutations. Our analysis reveals that while CRISPR-Cas9 performs better in genomic adaptability, it faces limitations due to delivery challenges. Bacteriophages impose powerful evolutionary trade-offs on bacteria through antagonistic pleiotropy, but their narrow host range restricts broad use and makes them hyper-specific. AMPs exhibit high durability against target-site mutations but face significant toxicity and stability barriers. As a result, no single alternative can serve as a long-term monotherapy replacement for conventional antibiotics. Because each therapy addresses a different bacterial resistance, the future therapeutics for AMR treatment must pivot toward combinatorial approaches, such as CRISPR-armed phages.

Keywords

Antibiotics; Antimicrobial resistance; CRISPR-Cas9; Bacteriophage; Next-Generation alternatives; Antimicrobial peptides

1. Introduction

For nearly a century, traditional antibiotics have served as the backbone of modern clinical medicine. Before the discovery of the first true antibiotic, penicillin, by Alexander Fleming in 1928 (Chhabra et al., 2024), bacterial diseases such as pneumonia were estimated to have a fatality rate of 30 to 40 percent (Ratner & Weiser, 2006). However, the mass production of antibiotics completely reshaped modern medicine and extended the average human lifespan; it did not only cure bacterial diseases, it laid the foundation for complex surgeries including chemotherapy, organ transplants, neonatal intensive care, prosthetic joint replacement, and caesarean section. These complex medical procedures are critically reliant on prophylactic antibiotics to prevent bacterial pathogens (Dhole et al., 2023). Without a consistent defense against these pathogens, the entire medical system is at risk; minor infections will once again be life-threatening and complex medical procedures will collapse, plunging us back to the pre-antibiotic era (Dohou et al., 2022). Alexander Fleming once stated that “The time may come when...the ignorant man may easily underdose himself and by exposing his microbes to non-lethal quantities of the drug make them resistant”(Fleming, 1945). Fast forward to over 70 years later in 2019, the World Health Organization declared antimicrobial resistance (AMR) as one of the top ten global public health threats to humanity, with an estimate of 1.27 million deaths in 2019 directly resulting from AMR and contributing to 4.95 million deaths globally (Murray et al., 2022). Though antibiotic resistance is an inevitable occurrence of natural selection, misuse of antibiotics in humans and animals serves as the primary accelerant to its spread (Watford & Warrington, 2023).

Ever since the first reports of penicillin resistance in the 1940s, the number of resistant bacteria has continued to grow exponentially, making antibiotics less effective against bacteria (Davies & Davies, 2010). When *Staphylococcus aureus* developed resistance against penicillin, scientists re-structured penicillin by synthetically attaching 2,6-dimethoxyphenyl side chains to shield the beta-lactam ring from penicillinase



(PubChem, n.d.), creating methicillin in 1959. However, just a year later in 1960, the first reports of methicillin-resistant *Staphylococcus aureus* (MRSA) emerged (Tobin et al., 2025). Scientists then discovered vancomycin could destroy MRSA; however, vancomycin is not completely immune to antibiotic resistance, as seen in emerging resistant strains such as VRSA and VISA (Cong et al., 2019), as well as resistance to advanced treatments like linezolid (LRSA). Though still rare, it shows the inevitability of bacteria developing resistance to antibiotics (Zhou et al., 2025). The ultimate failure of this current defense strategy stems from a foundational disparity where we are fighting bacteria, which rapidly evolve and reproduce, using non-living antibiotics that target a specific biochemical pathway.

The production of new antibiotics has also reached innovation fatigue. Scientists develop new antibiotics mainly by tweaking the chemical structures of existing drugs (Homer et al., 2024), a process which costs an estimate of 1 billion dollars and takes 10 to 15 years. Yet resistance to those new drugs can emerge within a few months upon introduction to the market (Brüssow, 2024). Traditional antibiotics cannot be used as a long-term solution to eradicate recurring infections as bacteria will evolve against this static chemical. Therefore, this paper argues that to manage and control bacterial infections and combat antibiotic resistance, funding and research should pivot toward dynamic and adaptable targeted alternative therapies—specifically CRISPR-Cas9 therapeutics, bacteriophage therapy, and antimicrobial peptides (AMPs)—while maintaining a smaller conventional pipeline for contexts where static drugs remain effective, rather than relying primarily on discovering new static antibiotics that bacteria will inevitably bypass. This paper aims to evaluate the defense techniques of bacteria against traditional antibiotics and compare the benefits and disadvantages of next-generation alternative therapies against three criteria: genomic adaptability, evolutionary trade-offs, and durability against mutations.

Methods

This paper is a narrative literature review conducted using PubMed and ScienceDirect to analyze the vulnerabilities of each major bacterial class, comparing them against next-generation alternatives. The search strategy involved utilizing keywords such as "antibiotic," "antibiotic resistance," "mechanisms of antibiotic resistance," and "next-generation alternatives." The searches were limited to legitimate peer-reviewed journal articles and the World Health Organization (WHO) official website to ensure the inclusion of only factual and relevant information. Articles were included based on their methodological quality, clinical relevance and credibility. Because this is a narrative rather than a systematic review, no formal screening protocol was applied. Relevant data points, statistical information, analyses and insights were selected from each article and compiled into a comparative analysis of antibiotic resistance.

Each next-generation alternative was then scored against three criteria, defined as follows: Genomic adaptability is the speed at which a therapy can be retargeted against a newly emerged resistance determinant: High means it can be retargeted in days by redesigning its guide sequence alone, Moderate means retargeting requires laboratory re-engineering of the molecule, and Weak means the structure is fixed once administered and cannot be retargeted. Durability against mutation is the number of independent mutational events a bacterium must accumulate to escape the therapy: High means escape requires multiple simultaneous changes or the loss of an essential structure, Moderate–High means escape is possible but sequential, slow, or costly, and Low means a single point mutation is enough. Evolutionary trade-off is whether documented resistance mutations carry a measured fitness or virulence cost: Strong means resistance consistently reduces growth, virulence, or existing antibiotic resistance, Context-dependent means the cost appears only under certain conditions or resistance mechanisms, and Weak means resistance carries little or no measured cost. The evidence supporting each rating is presented in Sections 3.3.1 to 3.3.3.

Results and Discussion

3.1 Mechanistic Vulnerabilities of Conventional Antibiotics

Conventional antibiotics rely on static structures to exert their antimicrobial effect; once this structure is altered, it is rendered ineffective. Bacteria have adopted several ways to alter, expel, and bypass antibiotics, frequently utilizing specialized enzymes (Abbas et al., 2024). To explain how antibiotics are slowly coming to a dead-end, this section examines the primary molecular mechanisms utilized by bacteria to neutralize major antibiotic classes.



3.1.1 β -lactam and β -lactamase

The entire β -lactam classes comprising penicillins, cephalosporins, and carbapenems all rely on a rigid four-membered β -lactam ring to bind to bacterial transpeptidases, resulting in bacterial lysis. However, the unchanging chemical shape of β -lactam is a critical vulnerability since many bacteria have evolved highly specialized hydrolytic enzymes known as β -lactamases. These enzymes utilize a highly effective mechanism: enzymatic hydrolysis, which introduces a water molecule across the amide bond, cracking open the β -lactam ring, rendering the antibiotic inactive before it even gets to the bacterial transpeptidases. Though scientists have developed β -lactamase inhibitors to neutralize β -lactamase enzymes, bacteria, as expected, have evolved sophisticated defense mechanisms against these inhibitors by either genetically altering or overproducing their β -lactamase enzymes or creating an entirely different class of enzyme.

The β -lactamase family exhibits a rapid evolution indicating why it will always develop a mechanism against any new β -lactam drug (Mora-Ochomogo & Lohans, 2021). Scientists retreated to the absolute "last-resort," carbapenems and the advanced fifth-generation cephalosporins, after bacteria responded to previous advancements by having evolved ESBLs (extended-spectrum beta-lactamases). Carbapenems became the standard treatment for ESBL infections (Maeda et al., 2024); bacteria have, however, aggressively evolved resistance to carbapenems by utilizing carbapenemases like the NDM-1, which utilizes Zn^{2+} to activate water molecules to break open the β -lactam ring. Consequently, these pathogens are increasingly bypassing advanced clinical dual-combinations like Ceftazidime-Avibactam plus Aztreonam (CZA-ATM), as bacteria are actively modifying the NDM-1 gene template into new variants, allowing them to bypass modern drugs (Simner et al., 2023). To combat an enzyme that utilizes active zinc-based sites, the curative agent must be capable of counter-adaptation.

3.1.2 Aminoglycoside Resistance: AMEs and 16S-RMTases

Aminoglycosides exert their antimicrobial effects by binding to the decoding A-site of helix 44 within the 16S rRNA of the 30S ribosomal subunit, which distorts the aminoacyl-tRNA selection center, therefore obliterating the ribosome's capacity for steric proofreading, causing mistranslation of mRNA sequences, triggering the death of the bacterial cell (Sutcliffe, 2005). Because aminoglycosides function by binding to helix 44, the entire class of aminoglycosides relies on helix 44 remaining unmodified.

Bacteria prevent this binding by attaching covalent functional groups to the aminoglycosides using aminoglycoside-modifying enzymes (AMEs), causing steric hindrance and the alteration of the electrostatic charge of the drug molecule, and the modified antibiotic can no longer fit into the narrow binding pocket of the 16S rRNA A-site, rendering the drug useless (Shakil et al., 2007). Bacteria have also evolved a highly catastrophic countermeasure against aminoglycosides by producing an enzyme: 16S rRNA methyltransferase (16S-RMTase), which grants bacteria broad-spectrum resistance to almost all clinically relevant aminoglycosides (Wachino et al., 2020).

Rather than modifying antibiotics like the AMEs, 16S-RMTases transfer CH_3 directly onto specific nucleotides within helix 44 and are encoded mostly alongside carbapenemases like NDM-1, making bacteria with 16S-RMTase plasmids pan-drug resistant (Wachino et al., 2020). Programmable therapies like CRISPR-Cas9 will be more effective against 16S-RMTase plasmids as they target the bacteria's genetic code by using complementary sequence matching rather than relying on a static ribosomal binding pocket (Yoon et al., 2026).

3.1.3 Fluoroquinolones and QRDR mutations

Fluoroquinolones such as ciprofloxacin, levofloxacin, and moxifloxacin exert their bactericidal action by forming a stable ternary complex with DNA gyrase and topoisomerase IV (Fàbrega et al., 2008). These type II bacterial topoisomerase enzymes introduce temporary double-stranded DNA breaks to relieve physical tension and decatenate daughter chromosomes. Fluoroquinolones exert their effects by using Mg^{2+} to stick to the enzyme-DNA complex, trapping the cleaved DNA strands and converting topoisomerases into cellular toxins that trigger cell lysis. Despite their widespread use, their use of the magnesium-water bridge holds no tolerance for structural change of the serine and acidic anchors in the quinolone resistance determining region (QRDR) (Aldred et al., 2014). Bacteria have exploited this by spontaneous mutations mainly to Ser83 and Asp87, altering the gyrA of DNA gyrase, or to Ser80 and Glu84, altering the parC of topoisomerase IV (Fàbrega et al., 2008).



Beyond the mutation of QRDR, research highlights the role of plasmid-mediated quinolone resistance (PMQR) in rendering fluoroquinolones ineffective. A study on plasmids in ciprofloxacin-resistant *Salmonella* revealed the emergence of "conjugative helper plasmids," helping them to aggressively spread, making this an epidemiologically dangerous resistance (Chen et al., 2019). The QNR determinants of PMQR physically bind to the topoisomerase, protecting it from fluoroquinolone inhibition by preventing the drug from stabilizing the cleaved DNA-enzyme complex, thereby allowing the enzyme to complete its normal catalytic cycle without being trapped (Collins & Osheroff, 2024). After the resistance of early-generation quinolones including nalidixic acid, drugs like ciprofloxacin were developed by introducing fluorine atoms and C-7 piperazinyl rings (Khwaza et al., 2024). However, previous scientific data reveals that this is not a sustainable long-term strategy (Shariati et al., 2022). Therefore, CRISPR-Cas9 has proven to be a more adaptable approach than static fluoroquinolones, as it can precisely target and clear these resistance plasmids (Javed et al., 2023).

3.1.4 Multi-Drug Efflux Systems

Efflux pumps contribute significantly to multi-drug resistance as many efflux transporters possess large, polyspecific binding cavities which can expel diverse classes of antibiotics (Nikaido & Pagès, 2011). Unlike specialized resistance mechanisms that target a specific antibiotic, efflux pumps are capable of pumping out multiple antibiotics simultaneously, meaning no single major class is completely immune to them. Efflux pumps can often recognize and clear them, even though the bacteria have never encountered that specific antibiotic before. Bacteria utilize six major families of efflux transporters to expel drugs, including the resistance nodulation division (RND) and the Major Facilitator Superfamily (MFS) (Thakur et al., 2021). Resistant bacteria like MRSA utilize NorA from the MFS family, which heavily exports ciprofloxacin and disinfectants, neutralizing frontline treatments (Yu et al., 2022). Though being the most clinically significant of secondary transporters, the tripartite RND pumps are primarily utilized by high-priority Gram-negative bacteria including *Pseudomonas aeruginosa* (MexAB-OprM) and *Escherichia coli* (AcrAB-TolC) (Daury et al., 2016), classified by the World Health Organization as 'critical priority,' causing ventilator-associated pneumonia and untreatable sepsis (World Health Organization, 2024).

Over the decades, scientists have tried developing EPIs (efflux pump inhibitors). However, previous literature reveals EPIs consistently fail in clinical trials due to their toxicity profiles because they inadvertently inhibit human cytochrome P450 enzymes and cause unpredictable drug interactions (Sharma et al., 2019). Therefore, the current strategy of directly targeting the pump with synthetic inhibitors is likely to fail. Among many next-generation alternatives, bacteriophage therapy shows particular promise against multidrug-resistant (MDR) Gram-negative pathogens as phages bind directly to bacterial surface structures, including efflux pump proteins. Although bacteria can evolve phage resistance, this adaptation often alters efflux pump function, rendering the bacteria more vulnerable to antibiotics (Barber et al., 2021).

3.2 Synthesis: Recurring Patterns of Resistance

Across the four classes of antibiotics examined, there is a consistent pattern of worse resistance after a countermeasure. Three out of the four mechanisms examined revealed the bacterial counter-response introduces resistance more dangerous than the original threat. Beta-lactam resistance began with narrow-spectrum beta-lactamases like penicillinases but escalated to NDM-1, a carbapenemase that renders last-resort combination drugs like CZA-ATM ineffective; aminoglycoside resistance began with helix 44-reliant AMEs then progressed to 16S-RMTases, broad-spectrum ribosomal RNA methyltransferases encoded alongside NDM-1 producing pan-drug resistance; and fluoroquinolone resistance started with QRDR mutations, restricting spread to only direct offspring, to horizontally transferable, epidemiologically dangerous PMQR, allowing bacteria to spread between unrelated bacteria. The efflux pump is an exception because EPIs have not been deployed as a counter-measure due to their failures in clinical trials, meaning they do not exert real selective pressure on bacteria. This reveals that fighting bacteria with static drugs does not just create a dead end but risks upgrading the threats.

In every mechanism examined, antibiotics target a specific phenotypic structure: the transpeptidases in the beta-lactam family, the A-site of the 16S rRNA within the 30S ribosomal subunit, in the aminoglycoside family, the gyrase-DNA complex in fluoroquinolones, and the pump's substrate cavity in efflux-related drugs. Bacteria counterattack each of these resistance mechanisms by altering their genetic templates through altered penicillin-binding proteins, methylated rRNA, mutated *gyrA/parC*, and modified pump genes. The antibiotic cannot adapt due to its unchanging target design. This reveals a mismatch and the main reason why bacteria can get resistant to antibiotics in a short time: these drugs are meant to exploit specific phenotypic structures



while bacteria defend themselves by genotypically altering their blueprints, making them an adaptable genome while the antibiotic remains permanently fixed. This drawback is what next-generation alternatives must address: they must be capable of adapting at the same level as bacteria, like CRISPR-Cas9, co-evolving like bacteriophages, or attacking a site that is not easily mutated like the AMPs.

Rather than modifying the same static structure that has been failing, the approach toward resistance must be entirely different, not just a newer form or modification of the old curative substance.

Despite how easily bacteria adapt to a new antibiotic, it is worth noting how difficult it is to modify or develop a new antibiotic despite using an antibiotic class blueprint as a physical template. The most recent completely new chemical class to reach regulatory approval was the spiropyrimidinetriones, approved on 12 December 2025 (Osheroff, 2026). Before it, the last entirely new class to be discovered was daptomycin, found in the early 1980s and approved for clinical use in 2003 (Vilhena & Bettencourt, 2012), leaving roughly four decades between the mid-1980s and the mid-2020s in which no completely new chemical class reached the market (Cunha-Ferreira et al., 2025). This is despite the initial discovery process taking 10 to 15 years and a cost of US\$1 billion, of which only 1 in 15 existing-class candidates or 1 in 30 new-class candidates successfully pass the pre-clinical phase (World Health Organization, 2022), of which 90% will fail in the clinical trial (Sun et al., 2022). This high failure rate has made many pharmaceutical companies abandon antibiotic research as it generates only \$46 million to \$100 million per newly launched drug despite the high development cost, leading to more scarcity in the development of new antibiotics (Gargate et al., 2025). A high-risk, billion-dollar, decade-long development cycle pitted against bacteria that can resist this drug in a fraction of that time makes it clear that no amount of investment in conventional antibiotic development can surpass the bacterial resistance rate.

These patterns reveal that the failure of conventional antibiotics lies in their static structure being incapable of evolving and the stalled development pipeline. An effective long-term strategy must break free from the static structure model entirely; instead, it must be capable of tracking how bacteria change over time instead of exploiting a structural target. Rather than targeting static structures and waiting for resistance to emerge, it must impose high evolutionary trade-offs on resistant mutants and be durable against mutations.

3.3 Next-Generation Alternatives: CRISPR-Cas9, Bacteriophage Therapy, and Antimicrobial Peptides

This section will evaluate three next-generation options: CRISPR-Cas9, Bacteriophage Therapy, and Antimicrobial Peptides against conventional antibiotics. They are evaluated against three main criteria: genomic adaptability, imposing high evolutionary trade-offs, and durability against mutations.

3.3.1 Clustered Regularly Interspaced Short Palindromic Repeats and CRISPR-associated protein 9 (CRISPR-CAS9)

Bacteria protect themselves from bacteriophages using their natural immune system, native CRISPR, undergoing a phase called spacer acquisition to store a piece of the viral DNA, enabling the Cas enzyme to recognize and cut the phage's DNA if it reappears (Saeed et al., 2025). As a therapeutic, CRISPR is repurposed as a gene editing tool, consisting of a guide RNA (gRNA) and a Cas9 protein that can locate a specific sequence of genetic code and cut the DNA strands at a precise location (Joo et al., 2025). Native CRISPR defends a bacterium against a phage, but the synthetic CRISPR can be used against different resistance genes; this section focuses on CRISPR-Cas9 as a therapeutic tool. It involves a multi-step sequence initiating with the Cas9 protein scanning and binding to the PAM site (5'-NGG-3'); upon binding, the Cas9 protein unwinds the DNA double helix, allowing the gRNA to hybridize with the target DNA strand and displace the non-target strand, forming a stabilizing R-loop structure, which stabilizes the complex and activates the endonuclease domains consisting of HNH and RuvC, which cut the target DNA strand and the opposite strand respectively. Afterwards, it releases its grip on the severed DNA, leaving the genome to repair the break (Jiang & Doudna, 2017). This target precision made scientists repurpose CRISPR-Cas9 as a therapeutic tool (Joo et al., 2025). CRISPR-Cas9 is specifically suited for clearing plasmids carrying resistance determinants, such as 16S-RMTases and PMQRs (Kuo et al., 2026). Unlike aminoglycosides and fluoroquinolones that attack specific protein and ribosomal targets, CRISPR-Cas9 targets the resistance genes on the plasmid by designing gRNAs to match the sequences (Tao et al., 2022) of 16S-RMTases (armA, rmtB) (Lee et al., 2018) and PMQRs (qnrA, aac(6')-Ib-cr) (Liang et al., 2025), allowing Cas9 to create a double-strand break, linearizing the plasmid, which the bacterial exonucleases degrade (Bikard et al., 2014). CRISPR-Cas9 also allows scientists to target several variants simultaneously by delivering multiple gRNAs at once, making



a single CRISPR-Cas9 capable of simultaneously targeting the 16S-RMTase gene *rmtB* and the PMQR gene *qnrS*, ensuring that the plasmid cannot survive through a single point mutation (Cheng et al., 2025).

Despite its strengths, CRISPR-Cas9 demonstrates some limitations. Genomic adaptability is CRISPR's greatest strength. CRISPR can be reprogrammed in a few days by modifying the gRNA against emergent resistance, allowing it to engage bacterial resistance at the same genetic level bacteria display (Yoon et al., 2026). However, in the case of imposing high evolutionary trade-offs, CRISPR is highly predictable, but it depends on whether it is being looked at as natural evolution or a controlled lab experiment. In natural populations, Westra et al. (2015) demonstrated that in *Pseudomonas aeruginosa*, under high phage exposure, the repeated costs of active CRISPR defense accumulate, leading bacteria to evolve alternative constitutive defenses, like surface receptor loss, but show a low evolutionary trade-off under low phage exposure. In contrast, a 2020 study reveals the use of synthetic applications to remove carbapenem-resistance genes such as *blaKPC*, *blaNDM*, and *blaOXA-48* from multiple *Enterobacteriaceae* species, making the bacteria vulnerable to antibiotics again, suggesting that by utilizing controlled, high-efficiency plasmid curing in vitro, synthetic CRISPR demonstrates its potential (Hao et al., 2020). On the criterion of durability against mutation, CRISPR-Cas9 fares better than conventional antibiotics. Scientists can easily change the RNA guide sequence to match the mutation of bacteria; also, with CRISPR multiplexing abilities, this barrier is further raised (Shen et al., 2017). Despite bacteria gaining the ability to physically block or destroy the Cas9 enzyme by evolving anti-CRISPRs (Zhang et al., 2019), CRISPR still has a higher advantage as it is highly modular and can be swapped for completely different variants like Cas12a or Cas13, which Cas9-targeted anti-CRISPRs have no effect on (Liao et al., 2019).

The ratings given above describe CRISPR as a tool in controlled lab experiments, not yet as a medicine adapted to be prescribed by doctors. CRISPR as a medicine consists of a Cas9 protein and designed gRNAs for plasmid curing (Hao et al., 2020). However, that design is too large to enter a cell and must be carried by a delivery vehicle. Every vehicle tested so far causes the loss of most of its therapeutic agent before reaching the cell target (Mayorga-Ramos et al., 2023). This shows that despite its adaptability being high as a tool in controlled labs, the medicine must still survive delivery and the immune system.

Unlike small molecules like antibiotics that can easily pass through cells and tissues, CRISPR faces a major limitation due to its large size, requiring a delivery vehicle to get inside a target bacterial or human cell. Scientists have tested many delivery methods that answer the need for delivery, including phagemids, nanoparticles, and conjugative plasmids, but each with its limitations (Mayorga-Ramos et al., 2023).

Since phagemids are hybrids engineered with a phage's packaging signal, they can be packed inside a phage's protein shell (Azzazy & Highsmith, 2002). Scientists load the phagemid with the Cas9 gene and guide RNA, and the phagemid attaches to the bacterial surface, injecting its DNA into the cell. However, phagemids are replication-deficient, so each particle can only deliver an initial copy of the CRISPR plasmid to a single bacterium. Treating a bacterial infection requires administering large quantities of phagemid particles and repeated dosing to sustain a therapeutic effect (Nittayasut et al., 2024).

Conjugative plasmids act as delivery vehicles by exploiting bacterial conjugation, where a donor bacterium carrying the Cas9 gene and guide RNA forms a pilus to transfer the plasmid directly into a target bacterium. However, this mechanism depends on close physical contact and high transfer rates. They work more effectively in dense environments like the gut microbiome rather than fast-flowing fluids such as the bloodstream, while some engineered plasmids are not self-transmissible and require additional machinery to conjugate. Even when they transfer the plasmid, it often fails to stay long within the bacterial population; without continuous selective pressure favoring bacteria that retain it, it gets lost across bacterial generations unless engineered with active toxin-antitoxin retention systems, therefore limiting how long the therapeutic effect lasts (Mayorga-Ramos et al., 2023).

As reviewed by Mayorga-Ramos et al. (2023), nanoparticles serve as a synthetic delivery mechanism, engineered to encapsulate CRISPR-Cas9 components and enter the bacterial cells, thereby releasing the CRISPR components. However, the manufacturing of clinical-grade nanoparticles is highly complex and expensive, and many of the cationic lipids and polymers used are cytotoxic, a trade-off scientists have tried to offset through strategies like PEGylation, which reduces toxicity but can itself lower delivery efficiency (Mayorga-Ramos et al., 2023). Even if these two limitations are solved, nanoparticle delivery is highly inefficient, as most nanoparticles are destroyed before reaching the bacterial target, meaning to get a few bacterial cells edited, scientists have to send in a wasteful amount of nanoparticles. Even if the vehicle problem



gets solved and CRISPR components reach the bacterial cell, bacteria can detect and cut the foreign DNA or RNA using their restriction-modification enzymes. Beyond bacterial defense mechanisms, the immune system of the human body may neutralize the CRISPR because most Cas9 variants originate from common bacteria, making many humans carry antibodies and T-cell immunity against Cas9 from prior bacterial exposure. Despite these limitations, CRISPR presents a promising future, as the problem and limitation are not its structural model, blueprint, or mechanism but delivery (Mayorga-Ramos et al., 2023).

3.3.2 Bacteriophage Therapy

Bacteriophages occur naturally as antimicrobial agents, attaching to bacteria and injecting their DNA to reproduce. They rely on receptor-binding proteins (RBPs) located in tail fibers or spikes to recognize and bind to the bacterial surface (Fathima & Archer, 2021). Bacteriophages kill bacteria through two distinct mechanisms. In the lytic cycle, the phage circumvents bacterial defenses upon entry, hijacks the cell's machinery, and halts the host's normal metabolism to rapidly produce new phage particles; the phage then produces holins to form pores in the inner membrane, allowing endolysins to pass through and degrade the peptidoglycan cell wall, causing osmotic lysis and bacterial death (Young, 2014). This is preferred for antimicrobial applications over the lysogenic cycle, which does not kill the bacteria instantly, but instead rests as a prophage in the bacterium, increasing the risks of introducing dangerous toxin genes, later releasing phages to infect other bacteria, and making them immune to similar phages (Kapoor et al., 2024).

Lytic phages bypass antibiotic resistance mechanisms because they inject genetic material rather than acting as a static chemical compound, making them highly effective against MDR pathogens, as efflux pumps work by chemically expelling drugs (Fathima & Archer, 2021; Kapoor et al., 2024). Also, phages mutate and replicate faster than bacteria, and with recent studies showing bacteriophages utilize contingency loci to outmaneuver bacteria, this high genetic adaptability allows them to counter-adapt to bacterial defenses (Meyer et al., 2012). As previously discussed, bacteria evolving faster than antibiotics is the major reason bacteria will always gain resistance, but with phage counter-adaptation surpassing the bacterial rate, and some phages using efflux pump components as their actual entry receptor (such as OMKO1 targeting OprM, part of MexAB-OprM in *Pseudomonas aeruginosa* (Chan et al., 2018), and other phages targeting TolC, part of AcrAB-TolC in *E. coli* (Burmeister et al., 2020), it creates an evolutionary trade-off whereby bacteria are vulnerable to phage attacks.

Phages also enforce antagonistic pleiotropy when bacteria try to stop the phage by altering surface receptors which are used to stick to human tissues or efflux pumps, thereby losing virulence and becoming resensitized to antibiotics; also, the human immune system can easily destroy the bacteria after the loss of its biofilm (Mangalea & Duerkop, 2020). With this high evolutionary cost, bacteriophages do not have to kill all bacteria, as they force MDR bacteria to become weaker and non-resistant (Mangalea & Duerkop, 2020). However, bacteria can deploy native abortive infection (Abi) systems, which help the bacterium kill itself before the phage can replicate, preventing phage replication and protecting the surrounding bacterial population. In one documented case, a two-phage cocktail failed against an MRSA strain carrying the *abiF* resistance gene, but adding a third phage achieved over a 4-log reduction in bacterial burden, evading the *abiF*-mediated defense entirely (Bleick et al., 2026). To address this problem more efficiently, scientists use a phage cocktail rather than deploying only one type of phage (Lu & Koeris, 2011). But phages cannot be classified as perfectly durable to mutation, as bacteria use sequential evolution or internal DNA-shredders to defend against cocktails (Labrie et al., 2010).

Despite bacteriophages having high durability against mutations, genomic adaptability, and evolutionary trade-offs, the use of receptor-binding proteins (RBPs) that recognize specific bacterial surface structures like OprM and TolC makes phages highly narrow in range, therefore being rendered ineffective against a bacterial strain that has mutated those specific receptor structures (Tarasenko et al., 2025). Additionally, the human reticuloendothelial system can recognize phages as foreign particles, meaning repeated dosing must be administered (Chung et al., 2023). Additionally, phages require specialized matrix-degrading enzymes to be effective in deep sites like inside a biofilm (Islam et al., 2024; Wacnik et al., 2026). Phages are also physically bigger, making it difficult to penetrate dense tissues or reach intracellular pathogens. Unlike antibiotics that are produced in predictable vats, phages must be grown inside living, toxic bacteria, which releases endotoxins that can trigger toxic shock; therefore, phages must be purified to reduce the endotoxins below strict regulatory safety thresholds. Also, strict lyophilization and unstable batch replication due to their ability to mutate make the production of phages a complex and expensive process (Chung et al., 2023).



Another main limitation of bacteriophages is regulatory and clinical approval (Zalewska-Piątek, 2023). Historically, regulatory bodies have been optimized to approve static and stable drugs, but phage therapy does not have a one-size-fits-all prescription; rather, each treatment is personalized per patient. Under traditional frameworks, altering a phage particle can trigger repetitive safety trials, creating a major hurdle as phage cocktails must change constantly to outpace mutating bacteria (Zalewska-Piątek, 2023). Also, because of the hyper-specific targeting of phages, phage susceptibility testing is required. While traditional testing methods create a problem for MDR diseases that need immediate intervention, emerging rapid diagnostics are beginning to narrow this window (Daubie et al., 2022).

3.3.3 Antimicrobial peptides (AMPs)

Antimicrobial peptides occur naturally as short bioactive amino acid chains in almost all living organisms as a first line of defense against microbial invaders. Unlike CRISPR-Cas9 or bacteriophage treatments which rely on complex biological processes, AMPs work primarily by using a strong electrostatic attraction to stick to the negatively charged outer surfaces of bacteria. Their amphipathic structure allows them to insert into the membrane, forming pores, causing the bacterial cell to rapidly lose its osmotic balance, leak out, therefore causing lysis (Ma et al., 2024). AMPs can also use another mechanism of targeting bacteria intracellularly by using their peptides to bind to DNA and block RNA, shutting down the cell's internal operating systems (Ho et al., 2016). However, the membrane disruption mechanism provides an advantage over intracellular targeting, as they destroy the cell from the outside and can bypass active efflux pump mechanisms, making them highly suitable against efflux-reliant MDR like ESKAPE (*Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* species) pathogens and also against carbapenem-resistant *A. baumannii* and *P. aeruginosa* since they do not depend on one specific binding site (Zack et al., 2024).

One similarity between AMPs and antibiotics is that they are both static molecules. They are not programmable like CRISPR and do not co-evolve like phages; instead, they act directly through physical interactions. Once administered, an AMP molecule is fixed and cannot track bacterial evolution or reconstruct its structure in response to bacterial resistance (Mwangi et al., 2023). This makes them score lower on the criterion of genomic adaptability. However, scientists can rationally redesign AMPs in the laboratory through amino acid substitution, D-amino acid incorporation, or cyclisation to improve stability and potency (Mwangi et al., 2023), but this process is slower and more reactive than phage co-evolution (Zhang & Ahn, 2025) or CRISPR reprogramming. This places AMPs the same as conventional antibiotics in terms of adaptability, but they remain below CRISPR-Cas9 and bacteriophage therapy, which can adapt in real time.

AMPs are especially strong in durability against mutations. ESKAPE bacteria constantly mutate their internal enzymes to deactivate traditional antibiotics, but a bacterium cannot mutate away its cell membrane as it is an important structural requirement. Also, AMPs attack the physical lipid bilayer instead. A single point mutation cannot block their action. Because of this, resistance to classic AMPs like LL-37 is harder to share through horizontal gene transfer (HGT) than resistance to small-molecule antibiotics (Novović & Jovčić, 2023).

Though bacteriophages are effective tools for MDR, AMPs lead in treating ESKAPE bacteria as they have a broader spectrum, minimizing the threat of gene swapping resistance. With constant exposure to non-lethal doses of AMPs, bacteria can make sequential mutations like adding positively charged groups like L-Ara4N to lipid A to reduce the membrane's negative charge, activating a stress-response pathway to pump out extra lipids, then thickening their outer cell wall to slow down the peptide, in a gradual process of resistance (Tajer et al., 2024). Though this mechanism grants bacteria higher tolerance for AMPs, it comes with a high evolutionary trade-off. A study on colistin-resistant *Acinetobacter baumannii* showed that the early resistant bacteria were vulnerable to oxidative stress with only a 2 percent survival rate in hydrogen peroxide (Jones et al., 2016). However, it does not act as a permanent barrier as bacteria can overcome it over time within the same host. The mutant bacteria require a large amount of cellular energy to run a resistant peripheral layer and need energy for synthesizing altered lipids. This extra use of energy plummets their growth and they can be easily cleared by the immune system. Also, by altering their membrane to defend against positively charged AMPs, they become collaterally sensitive as they become hyper-susceptible to conventional antibiotics that they previously had resistance to, while also destroying their virulence (Tajer et al., 2024).

Even though AMPs impose a high evolutionary trade-off when resistance requires alteration of the membrane, this trade-off specifically applies to the chromosomal mutations observed in the *Acinetobacter* study. Bacteria have another method of resisting colistin, a polymyxin analogue that shares the same membrane-targeting



mechanism as AMPs, by shielding their outside using Mobilized Colistin Resistance-1 (*mcr-1* gene), a bacterial gene that makes Gram-negative bacteria resistant. Unlike the chromosomal mutations seen in the *Acinetobacter* study, the *mcr-1* plasmid requires minimal energy and is easily transferable through HGT, leading to a low evolutionary cost (Choi et al., 2020). Therefore, the evolutionary cost is dependent on the resistance mechanism the bacteria use.

Even though AMPs act fast enough to kill bacteria, rapid proteolytic degradation still serves as a major limitation as natural AMPs are destroyed by the cytosolic proteases of human erythrocytes upon entry into the human body, making them unable to reach deep tissue infections (Starr & Wimley, 2017). Also, since AMPs rely on electrostatic interactions, blood with high salt concentrations and pH fluctuations can render AMPs inactive, as once in the blood, AMPs frequently bind to human protein albumin, leaving a small amount of peptide to kill bacteria. Many AMPs are hemolytic as they are amphipathic, with estimates of about 70% of known AMPs having hemolytic tendencies (Zhang et al., 2021).

There is a very narrow line between the dosage enough to kill ESKAPE bacteria and one that could damage organs or tissues (Zhang et al., 2021). All these are the reasons why most FDA-approved AMPs are restricted to creams for skin rather than for internal use (Moretta et al., 2021). AMPs are also more expensive compared to the production of antibiotics, with the manufacturing cost for antibiotics costing a few dollars and AMPs costing hundreds of dollars (Chen & Lu, 2020).

The use of bioreactors to produce AMPs poses another obstacle. AMPs always kill the host before they mature for viable yield (Li, 2011). To stop this, scientists fuse AMPs to a fusion tag to prevent AMPs from attacking the host cell, neutralizing them. This prevents the premature death of the host cell (Li, 2011; Park et al., 2021). The fusion tag added must be removed using expensive enzymes; these enzymes cause a mixture of AMPs, severed fusion tags, and cutting enzymes that complicates the downstream purification process (Wright et al., 2011; Park et al., 2021).

3.4 Comparative Analysis

To determine whether AMPs, Bacteriophages, and CRISPR-Cas9 are better alternatives and yield better results than antibiotics, Table 1 compares them against the three criteria already established previously, compares the next-generation alternatives against each other, and analyses them together to identify a promising, effective framework that would work against bacteria in the long run.

Table 1. Comparative evaluation of the three next-generation alternatives (CRISPR-Cas9, bacteriophage therapy, and antimicrobial peptides) against conventional antibiotics on genomic adaptability, evolutionary trade-offs, and durability against mutation.

	CRISPR-Cas9	Bacteriophage Therapy	AMPs
Primary Target	Specific nucleic acid sequences	Bacterial surface receptors	Bacterial cell membrane
Resistance Mechanism Addressed	Plasmid-borne resistance	Efflux-pump mediated resistance	Broad MDR resistance including ESKAPE pathogens
Genomic Adaptability	High: gRNA can be reprogrammed in days to match new resistance sequences	High: Phages naturally co-evolve with bacteria	Weak to moderate: AMPs are static molecules



	CRISPR-Cas9	Bacteriophage Therapy	AMPs
Evolutionary trade-off	Context-dependent: as a human therapy, synthetic CRISPR plasmid curing re-sensitizes bacteria to antibiotics (Hao et al., 2020) ; however, low-cost resistance (anti-CRISPRs, PAM/target mutations) remains possible, so a trade-off is not guaranteed.	Strong: Antagonistic pleiotropy: phage-resistance mutations often disable efflux pumps, surface receptors, or biofilm formation, reducing virulence and resensitising bacteria to antibiotics	Dependent on resistance mechanism: imposes high cost when resistance requires alteration of membrane, but a low cost when the mcr-1 gene is used.
Durability Against Mutation	High: Multiplexed gRNAs target multiple resistance genes simultaneously	Moderate–High: Cocktails can overcome single-phage resistance but bacteria can evolve sequential resistance	Moderate–High: Multi-targets membrane but gradual resistance development and proteolytic degradation can make it less effective
Limitations	Delivery and immunogenicity	Narrow host range and regulatory mismatch	Production cost, toxicity and stability

Evaluations in this table are supported by the references cited in Sections 3.3.1 to 3.3.3

Though CRISPR leads in genomic adaptability and durability against mutation, its evolutionary trade-off uncertainty creates a major risk, as it could persist and spread resistance without weakening the bacterium at all. Bacteriophages win the criterion on evolutionary trade-offs but struggle with durability, posing a threat to their inactivation and therapeutic failure. AMPs excel in durability against mutations but their low genomic adaptability poses a threat of pathogens eventually developing widespread resistance that AMPs cannot evolve quickly enough to counter. Out of the three next-generation alternatives, each satisfies a different criterion but no single alternative dominates across all criteria.

Also, Table 1 reveals that each next-generation alternative does not target all resistance mechanisms, but each is suited to solve different resistance problems. CRISPR-Cas9 is best suited for targeting plasmid-mediated antibiotic resistance identified in Sections 3.1.2 and 3.1.3, like 16S-RMTases and PMQR determinants. Bacteriophage therapy is best matched to efflux-mediated multidrug resistance identified in Section 3.1.4. AMPs, though best for targeting ESKAPE, address the foundational problem underlying all four major resistance mechanisms. This shows a pattern that one next-gen alternative cannot replace antibiotics, although AMPs seem to be a full replacement option as they can defeat efflux pumps, plasmids, and mutated enzymes, but their imperfect selectivity and static obsolescence put them at a huge disadvantage. This limitation reinforces combining these alternatives rather than as a long-term monotherapy.

A highly promising combination is CRISPR-armed phages, a combination of bacteriophages and CRISPR-Cas9 technology. Integrating these systems helps deliver CRISPR components into specific cells of bacteria using bacteriophages (Ghazaei, 2026). Incorporating AMPs creates a more sophisticated weapon against bacteria as it utilizes surface-displayed AMPs to destabilize the outer membrane while CRISPR shreds the genome from the inside, accelerating bacterial cell death (Getahun et al., 2022).

This tripartite combination has been utilized by scientists to modify Salmonella phages using CRISPR-Cas9 to express the potent antimicrobial peptide LL37 to enhance antibacterial activity, with the engineered phage sustaining bacterial suppression for 24–72 hours (Jo et al., 2026). Although combinations still face severe limitations and would require navigating a highly complex combination biologic regulatory pathway, managing complex pharmacokinetic interactions, and significantly increasing manufacturing costs, to be put in use, in vitro and in vivo concepts must eventually survive real-world human trials because they are a highly adaptive alternative in comparison to traditional antibiotics that bacteria will rapidly develop resistance against.

Conclusion



The evidence reviewed in this paper points to one consistent conclusion: conventional antibiotics are failing not because they are weak drugs, but because they are static. Across the four mechanisms examined, the bacterial counter-response repeatedly upgraded the threat, from narrow-spectrum β -lactamases escalating to NDM-1, to QRDR mutations giving way to horizontally transferable PMQR. At the same time, the pipeline for replacing these drugs has stalled, trapped in a years-long, billion-dollar cycle that bacteria can bypass in a short period. This confirms the foundational mismatch of the crisis: a fixed chemical structure cannot outpace an adaptive genome.

The next-generation alternatives each address this mismatch in a different way, yet none resolves it alone. CRISPR-Cas9 engages resistance at the genetic level and can be reprogrammed within days, but its large size makes delivery its biggest barrier. Bacteriophages impose the strongest evolutionary trade-offs, often turning resistance into a weakness, but their narrow host range and the regulatory mismatch limit their use. AMPs attack a target the bacterium cannot easily mutate, yet toxicity, instability, and high production costs keep them mostly restricted to topical application. Since each therapy wins a different criterion and addresses a different vulnerability, no single alternative can replace conventional antibiotics as a long-term monotherapy.

The way forward is therefore not a newer static drug, but combinations of dynamic ones. CRISPR-armed phages and phages displaying AMPs show that pairing these systems lets each cover the other's weaknesses. Such combinations must still survive human trials and a regulatory system built for static drugs. Even so, shifting from static chemicals to adaptable, evolution-aware therapies is the only strategy that gives modern medicine a real chance of outpacing the bacterial genome.

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References

- Abbas, A., Barkhouse, A., Hackenberger, D., & Wright, G. D. (2024). Antibiotic resistance: A key microbial survival mechanism that threatens public health. *Cell Host & Microbe*, 32(6), 837–851.
- Aldred, K. J., Kerns, R. J., & Osheroff, N. (2014). Mechanism of quinolone action and resistance. *Biochemistry*, 53(10), 1565–1574.
- Azzazy, H. M., & Highsmith, W. (2002). Phage display technology: Clinical applications and recent innovations. *Clinical Biochemistry*, 35(6), 425–445.
- Barber, O. W., Miramontes, I. M., Jain, M., Ozer, E. A., & Hartmann, E. M. (2021). The future of bacteriophage therapy will promote antimicrobial susceptibility. *mSystems*, 6(4), e0021821.
- Bikard, D., Euler, C. W., Jiang, W., Nussenzweig, P. M., Goldberg, G. W., Duportet, X., Fischetti, V. A., & Marraffini, L. A. (2014). Exploiting CRISPR-Cas nucleases to produce sequence-specific antimicrobials. *Nature Biotechnology*, 32(11), 1146–1150.
- Bleick, C., Van Helden, S. R., Berti, A. D., & Rybak, M. J. (2026). P-1190. Targeting phage defense mechanisms: Expanding phage activity in the context of suspected *abiF*-mediated resistance against MRSA [Conference abstract]. *Open Forum Infectious Diseases*, 13(Supplement_1).
- Brüssow, H. (2024). The antibiotic resistance crisis and the development of new antibiotics. *Microbial Biotechnology*, 17(7), e14510.
- Burmeister, A. R., Fortier, A., Roush, C., Lessing, A. J., Bender, R. G., Barahman, R., Grant, R., Chan, B. K., & Turner, P. E. (2020). Pleiotropy complicates a trade-off between phage resistance and antibiotic resistance. *Proceedings of the National Academy of Sciences*, 117(21), 11207–11216.
- Chan, B. K., Turner, P. E., Kim, S., Mojibian, H. R., Eleftheriades, J. A., & Narayan, D. (2018). Phage treatment of an aortic graft infected with *Pseudomonas aeruginosa*. *Evolution, Medicine, and Public Health*, 2018(1), 60–66.
- Chhabra, S., Taksande, A. B., & Munjewar, P. (2024). The penicillin pioneer: Alexander Fleming's journey to a medical breakthrough. *Cureus*, 16(7), e65179.



- Chen, C. H., & Lu, T. K. (2020). Development and challenges of antimicrobial peptides for therapeutic applications. *Antibiotics*, 9(1), 24.
- Chen, K., Dong, N., Chan, E. W., & Chen, S. (2019). Transmission of ciprofloxacin resistance in *Salmonella* mediated by a novel type of conjugative helper plasmids. *Emerging Microbes & Infections*, 8(1), 857–865.
- Cheng, H., Jeong, E., & Cho, S. W. (2025). Applications of multiplexed CRISPR–Cas for genome engineering. *Experimental & Molecular Medicine*, 57(7), 1373–1380.
- Choi, Y., Lee, J., Lee, H., Park, M., Kang, K., Lim, S., Shin, D., & Ko, K. S. (2020). Comparison of fitness cost and virulence in chromosome- and plasmid-mediated colistin-resistant *Escherichia coli*. *Frontiers in Microbiology*, 11, 798.
- Chung, K. M., Nang, S. C., & Tang, S. S. (2023). The safety of bacteriophages in treatment of diseases caused by multidrug-resistant bacteria. *Pharmaceuticals*, 16(10), 1347.
- Collins, J. A., & Osheroff, N. (2024). Gyrase and topoisomerase IV: Recycling old targets for new antibacterials to combat fluoroquinolone resistance. *ACS Infectious Diseases*, 10(4), 1097–1115.
- Cong, Y., Yang, S., & Rao, X. (2019). Vancomycin resistant *Staphylococcus aureus* infections: A review of case updating and clinical features. *Journal of Advanced Research*, 21, 169–176.
- Cunha-Ferreira, I. C., Vizzotto, C. S., Peixoto, J., & Krüger, R. H. (2025). Antibiotic resistance crisis: From bacterial bioprospecting to artificial intelligence. *Environmental Microbiology Reports*, 17(6), e70267.
- Daubie, V., Chalhoub, H., Blasdel, B., Dahma, H., Merabishvili, M., Glonti, T., De Vos, N., Quintens, J., Pirnay, J., Hallin, M., & Vandenberg, O. (2022). Determination of phage susceptibility as a clinical diagnostic tool: A routine perspective. *Frontiers in Cellular and Infection Microbiology*, 12, 1000721.
- Dauray, L., Orange, F., Taveau, J., Verchère, A., Monlezun, L., Gounou, C., Marreddy, R. K. R., Picard, M., Broutin, I., Pos, K. M., & Lambert, O. (2016). Tripartite assembly of RND multidrug efflux pumps. *Nature Communications*, 7(1), 10731.
- Davies, J., & Davies, D. (2010). Origins and evolution of antibiotic resistance. *Microbiology and Molecular Biology Reviews*, 74(3), 417–433.
- Dhole, S., Mahakalkar, C., Kshirsagar, S., & Bhargava, A. (2023). Antibiotic prophylaxis in surgery: Current insights and future directions for surgical site infection prevention. *Cureus*, 15(10), e47858.
- Dohou, A. M., Buda, V. O., Yemoa, L. A., Anagonou, S., Van Bambeke, F., Van Hees, T., Dossou, F. M., & Dalleur, O. (2022). Antibiotic usage in patients having undergone caesarean section: A three-level study in Benin. *Antibiotics*, 11(5), 617.
- Fàbrega, A., Madurga, S., Giralt, E., & Vila, J. (2008). Mechanism of action of and resistance to quinolones. *Microbial Biotechnology*, 2(1), 40–61.
- Fathima, B., & Archer, A. C. (2021). Bacteriophage therapy: Recent developments and applications of a renaissance weapon. *Research in Microbiology*, 172(6), 103863.
- Fleming, A. (1945, December 11). Penicillin (Nobel Lecture). NobelPrize.org. <https://www.nobelprize.org/prizes/medicine/1945/fleming/lecture/>
- Gargate, N., Laws, M., & Rahman, K. M. (2025). Current economic and regulatory challenges in developing antibiotics for Gram-negative bacteria. *Npj Antimicrobials and Resistance*, 3(1), 50.
- Getahun, Y. A., Ali, D. A., Taye, B. W., & Alemayehu, Y. A. (2022b). Multidrug-Resistant microbial therapy using antimicrobial peptides and the CRISPR/CAS9 system. *Veterinary Medicine Research and Reports*, 13, 173–190.
- Ghazaei, C. (2026). The role of bacteriophages and CRISPR-Cas in combating multidrug-resistant bacteria. *Natural Products and Bioprospecting*, 16(1), 14.



- Hao, M., He, Y., Zhang, H., Liao, X., Liu, Y., Sun, J., Du, H., Kreiswirth, B. N., & Chen, L. (2020). CRISPR-Cas9-mediated carbapenemase gene and plasmid curing in carbapenem-resistant Enterobacteriaceae. *Antimicrobial Agents and Chemotherapy*, 64(9).
- Ho, Y., Shah, P., Chen, Y., & Chen, C. (2016). Systematic analysis of intracellular-targeting antimicrobial peptides, bactenecin 7, hybrid of pleurocidin and dermaseptin, proline–arginine-rich peptide, and lactoferricin B, by using *Escherichia coli* proteome microarrays. *Molecular & Cellular Proteomics*, 15(6), 1837–1847.
- Homer, J. A., Johnson, R. M., Koelln, R. A., Moorhouse, A. D., & Moses, J. E. (2024). Strategic re-engineering of antibiotics. *Nature Reviews Bioengineering*, 3(3), 213–229.
- Islam, M. M., Mahbub, N. U., Shin, W. S., & Oh, M. H. (2024). Phage-encoded depolymerases as a strategy for combating multidrug-resistant *Acinetobacter baumannii*. *Frontiers in Cellular and Infection Microbiology*, 14, 1462620.
- Javed, M. U., Hayat, M. T., Mukhtar, H., & Imre, K. (2023). CRISPR-Cas9 system: A prospective pathway toward combatting antibiotic resistance. *Antibiotics*, 12(6), 1075.
- Jiang, F., & Doudna, J. A. (2017). CRISPR–Cas9 structures and mechanisms. *Annual Review of Biophysics*, 46(1), 505–529.
- Jo, S. J., Park, S. C., & Kim, S. G. (2026). CRISPR/Cas9-engineered *Salmonella* phage displaying antimicrobial peptide LL37 for enhanced antibacterial activity. *International Journal of Antimicrobial Agents*, 67(4), 107734.
- Joo, J. H., Lee, S., & Kim, K. P. (2025). Precision gene editing: The power of CRISPR-Cas in modern genetics. *Molecular Therapy — Nucleic Acids*, 36(4), 102733.
- Jones, C. L., Singh, S. S., Alamneh, Y., Casella, L. G., Ernst, R. K., Lesho, E. P., Waterman, P. E., & Zurawski, D. V. (2016). In vivo fitness adaptations of colistin-resistant *Acinetobacter baumannii* isolates to oxidative stress. *Antimicrobial Agents and Chemotherapy*, 61(3).
- Kapoor, A., Mudaliar, S. B., Bhat, V. G., Chakraborty, I., Prasad, A. S. B., & Mazumder, N. (2024). Phage therapy: A novel approach against multidrug-resistant pathogens. *3 Biotech*, 14(10), 256.
- Khwaza, V., Mlala, S., & Aderibigbe, B. A. (2024). Advancements in synthetic strategies and biological effects of ciprofloxacin derivatives: A review. *International Journal of Molecular Sciences*, 25(9), 4919.
- Kuo, S., Huang, T., Chen, F., Lee, C., & Lee, C. (2026). CRISPR-Cas9-mediated elimination of plasmid-borne carbapenemase genes restores ertapenem susceptibility in clinical *Klebsiella pneumoniae* isolates. *Biomedical Journal*, 100966.
- Labrie, S. J., Samson, J. E., & Moineau, S. (2010). Bacteriophage resistance mechanisms. *Nature Reviews Microbiology*, 8(5), 317–327.
- Lee, T. H., Hwang, J., Lee, W. K., Shin, M., Woo, H. R., Chung, K. M., & Lee, C. (2018). *armA* and *rmtB* were the predominant 16S RMTase genes responsible for aminoglycoside-resistant isolates in Korea. *Journal of Korean Medical Science*, 33(42), e262.
- Li, Y. (2011). Recombinant production of antimicrobial peptides in *Escherichia coli*: A review. *Protein Expression and Purification*, 80(2), 260–267.
- Liang, S., Cai, W., Mao, R., Chen, M., Dai, X., Jin, X., & Kong, W. (2025). Three simple and cost-effective assays for AAC(6′)-Ib-cr enzyme activity. *Frontiers in Microbiology*, 16, 1513425.
- Liao, C., Ttofali, F., Slotkowski, R. A., Denny, S. R., Cecil, T. D., Leenay, R. T., Keung, A. J., & Beisel, C. L. (2019). Modular one-pot assembly of CRISPR arrays enables library generation and reveals factors influencing crRNA biogenesis. *Nature Communications*, 10(1), 2948.
- Lu, T. K., & Koeris, M. S. (2011). The next generation of bacteriophage therapy. *Current Opinion in Microbiology*, 14(5), 524–531.



- Ma, X., Wang, Q., Ren, K., Xu, T., Zhang, Z., Xu, M., Rao, Z., & Zhang, X. (2024). A review of antimicrobial peptides: Structure, mechanism of action, and molecular optimization strategies. *Fermentation*, 10(11), 540.
- Maeda, M., Sunaga, T., Sato, M. T., Hasegawa, T., Noma, H., & Ota, E. (2024). Efficacy of carbapenems and alternative antimicrobials for treating complicated urinary tract infections caused by third-generation cephalosporin-resistant gram-negative bacteria: A systematic review and meta-analysis of randomised controlled trials. *Journal of Infection and Chemotherapy*, 30(11), 1147–1155.
- Mangalea, M. R., & Duerkop, B. A. (2020). Fitness trade-offs resulting from bacteriophage resistance potentiate synergistic antibacterial strategies. *Infection and Immunity*, 88(7).
- Mayorga-Ramos, A., Zúñiga-Miranda, J., Carrera-Pacheco, S. E., Barba-Ostria, C., & Guamán, L. P. (2023). CRISPR-Cas-based antimicrobials: Design, challenges, and bacterial mechanisms of resistance. *ACS Infectious Diseases*, 9(7), 1283–1302.
- Meyer, J. R., Dobias, D. T., Weitz, J. S., Barrick, J. E., Quick, R. T., & Lenski, R. E. (2012). Repeatability and contingency in the evolution of a key innovation in phage lambda. *Science*, 335(6067), 428–432.
- Mora-Ochomogo, M., & Lohans, C. T. (2021). β -lactam antibiotic targets and resistance mechanisms: From covalent inhibitors to substrates. *RSC Medicinal Chemistry*, 12(10), 1623–1639.
- Moretta, A., Scieuzo, C., Petrone, A. M., Salvia, R., Manniello, M. D., Franco, A., Lucchetti, D., Vassallo, A., Vogel, H., Sgambato, A., & Falabella, P. (2021). Antimicrobial peptides: A new hope in biomedical and pharmaceutical fields. *Frontiers in Cellular and Infection Microbiology*, 11, 668632.
- Murray, C. J. L., Ikuta, K. S., Sharara, F., Swetschinski, L., Aguilar, G. R., Gray, A., Han, C., Bisignano, C., Rao, P., Wool, E., Johnson, S. C., Browne, A. J., Chipeta, M. G., Fell, F., Hackett, S., Haines-Woodhouse, G., Hamadani, B. H. K., Kumaran, E. A. P., McManigal, B., . . . Naghavi, M. (2022). Global burden of bacterial antimicrobial resistance in 2019: A systematic analysis. *The Lancet*, 399(10325), 629–655.
- Mwangi, J., Kamau, P., Thuku, R., & Lai, R. (2023). Design methods for antimicrobial peptides with improved performance. *Zoological Research*.
- Nikaido, H., & Pagès, J. (2011). Broad-specificity efflux pumps and their role in multidrug resistance of Gram-negative bacteria. *FEMS Microbiology Reviews*, 36(2), 340–363.
- Nittayasut, N., Yata, T., Chirakul, S., Techakriengkrai, N., & Chanchaithong, P. (2024). Non-replicative phage particles delivering CRISPR-Cas9 to target major blaCTX-M variants. *PLoS ONE*, 19(5), e0303555.
- Novović, K., & Jovčić, B. (2023). Colistin resistance in *Acinetobacter baumannii*: Molecular mechanisms and epidemiology. *Antibiotics*, 12(3), 516.
- Osheroff, N. (2026). Gyrase and topoisomerase IV as antibacterial targets for gepotidacin and zoliflodacin: Teaching old enzymes new tricks. *International Journal of Molecular Sciences*, 27(1), 496.
- Park, A. R., Kim, S. W., Kim, S. W., Kim, S. Y., Kim, S. Y., & Kwon, K. (2021). Expression of antimicrobial peptide (AMP), cecropin B, in a fused form to SUMO tag with or without three-glycine linker in *Escherichia coli* and evaluation of bacteriolytic activity of the purified AMP. *Probiotics and Antimicrobial Proteins*, 13(6), 1780–1789.
- PubChem. (n.d.). Methicillin. In *PubChem*. <https://pubchem.ncbi.nlm.nih.gov/compound/Methicillin>
- Ratner, A. J., & Weiser, J. N. (2006). Pneumonia before antibiotics: Therapeutic evolution and evaluation in twentieth-century America. *Journal of Clinical Investigation*, 116(9), 2311.
- Saeed, K., Ayub, F., Durrani, M. A., & Mujahid, M. (2025). CRISPR Cas systems: From bacterial defense mechanisms to revolutionary tools reshaping genetic research and translation therapeutics. *The Microbe*, 7, 100344.
- Shakil, S., Khan, R., Zarrilli, R., & Khan, A. U. (2007). Aminoglycosides versus bacteria: A description of the action, resistance mechanism, and nosocomial battleground. *Journal of Biomedical Science*, 15(1), 5–14.



- Shariati, A., Arshadi, M., Khosrojerdi, M. A., Abedinzadeh, M., Ganjalishahi, M., Maleki, A., Heidary, M., & Khoshnood, S. (2022). The resistance mechanisms of bacteria against ciprofloxacin and new approaches for enhancing the efficacy of this antibiotic. *Frontiers in Public Health*, 10, 1025633.
- Sharma, A., Gupta, V. K., & Pathania, R. (2019). Efflux pump inhibitors for bacterial pathogens. *The Indian Journal of Medical Research*, 149(2), 129–145.
- Shen, S., Loh, T. J., Shen, H., Zheng, X., & Shen, H. (2017). CRISPR as a strong gene editing tool. *BMB Reports*, 50(1), 20–24.
- Simner, P. J., Bergman, Y., Conzemius, R., Jacobs, E., Tekle, T., Beisken, S., & Tamma, P. D. (2023). An NDM-producing *Escherichia coli* clinical isolate exhibiting resistance to cefiderocol and the combination of ceftazidime-avibactam and aztreonam: Another step toward pan- β -lactam resistance. *Open Forum Infectious Diseases*, 10(7), ofad276.
- Starr, C. G., & Wimley, W. C. (2017). Antimicrobial peptides are degraded by the cytosolic proteases of human erythrocytes. *Biochimica et Biophysica Acta (BBA) - Biomembranes*, 1859(12), 2319–2326.
- Sun, D., Gao, W., Hu, H., & Zhou, S. (2022). Why 90% of clinical drug development fails and how to improve it? *Acta Pharmaceutica Sinica B*, 12(7), 3049–3062.
- Sutcliffe, J. A. (2005). Improving on nature: Antibiotics that target the ribosome. *Current Opinion in Microbiology*, 8(5), 534–542.
- Tajer, L., Paillart, J., Dib, H., Sabatier, J., Fajloun, Z., & Khattar, Z. A. (2024). Molecular mechanisms of bacterial resistance to antimicrobial peptides in the modern era: An updated review. *Microorganisms*, 12(7), 1259.
- Tao, S., Chen, H., Li, N., & Liang, W. (2022). The application of the CRISPR-CAS system in antibiotic resistance. *Infection and Drug Resistance*, 15, 4155–4168.
- Tarasenko, A., Papudeshi, B. N., Grigson, S. R., Mallawaarachchi, V., Hutton, A. L. K., Warner, M. S., Barr, J. J., Iredell, J., Eijkelkamp, B., & Edwards, R. A. (2025). Reprogramming resistance: Phage-antibiotic synergy targets efflux systems in ESKAPEE pathogens. *mBio*, 16(10), e0182225.
- Thakur, V., Uniyal, A., & Tiwari, V. (2021). A comprehensive review on pharmacology of efflux pumps and their inhibitors in antibiotic resistance. *European Journal of Pharmacology*, 903, 174151.
- Tobin, E. H., Jogu, P., & Koirala, J. (2025). Methicillin-resistant *Staphylococcus aureus*. In *StatPearls*. StatPearls Publishing.
- Vilhena, C., & Bettencourt, A. (2012). Daptomycin: A review of properties, clinical use, drug delivery and resistance. *Mini-Reviews in Medicinal Chemistry*, 12(3), 202–209.
- Wachino, J., Doi, Y., & Arakawa, Y. (2020). Aminoglycoside resistance. *Infectious Disease Clinics of North America*, 34(4), 887–902.
- Wacnik, M., Hauza, E., Skaradzińska, A., & Śliwka, P. (2026). Bacteriophage therapy: Overcoming antimicrobial resistance through advanced delivery methods. *Molecules*, 31(2), 324.
- Watford, S., & Warrington, S. J. (2023). Bacterial DNA mutations. In *StatPearls*. StatPearls Publishing.
- Westra, E. R., Van Houte, S., Oyesiku-Blakemore, S., Makin, B., Broniewski, J. M., Best, A., Bondy-Denomy, J., Davidson, A., Boots, M., & Buckling, A. (2015). Parasite exposure drives selective evolution of constitutive versus inducible defense. *Current Biology*, 25(8), 1043–1049.
- World Health Organization. (2022, June 22). *Lack of innovation set to undermine antibiotic performance and health gains*.
- World Health Organization. (2024). *Bacterial pathogens of public health importance to guide research, development and strategies to prevent and control antimicrobial resistance*.
- Wright, O., Yoshimi, T., & Tunnacliffe, A. (2011). Recombinant production of cathelicidin-derived antimicrobial peptides in *Escherichia coli* using an inducible autocleaving enzyme tag. *New Biotechnology*, 29(3), 352–358.



Yoon, B., Kim, J. A., & Kang, Y. K. (2026). CRISPR–CAS-mediated reprogramming strategies to overcome antimicrobial resistance. *Pharmaceutics*, 18(1), 95.

Young, R. (2014). Phage lysis: Three steps, three choices, one outcome. *The Journal of Microbiology*, 52(3), 243–258.

Yu, X. H., Hao, Z. H., Liu, P. L., Liu, M. M., Zhao, L. L., & Zhao, X. (2022). Increased expression of efflux pump *norA* drives the rapid evolutionary trajectory from tolerance to resistance against ciprofloxacin in *Staphylococcus aureus*. *Antimicrobial Agents and Chemotherapy*, 66(12), e0059422.

Zack, K. M., Sorenson, T., & Joshi, S. G. (2024). Types and mechanisms of efflux pump systems and the potential of efflux pump inhibitors in the restoration of antimicrobial susceptibility, with a special reference to *Acinetobacter baumannii*. *Pathogens*, 13(3), 197.

Zalewska-Piątek, B. (2023). Phage therapy: Challenges, opportunities and future prospects. *Pharmaceutics*, 16(12), 1638.

Zhang, F., Song, G., & Tian, Y. (2019). Anti-CRISPRs: The natural inhibitors for CRISPR-Cas systems. *Animal Models and Experimental Medicine*, 2(2), 69–75.

Zhang, Q., Yan, Z., Meng, Y., Hong, X., Shao, G., Ma, J., Cheng, X., Liu, J., Kang, J., & Fu, C. (2021). Antimicrobial peptides: Mechanism of action, activity and clinical potential. *Military Medical Research*, 8(1), 48.

Zhang, S., & Ahn, J. (2025). Phage therapy as a novel alternative to antibiotics through adaptive evolution and fitness trade-offs. *Antibiotics*, 14(10), 1040.

Zhou, S., Zhou, K., Yang, P., Kong, M., Liu, H., Zhang, R., Hou, Z., & Liu, J. (2025). Molecular characteristics and antimicrobial resistance of linezolid-resistant *Staphylococcus aureus* in osteoarticular infections: A 11-year study from a hospital in Xi'an. *Infection and Drug Resistance*, 18, 2987–2996.

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Sign, Structure, Labour: Layered Object Analysis of Three Design Mediations of Danzhai Miao Indigo Costume

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Abstract

Miao batik from Danzhai County, Guizhou, belongs to China's first national inventory of intangible cultural heritage, yet ceremonial indigo costume is less often worn as everyday dress while its signs travel through fashion and tourism. This article asks a design question rather than a safeguarding one: when fashion branding, structural reconstruction, and community making intervene in this practice, which layer of design does each actually change—sign, structure, or labour—and what does each leave untouched? A layered object-analysis protocol is applied to three mediations: MsMIN's recasting of glossy indigo cloth in technical nylon; He Yang's reconstructions of rectangular, low-waste cutting; and a one-day workshop visit to the Mama Makes cooperative in Danzhai. The comparison shows a recurrent misalignment. Branding can move textile signs without the hand–mind encounter of wax-resist; structural ethics can be demonstrated at high density without paying village makers; community making can wage skill and invite visitors to draw wax, yet remains a locally bounded service. The article does not propose that the three form a collaborative ecology. It argues that treating them as interchangeable sustainable pathways conceals which layer of design has been changed.

Keywords

layered object analysis; cultural sustainability; craft; fashion mediation; Miao indigo dyeing; Danzhai

Introduction

Design interventions in living craft often announce themselves as sustainable because they keep a look, revive a cut, or generate a wage. Those three outcomes are not the same design act. A motif can travel on a knitted hoodie while no one in the locality of origin draws wax. A ceremonial jacket can be reconstructed with exemplary economy of cloth while village women are not paid to make it. A cooperative can wage skill and teach visitors to handle a wax pot while the garments that leave the workshop no longer carry the structural intelligence that once organised everyday dress. Confusing these layers produces an optimistic recipe: brand, aesthetics, and community, working together. This article treats that recipe as the assumption to be tested, not as the finding.

The empirical ground is Danzhai County, in Qiandongnan Miao and Dong Autonomous Prefecture, Guizhou Province. Miao batik (miao zu laran jiyi) was inscribed on China's first national inventory of intangible cultural heritage in 2006; Danzhai is one of the practice's principal localities (Song 2023). The 2003 UNESCO Convention frames such practices as living media of communication among communities rather than as relics to be stored (UNESCO 2003). Listing, however, does not by itself keep indigo costume inhabitable. Ceremonial dress thins as everyday wear; synthetic prints and bright chemical yarns occupy local markets; young consumers inhabit transnational taste regimes. Designers then face a familiar pair of failures. Repeating old silhouettes will not enter present life. Borrowing motifs as surface decoration empties the practice of the thought that once joined hand, cloth, and community (Walker 2011; Zhan et al. 2017). Between those failures, design has work to do. The work is not to choose a single correct pathway. It is to specify which layer of the designed object—and of the labour that produces it—has been changed.

The term Miao is used throughout in its official Chinese sense (Miaozu) and is geographically restricted, for the field material, to Danzhai. The communities in question belong principally to the eastern, Qiandong branch of Miao—often designated Hmu in linguistic scholarship—rather than to the Western Hmong of the Chuanqiandian dialect area, or to Hmong communities in Laos, Vietnam, Thailand, and the overseas diaspora. English-language writing sometimes treats Hmong as a simple equivalent of Miao; that equation is not adopted here. Where the argument turns to published reconstructions of Miao cutting beyond Danzhai, that wider nationality is named as such, and the cases are not presented as Danzhai practice.

Craft scholarship in this journal has already argued that locally based, context-specific making can be a direction for more sustainable manufacturing, and that design interventions fail when they parachute into artisan communities without remaining situated (Zhan et al. 2017; Mazzarella, Mitchell, and Escobar-Tello 2017). Research on design for social innovation has distinguished expert design from the diffuse design already performed by communities, and has warned that enabling solutions are not the same as extracting a look (Manzini 2015). Systemic design has shifted attention from isolated objects to circulating relations among people, materials, and institutions (Bistagnino 2011; Jones 2014). What remains underspecified, in the growing literature on Chinese craft and fashion mediation, is a method for reading garments and workshops with the same protocol, so that a brand lookbook, a lecture reconstruction, and a rural cooperative are not compared as if they were interchangeable tools.

This article therefore examines three existing mediations rather than proposing a studio collection of its own. It asks: (1) through what mechanisms do fashion branding, structural reconstruction, and community making each change—or fail to change—the living design of Danzhai Miao indigo costume; (2) which layer of design, sign, structure, or labour, does each mediation actually touch; and (3) what follows for design knowledge if the three do not automatically reinforce one another. The contribution is a layered object-analysis protocol and a misalignment claim: visibility, cutting ethics, and wages repair different damages, and in the material assembled here they do not recombine into a single sustainable pathway.

- 1. Which Layer Does Design Change?**
- 2. Cultural sustainability is not a motif kept**

Walker has argued that sustainable design cannot be reduced to cleaner materials or longer product life if the meanings that make objects worth keeping are stripped away (Walker 2011, 2014). Form, in this view, has to follow meaning rather than the stimulation of desire. Applied to indigo costume, the point is severe. A nylon surface that imitates the sheen of calendered glossy cloth (liangbu) may reduce some use-phase inconveniences of ceremonial dress, yet it does not carry the sequence of planting, fermenting, dyeing, beating, and wax drawing through which that sheen was historically produced. Calling the substitution sustainable because the polymer is said to be recyclable in its raw state mistakes a brand claim for a life-cycle argument, and mistakes a sign for a practice (Fry 2009). Zhan, Walker, Hernandez-Pardo, and Evans, writing in this journal on crafts in the Yangtze River Delta, likewise insist that craft's relation to sustainability lies in holistic making, context-based knowledge, and community-centred production, not in the quantity of goods issued under a heritage label (Zhan et al. 2017). Productivity is not the issue; quality of making and of livelihood is.

That distinction matters in China because ICH policy has strongly favoured systematic, often production-oriented, safeguarding (Song 2023). Systematic protection can thicken institutions around a craft. It can also license design to treat the craft as a repertoire of extractable signs. Zhu and Luo's account of relic elements re-created in product design describes exactly this extraction as a design method (Zhu and Luo 2013). The method is not illegitimate as fashion. It becomes a problem for cultural sustainability when it is reported as transmission.

- 3. Fashion mediation moves signs**

Barthes treated fashion as a system that converts garments into written and photographed signs (Barthes 1990). Kawamura's fashion-ology likewise locates fashion in the institutions that confer value, not only in cloth (Kawamura 2005). When a high-fashion collection dismantles Miao dress into elements and reassembles them, the decisive design operation is often decontextualisation: a sign is

lifted from ceremonial life and set to work inside another system of cut, price, and display. Public attention may increase. The hand–mind encounter of wax-resist may not. Design research needs a way to keep those two outcomes on different lines of the same analysis, rather than scoring both as innovation.

4. *Structure can travel without labour*

A second layer is construction. Cross's designerly ways of knowing include the reading of objects as evidence of how problems were framed (Cross 2006). Prown's material-culture method, though developed for historical artefacts, remains usable for designed garments: description, deduction, and speculation must be kept distinct, and what the object can show is not the same as what a community can still do (Prown 1982). He Yang's research on 'one piece of cloth' (yifang bu) argues that much Chinese, and specifically Miao, cutting proceeds from rectangular widths, with little waste, because cloth was hard-won from women's labour of spinning, weaving, and dyeing (He 2023). That ethic coincides with contemporary concerns for material restraint. Coincidence is not identity. A reconstruction in gambiered silk or machine-printed cloth can demonstrate the cut while changing the material system and leaving Danzhai wages untouched. Structure, in other words, can be taught as design knowledge without being practised as local labour.

5. *Labour, services, and the workshop*

A third layer is the organisation of making. Manzini distinguishes diffuse design, performed by everybody, from expert design, and describes enabling solutions in which communities collaborate toward more sustainable ways of living (Manzini 2015). Mama Makes, which invites visitors to draw wax, looks at first like such an enabling solution: consumers become makers, if only for an afternoon. Sanders and Stappers remind us that co-creation redistributes roles; it does not automatically redistribute power (Sanders and Stappers 2008). Mazzarella, Mitchell, and Escobar-Tello, again in this journal, warn against the designer's parachuting into textile artisan communities and call for situated services that remain meaningful locally (Mazzarella, Mitchell, and Escobar-Tello 2017). A study-tour in which students keep what they draw can be read as social innovation. It can also be read as a designed service that turns skill into an experience product. Both readings must remain available.

Systemic design, as developed by Bistagnino and extended by Jones and by Sevaldson's giga-mapping, would require that persons, materials, money, and authorisations be treated as one field (Bistagnino 2011; Jones 2014; Sevaldson 2011). This article does not claim to have mapped that field for Danzhai. A one-day visit cannot support a giga-map. What it can support is a workshop slice on the labour layer, set beside two object analyses on the sign and structure layers, under one protocol. That limitation is methodological, not rhetorical.

Methods

The research is qualitative and comparative. It does not treat the three cases as a statistical sample, nor as three tools already at work inside one Danzhai design field. They are three mediations of Miao indigo dress that designers and heritage actors currently cite as models of continuation. Only one of them was observed in Danzhai. The protocol is therefore used both to compare and to refuse false equivalence.

Layered object analysis asks the same three questions of each mediation. Sign: what identifiable marks of Miao or indigo practice are retained, and do they still connect to wax drawing, glossy cloth, or ceremonial use? Structure: what happens to loom width, seaming, the possibility of a continuous front-and-back plane, the destination of offcuts, and the substitution of cloth? Labour: who draws wax, who cuts, who prices, who appears in photographs, and where does money come from—orders, study-tours, subsidies, or retail markup? The questions are filled from what the object and the situation can show. Where they cannot be filled, the cell is left as a limit, not as a speculation dressed as a finding (Prown 1982).

Case selection follows contrast in layer, not typicality in Danzhai. MsMIN, founded in 2010 by the Xiamen-based designer Liu Min, is read as a high-fashion mediation of Chinese historical luxury. The garments discussed here belong to the Oilcloth / Modern Oilcloth series, released on 7 August 2024 as part of the brand's early-autumn 2024 collection, dated to the solar term Beginning of Autumn (liqiu). A coat from the series retailed at about 4,800 RMB. Published brand profiles document Liu Min's training at the London College of Fashion and the brand's circulation through Lane Crawford and later international retailers; they do not document a production relationship with Danzhai (Liu 2018). The author has further confirmed that Mama Makes, the only Danzhai workshop in this study, has no partnership, commission, co-branding, or supply relationship with MsMIN. Images are reproduced with permission of the brand. The case is therefore a contrast on the sign layer, not a pathway shown to be shaping Danzhai making, and not a collaborator of the cooperative analysed below. He Yang, former director of the National Costume Museum at the Beijing Institute of Fashion Technology, has since 2013 conducted fieldwork on traditional structure in southwest China and presented reconstructions in the Huaxia Yichang (Chinese Dress) lecture series in 2023 under the heading of yifang bu, 'one piece of cloth' (He 2023). The reconstructions analysed here concern a straight-collar, centre-opening Miao ceremonial jacket. They were not offered for sale. Lecture images are reproduced with permission. They are a contrast on the structure layer, not a Danzhai workshop practice. The Mama Makes (Mama zhizao) cooperative in Danzhai is the only situated case. Its principal is Zhang Yiping. Field material was gathered at its base on 23 October 2023: observation of wax drawing and teaching, photographic documentation, and one interview with a local woman textile artisan, aged forty-six, about livelihood before and after she entered the cooperative in 2019. Written informed consent was obtained for the interview, for publication of the consented livelihood passages, and for the workshop photographs. Secondary published sources locate the cooperative in a wider institutional landscape and are not treated as the author's observation.

The author's position is that of a visiting graduate student from outside the county, working in Mandarin, entering through the cooperative's public teaching space. The visit lasted one day. It is used as a workshop slice, not as an ethnography of Danzhai, and not as proof that a cultural-ecological system has been completed. After the visit, the author confirmed further organisational facts with the cooperative: study-tour fees enter the cooperative's accounts; students keep what they make and may alter motifs; income comes from government subsidy together with market orders; the cooperative supplies Guizhou Lanjin Dyeing Art Co., Ltd.; workshop production pauses during the busy farming season; and Mama Makes has no partnership, commission, co-branding, or supply relationship with MsMIN. Evidence for MsMIN and for He Yang's team is drawn from published collections, official brand presentation, and 2023 lecture documentation. Figures are cited in the order of first appearance. Income figures from a single life are not expanded into a regional average. In 2024 the author also recorded the cooperative's piece-rate schedule and local agricultural day rates, used below to locate the 2023 interview in a typical working year rather than to replace it.

Results and Discussion

6. *A Contemporary Design Predicament*

The difficulty of Danzhai Miao costume, for design, is not a single shock and does not require a civilisational origin story. It is a present split among wearing, showing, and selling.

First, ceremonial costume in many traditions has lost much of its everyday function. Beauty that cannot be worn to work, to school, or into a city street must find another vehicle. Elderly women in remote villages may still wear customary dress as a daily habit; younger residents often do not. The visual grammar of ritual Miao dress and the grammar of mass fashion no longer share a common ground, so the former cannot walk directly into the latter's market. Slow development of cut and cloth relative to urban Chinese fashion, and an aesthetic break, compound each other.

Second, transmission is internally contradictory. Entry into elite culture can keep a high density of design intelligence—cloth substitution, structural demonstration, editorial photography—but the public is small and the cost of circulation is high. Entry into popular life requires breaking and remaking cloth, cut, and pattern so that many people can accept the result. Either route demands technical change. A

practice that refuses all change will not be conserved; it will be abandoned. The design risk is the opposite refusal: to keep the look and discard the thought that once arose from the meeting of person, material, and locality (Walker 2011). In local markets, batik is already displaced in many settings by bright chemical threads, acrylic yarns, or machine prints. If designers merely insert indigo into that technical stream, they do not continue a craft. They overwrite it.

Third, China's ICH apparatus and rural creative industries now offer ready infrastructures for the overwrite: inventories, inheritor titles, study-tours, live-stream retail, and designer collaborations (Song 2023). Those infrastructures are not, by themselves, the problem. They become a design problem when every intervention is counted as safeguarding. The three mediations that follow are read against that risk, with attention to which layer each actually changes.

7. *Sign: Fashion Mediation without a Place of Making*

MsMIN has, since 2010, taken Chinese cultural sources as a well of form and has sought to present historical luxury through refined contemporary design. In the Oilcloth / Modern Oilcloth series, released on 7 August 2024 for early autumn, traditional Miao dress is dismantled into elements and reassembled. The decisive move is not a printed motif but a transformation of cloth. Designers work from the visual memory of Miao glossy indigo cloth (liangbu)—a calendered, light-catching surface that, in local dress, functions as a recognisable sign of indigo skill. The collection substitutes an Italian nylon, one hundred per cent, that is light, smooth, described by the brand as recyclable in its raw material, and finished for water resistance and calendering (Figures 1 and 2). A coat from the series was priced at about 4,800 RMB. That sum is already about one-third of Danzhai's 2023 rural per capita disposable income of 14,082 RMB (Danzhai County Bureau of Statistics 2024). The sign of glossy cloth remains; the performance of the garment, and its public, change. From the standpoint of fashion as a sign system, the operation is decontextualisation: a sheen produced by repeated dyeing, beating, and finishing is recoded as a technical textile inside another system of cut, price, and display (Barthes 1990; Kawamura 2005).



Figure 1. MsMIN Oilcloth / Modern Oilcloth padded jacket, recasting the sheen of Miao glossy cloth in technical nylon. Early autumn 2024. Source: MsMIN. Reproduced with written email permission of the brand.



Figure 2. MsMIN Oilcloth / Modern Oilcloth jacket and wide trousers in waterproof Italian nylon. Early autumn 2024. Source: MsMIN. Reproduced with written email permission of the brand.

The cut of the series also borrows a Miao intelligence that is easy to miss if one looks only at pattern: a complete garment can be obtained from relatively whole widths of cloth by simple cutting and seaming. That economy is not poverty of invention. It is an ethic of restraint, close to the insistence on using things without waste that He Yang isolates as *yifang bu* (He 2023). In the layered protocol, this is a structural borrowing attached to a sign conversion. It does not return labour or orders to Mama Makes: the two organisations have no partnership. On published evidence, no other Danzhai production relationship is documented either. In another series of batik-inspired knitwear, motifs are broken apart, screened, and rebuilt so that they can leave their original carrier and move across media (Figures 3 and 4). Floral signs that once sat on ceremonial cloth are enlarged onto a hooded ground. The brand thus uses a modern design language to recast cultural signs. The gain is real:

public attention to indigo culture can increase, and a rural craft can enter mainstream aesthetic discussion. The labour cell, however, stays empty. Who drew the original wax, and who owns the motif, cannot be read from the lookbook. What can be stated more firmly is narrower: MsMIN and Mama Makes are not collaborators.



Figure 3. MsMIN knitwear with enlarged batik-derived floral signs moved onto a hooded ground. Source: MsMIN. Reproduced with written email permission of the brand.



Figure 4. MsMIN batik sweater in an editorial presentation, with floral signs detached from ceremonial cloth. Source: MsMIN. Reproduced with written email permission of the brand.

The same method is open to a serious objection from cultural sustainability. Transmission is not exhausted by the recombination of patterns (Walker 2014; Zhan et al. 2017). Wax-resist dyeing is a practice in which mind and hand meet on cloth within a local ecology of skill. If that encounter is dropped, public knowledge of batik may stop at a portable emblem (Zhu and Luo 2013). High-fashion positioning further limits the radius of the work: a coat at about 4,800 RMB does not become ordinary dress in Danzhai, where the same year's rural per capita disposable income was 14,082 RMB. The brand's claim that the nylon is recyclable in its raw material cannot be treated as a completed

environmental argument. The substitution removes plant indigo, beeswax, and calendered cotton from the object; it introduces a fossil-based fibre whose microplastic shedding and end-of-life recovery are not evidenced here. Fry's warning against treating technical enablement as ethical completion applies directly (Fry 2009).

None of this makes the collection trivial as fashion. Breaking the ceremonial frame is one of the few ways Miao dress obtains visibility in contemporary editorial culture. The layered analysis simply refuses to count that visibility as a change in labour or as a verified change in Danzhai making. On present evidence, MsMIN is a contrast case in which the sign layer is highly worked, the structure layer is partly quoted, and the labour layer is not shown to be local. The collection post-dates the October 2023 workshop visit; it is read as a contemporary mediation of Miao indigo signs, not as an event in that day's field. If later research can document orders, co-design, or attribution to Danzhai artisans, the labour cell should be rewritten. Until then, the honest description is fashion mediation, not a Danzhai pathway.

8. *Structure: An Ethic of Cloth without a Local Wage*

In a 2023 lecture in the Huaxia Yichang series, He Yang argued that Miao cutting contains an ethic of using cloth to the full (He 2023). The point is not a folk curiosity. It is a view of making in which materials are treated with restraint because they were produced through long, often gendered, labour: planting, spinning, weaving, dyeing. 'One piece of cloth' names a construction logic in which rectangular widths are pieced with minimal cutting, and in which front and back may remain a continuous plane. The same structural family can, through wrapping, tying, and proportion, dress different bodies. Decoration then carries distinctions of group, gender, and marital status that the cut itself does not have to invent each time. Li and He have documented related square constructions in Miao poncho-style garments (Li and He 2018). This is design knowledge of a high order. It is also, in origin, a labour-saving method for women who had to clothe a household without being professional cutters (He 2023).

In reconstructions of the straight-collar, centre-opening ceremonial jacket, He Yang's team has kept the intelligence of single-cut construction and of minimal cutting with extensive piecing (Figures 5 and 6). Traditional structure is held; the cloth itself may change. Gambiered silk (xiangyunsha) and machine-printed grounds, more familiar to a contemporary public, are introduced so that an old silhouette can re-enter ordinary sight. The reconstructions were not offered for sale. The layered protocol records this clearly. Structure: strongly held. Sign: mixed, because machine-printed grounds can carry pattern without wax. Labour: not Danzhai labour, and not a market wage even for the reconstructed garments. Xiangyunsha is itself a demanding dyed and coated silk from another regional system. Substituting it for indigo-resist cotton demonstrates the cut while replacing the material ecology in which Danzhai batik is thinkable. The reconstruction is therefore an ethical demonstration of making, not a continuation of Danzhai making.



Figure 5. Traditional Miao straight-collar, centre-opening ceremonial jacket, laid flat to show panel construction. Source: lecture documentation, Huaxia Yichang, 2023. Reproduced with permission.



Figure 6. Contemporary reconstructions that retain a straight-collar Miao logic while changing cloth and motion. Source: He Yang team / lecture documentation, 2023. Reproduced with permission. The garments were not offered for sale.

The extreme economy of Miao cutting grew from a care for cloth. That origin coincides with contemporary sustainable design's interest in waste (Walker 2014; Zhan et al. 2017). Coincidence can be a resource. Innovation that begins from structure rather than from print is better placed to hold a cultural root and to return design to making rather than to styling. The garments that result still function as cultural carriers for those who can read them. Their prices often remain high, and the pleasure they offer is aimed at clients who can read brand value and cut together. The mass public may not buy. That fact does not cancel the circulation of the idea. It does, however, keep the labour cell empty for village artisans. Without feedback into local livelihood and place-based teaching, this mediation remains an ethical demonstration detached from living transmission on the ground. It

should be valued as design research and teaching. It should not be listed, without further evidence, among pathways currently shaping Danzhai indigo practice.

9. *Labour: A Workshop Slice at Mama Makes*

If sign and structure can travel without wages, the remaining question is whether a local organisation of making can hold labour without being reduced to souvenir manufacture or to a tourism service. Mama Makes (Mama zhizao) is a national programme initiated in 2016 by the China Women's Development Foundation with partners in social enterprise, intended to connect low-income women makers with design and markets across several crafts and provinces (Zhang 2020). In Danzhai, the batik node is led by Zhang Yiping, a Miao inheritor of batik who returned from migrant factory work, organised a cooperative, and later operated Guizhou Lanjin Dyeing Art Co., Ltd. under a company-plus-cooperative-plus-household model (CYOL 2020; Zhang 2020). The cooperative supplies the company. Those published facts locate the workshop. They are not a substitute for the 23 October 2023 visit, and they do not imply a fashion-brand partnership: Mama Makes and MsMIN have no cooperative, commission, or co-branding relationship.

On that day, at the Mama Makes base in Danzhai, batik was treated as a local cultural system involving artisans, a teaching studio, study-tour programmes, and rural income. Senior local artisans taught wax drawing (Figure 7). Visitors and students were given space to draw wax themselves and might keep what they made (Figure 8). Study-tour fees enter the cooperative's accounts; students may alter the motifs they draw. Consumers were not left only in the position of passive receivers. Producers and visitors stood, for the duration of the class, in a two-way relation. In Manzini's terms, this is close to an enabling solution: expert and non-expert design meet in a collaborative act (Manzini 2015). In Mazzarella, Mitchell, and Escobar-Tello's terms, it is also a service that must be judged as situated or as parachuted (Mazzarella, Mitchell, and Escobar-Tello 2017). A one-day visit cannot settle that judgement for the whole enterprise. It can describe what the service did in the room: it turned aesthetic recreation into an act rather than only a purchase, and it placed heated wax pots on shared tables where students' hands followed artisans' hands.



Figure 7. Artisans at the Mama Makes workshop in Danzhai drawing wax-resist motifs. Source: photograph by the author, 23 October 2023. Published with written informed consent.



Figure 8. Students practising wax drawing at Mama Makes, with heated wax pots on shared tables. Source: photograph by the author, 23 October 2023. Published with written informed consent.

The same afternoon, the author interviewed a local woman textile artisan, aged forty-six. She is not in the ordinary home-based group that takes mainly simple and medium orders. She takes more technically demanding work—large batik yardage, dense motifs, and costume parts of the kind Table 2 classifies as complex, and which only a skilled core of embroiderers can accept. She said that she had previously worked in farming, earning about 200 to 300 RMB a month, with little stability. After joining the cooperative in 2019 she could earn 3,000 to 4,000 RMB in a month when the workshop was running. Workshop production pauses in the busy farming season. Pay is piece-work, not a fixed monthly wage; the 3,000–4,000 RMB figure is a converted working-month total for this higher-skill load. Gender is not incidental. The makers in the room were women; wax drawing is a women's skill in this locality; the programme's name addresses mothers.

A converted month of 3,000–4,000 RMB is consistent with Table 2's complex tier, not with the ordinary home-based band. Local agricultural day labour in 2024 paid about 80–100 RMB a day for ordinary field work (weeding, planting, general harvest), 90–100 RMB for chilli and fruit picking, and 100–150 RMB, highly variable, for skilled spring-tea picking. Ordinary women farmers—the most common group, middle-aged and older—assemble only about 60–90 agricultural days a year, fragmented across spring tea in March–April and chilli, blueberry, or medicinal-herb work in June–September, and further cut by rain on Danzhai's slopes. Labourers who are called first to commercial bases may reach 100–130 days, still far short of 200. Sixty to ninety days at 80–100 RMB would give about 4,800–9,000 RMB a year from agricultural casual work. The interviewee's earlier 200–300 RMB a month from farming (about 2,400–3,600 RMB if counted across a year) is therefore a low, unstable cash return from household plots, not the 2024 base day-rate, and not Danzhai's official rural per capita disposable income of 14,082 RMB in 2023 (Danzhai County Bureau of Statistics 2024).

Mama Makes itself pays by the piece. A 2024 inquiry at the cooperative distinguished three product tiers (Table 2). Ordinary stay-at-home mothers, the main workforce, rarely work a full eight-hour day. Effective handicraft time is usually three to five hours; farming days compress it further. Most women mix simple and medium orders.

Table 2. Piece rates and daily output at Mama Makes, Danzhai, 2024 inquiry. Home-based figures assume housework; they are not eight-hour workshop shifts.

Tier (2024)	Typical goods	Piece rate (RMB)	Full 8-hour day	Home-based day (with housework)	Converted daily return (RMB)
Simple	Sachets, small ornaments, easy embroidered slips, bookmarks; main work for ordinary women	8–22 / piece	3–6 pieces	1–3 pieces	8–66; commonly 30–50
Medium (order mainstay)	Batik squares, simple scarves, small bags, simplified motifs	30–70 / piece	1–2 pieces	0.5–1 piece (half-days)	15–70
Complex (skilled core only)	Large batik yardage, dense Miao embroidery, traditional scarves, costume parts	100–300+ / piece	Cannot finish one piece in a day (1–3+ days)	2–5 days per piece	20–100

On that schedule, an ordinary woman mixing simple and medium work, at about 60–100 RMB of labour a day across 80–140 effective handicraft days, takes home about 4,800–14,000 RMB a year from the cooperative. The upper bound meets Danzhai's 2023 rural per capita disposable income; the lower bound does not. The forty-six-year-old interviewee belongs to the skilled core. Complex pieces pay 100–300 RMB or more but take one to three days, or two to five days at home; a converted working month of 3,000–4,000 RMB implies sustained complex work rather than the common home-based day of 30–50 RMB. The two figures describe two positions in the same piece-rate system: typical stay-at-home mothers on simple and medium orders, and a smaller group who can still take traditional, high-skill cloth. They should not be averaged. Even the skilled month, however, does not approach the 4,800 RMB retail price of a single MsMIN oilcloth coat unless several such months are stacked; and He Yang's reconstructions, which hold that skill as cut, were not for sale at all.

Figure 9 sets out only the flows the author can confirm. Materials (wax, cloth, dye pots) meet women artisans in piece-work across three product tiers. Cloth products leave for sale and teaching; they are not sold as full costume replicas. Typical home-based return in 2024 is about 30–50 RMB a day and 4,800–14,000 RMB a year, pausing when farming peaks. Study-tour fees enter the cooperative, whose principal is Zhang Yiping; students keep their work and may alter motifs. Income is a mix of government subsidy and market orders. The cooperative supplies Guizhou Lanjin Dyeing Art Co., Ltd., with livestream retail as an additional channel. The diagram's bottom band is the misalignment claim: agricultural day labour competes for the same calendar; Mama Makes has no partnership, commission, or co-branding with MsMIN, so the Oilcloth sign conversion does not enter this workshop as orders or wages; and He Yang's unsold reconstructions were not used here (Bistagnino 2011; Jones 2014; Sevaldson 2011).

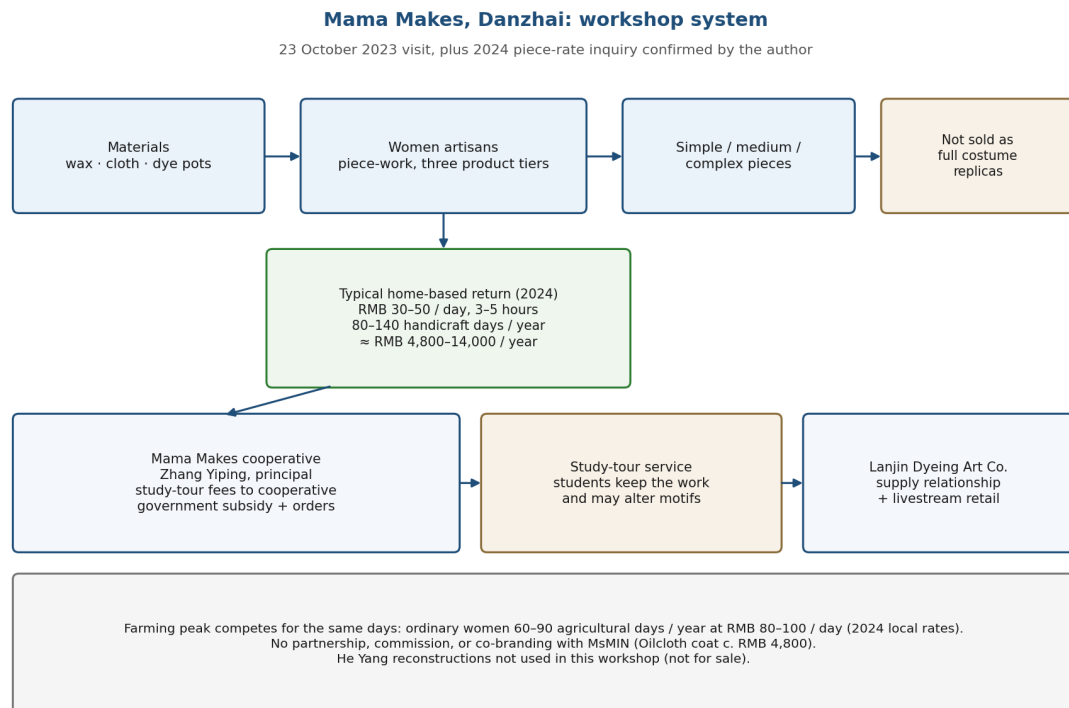


Figure 9. Confirmed material, labour, teaching, and market flows at Mama Makes, Danzhai. Piece-rate and farming-day figures: 2024 inquiry. Bottom band: no MsMIN partnership; He Yang reconstructions not used in the workshop. Source: drawn by the author.

Sanders and Stappers's caution applies. Visitors who draw wax are co-creators of an experience, not automatically co-authors of the craft's future (Sanders and Stappers 2008). If the cooperative's products slide toward souvenirs emptied of structural thought, the labour gain will have been real and still incomplete. The workshop slice shows that culture and livelihood can be organised as one process in a room in Danzhai. It does not show a commercial relationship with MsMIN, nor that this process already includes high-fashion sign conversions or the structural demonstrations of the academy.

10. Misalignment rather than a Single Path

Read together, the three mediations are not interchangeable tools and are not, on present evidence, three positions inside one local heritage field. They have different strengths and different relations to sign, structure, and labour (Table 1). High-end branding works the sign layer with great fluency and can quote structure; it does not show local labour. Structural reconstruction works the ethics of cloth and cut; it does not wage Danzhai makers and it may change the material system. Community making wages and teaches; it is territorially bounded, and in the slice observed it did not carry the full structural lesson of costume. Sustainable design for Miao batik is therefore not a matter of choosing one path, nor of declaring a division of labour in which community is foundation, aesthetics soul, and brand window. That triad would be a plan for a system that has not been evidenced. What has been evidenced is misalignment.

Table 1. Layered object analysis of three design mediations of Miao indigo costume.

Mediation	Relation to Danzhai	Sign layer	Structure layer	Labour layer	What remains untouched
MsMIN (fashion branding)	Contrast: no documented Danzhai production; no partnership with	High: liangbu sheen and batik florals recoded in 2024 Oilcloth / Modern Oilcloth	Quoted: whole-width cut, simple seaming	Not shown as local; coat c. RMB 4,800	Wax-resist encounter; village wage; everyday wear

	Mama Makes				
He Yang team (structural reconstruction)	Contrast: southwest Miao research, not a Danzhai workshop	Mixed: silhouette held; print may replace wax	High: yifang bu, continuous planes, little waste	Academic labour; reconstructions not for sale	Danzhai livelihood; indigo-resist material ecology
Mama Makes (community making)	Situated: 23 Oct. 2023 slice; Zhang Yiping principal	Teachable motif on simple/medium goods; students may alter; ceremonial grammar thinned	Not the lesson observed	Piece-work, 3 tiers; typical home 30–50 RMB/day (4,800–14,000 RMB/year); skilled core (interview) 3,000–4,000 RMB in a working month on complex pieces; farming-peak pause	Reach beyond locality; costume structure; no MsMIN partnership; He Yang reconstructions unused here

Two implications follow for design knowledge. First, technical enablement is layer-specific. Nylon that holds a sheen, silk that holds a silhouette, and a study-tour that holds a wax pot each enable something. None enables the whole practice. Designers who report a layer change as a system change overwrite the craft in the very language of saving it (Fry 2009; Walker 2011). Second, feedback among layers is an empirical question. It would count as feedback if a brand commissioned Danzhai wax drawing rather than only quoting its signs; if reconstructions were taught in the cooperative as well as in lectures; if study-tour fees and product orders paid for structural costume, not only for motif souvenirs. Those mechanisms are not in place between Mama Makes and MsMIN, and they were not observed with He Yang's reconstructions. They remain possible as future design work. Possibility is not a finding.

The evaluation criterion offered at the end of many heritage-design essays—whether makers still recognise themselves in the cloth that travels—can now be used rather than merely quoted. On the MsMIN garments, Danzhai makers are not shown as authors. On He Yang's reconstructions, makers are present as a historical intelligence of cutting, not as living wage-earners in Danzhai. In the Mama Makes room, makers are present, paid, and teaching, but the cloth that visitors take away is often a student exercise. None of the three mediations, in this material, fully meets the criterion. That is a more precise result than a call for collaboration.

Conclusion

Set against the thinning of everyday indigo dress and the thickening of fashion and tourism around its signs, this article has taken Danzhai Miao batik as a case of layered design change. Three questions organised the argument: which mechanisms of branding, reconstruction, and community making actually operate; which layer—sign, structure, or labour—each touches; and what follows if the three do not recombine. The discussion has not read the three as complementary recipes. It has read them as mediations that repair different damages and that, in the evidence assembled here, remain misaligned.

Three conclusions follow. First, living transmission of costume cannot be separated from present life, but present life has more than one design layer. A form that cannot be inhabited, paid for, or taught will not be kept; a form that is only photographed, only reconstructed, or only experienced for an afternoon is kept as something else. Second, the three mediations are unequally situated. Only Mama Makes was observed in Danzhai, and only as a one-day slice. MsMIN and He Yang are contrastive design analyses; MsMIN is not a partner of Mama Makes. Collapsing the three into pathways currently shaping Danzhai would repeat the extraction the article criticises. Third, the substance of sustainable design here is not a balance declared in advance among community, aesthetics, and brand. It is the discipline of saying which layer has been changed. Designers who wish to connect the layers will have to show the connecting mechanism—orders, teaching, attribution, wages—rather than the hope that visibility, ethics, and livelihood will support one another because they ought to.

The layered object-analysis protocol is offered as a working method for other craft mediations, not as a closed programme. Its test, in Danzhai as elsewhere, remains whether makers still recognise

themselves—and can still make a living—in the cloth that travels. On present evidence they do so most nearly in the workshop, least of all in the lookbook, and only as historical intelligence in the reconstruction. That distribution is the article's finding.

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13. Ethics statement

The 23 October 2023 visit comprised observation in a public teaching workshop and one conversation with a woman textile artisan, aged forty-six, who takes technically demanding piece-work, about livelihood. Informed consent was obtained for the interview of 23 October 2023 and for publication of the workshop photographs (Figures 7 and 8). The interviewee reviewed the Chinese wording of the passages concerning age, skill tier, piece-work, the farming-season pause, and the income range, as well as the photographs, and gave written consent to their publication. Identifying details beyond age, gender, skill level, and the consented income range are withheld. Written informed consent for publication of identifiable details was also obtained from the cooperative principal on the Taylor & Francis consent-to-publish form. Formal institutional ethics review was not obtained for this short visit; the author treats that as a remaining limitation for further fieldwork. Income figures are reported as a single life-history and are not generalised to ordinary home-based workers. Signed consent forms are retained by the author and are available to the journal editorial office on request.

14. Figure permissions

Figures 1–4 are reproduced with written permission of MsMIN, obtained by email; the correspondence is retained by the author and is available to the journal editorial office on request. Figures 5–6 are reproduced with permission from the Huaxia Yichang lecture documentation / He Yang team. Figures 7 and 8 are the author's photographs, published with the written informed consent described in the Ethics statement. Figure 9 is drawn by the author.

15. Data availability statement

Interview notes are not deposited in a public repository in order to protect the interviewee. Reasonable requests to the author will be considered in anonymised form.

16. Use of generative AI

Generative AI assistance was used in restructuring an earlier draft, integrating English-language design-research literature, and standardising Chicago author-date references. The author reviewed the manuscript and remains responsible for the accuracy of field observations, case descriptions, citations, and all statements of consent and permission.

References

Barthes, Roland. 1990. *The Fashion System*. Translated by Matthew Ward and Richard Howard. Berkeley: University of California Press.

Bistagnino, Luigi. 2011. *Systemic Design: Designing the Productive and Environmental Sustainability*. 2nd ed. Bra: Slow Food Editore.

Cross, Nigel. 2006. *Designers' Ways of Knowing*. London: Springer.

CYOL (China Youth Online). 2020. "Guizhou Danzhai: Zhijian shang de tuopin shiyan [Danzhai, Guizhou: A poverty-alleviation experiment at the fingertips]." China Youth Online, 22 October 2020. http://article.cyol.com/news/yuanchuang/2020-10/22/content_18823580.htm. (in Chinese)

Danzhai County Bureau of Statistics. 2024. "Danzhai xian 2023 nian guomin jingji he shehui fazhan tongji gongbao [Statistical bulletin on the national economic and social development of Danzhai County, 2023]." Rural per capita disposable income 14,082 RMB. (in Chinese)

Fry, Tony. 2009. *Design Futuring: Sustainability, Ethics and New Practice*. Oxford: Berg.

He, Yang. 2023. "Jijian xinxiang: 'Yifang bu' Zhongguo chuantong fuzhuang jiegou sheji yanjiu [Minimal mind-image: Research on 'one piece of cloth' in traditional Chinese garment structure]." Public lecture, Huaxia Yichang academic series / Donghua University Press livestream, 20 April 2023. <https://dhupress.dhu.edu.cn/2023/0626/c17161a327516/page.htm>. (in Chinese)

Jones, Peter. 2014. "Systemic Design Principles for Complex Social Systems." In *Social Systems and Design*, edited by Gary S. Metcalf, 91–128. Tokyo: Springer.

Kawamura, Yuniya. 2005. *Fashion-ology: An Introduction to Fashion Studies*. Oxford: Berg.

Li, Xin, and Yang He. 2018. "Miaozu fuzhuang zhong de fangxing jiegou yanjiu: Yi guanshouyi weili [Square structure in Miao dress: The case of the poncho-style garment]." In *Zhongguo fushi zhi mei [The beauty of Chinese dress]*, proceedings of the 4th symposium of the Textile Relics Committee of the China Cultural Relics Academy. (in Chinese)

Liu, Min. 2018. Interview and profile in "Chasing the Pavement." China Daily, 28 August 2018. <http://www.chinadaily.com.cn/a/201808/28/WS5b85021ca310add14f388387.html>.

Manzini, Ezio. 2015. *Design, When Everybody Designs: An Introduction to Design for Social Innovation*. Cambridge, MA: MIT Press.

Mazzarella, Francesco, Val Mitchell, and Carolina Escobar-Tello. 2017. "Crafting Sustainable Futures: The Value of the Service Designer in Activating Meaningful Social Innovation from within Textile Artisan Communities." *The Design Journal* 20 (sup1): S2935–S2950. <https://doi.org/10.1080/14606925.2017.1352803>.

Prown, Jules David. 1982. "Mind in Matter: An Introduction to Material Culture Theory and Method." *Winterthur Portfolio* 17 (1): 1–19.

Sanders, Elizabeth B.-N., and Pieter Jan Stappers. 2008. "Co-creation and the New Landscapes of Design." *CoDesign* 4 (1): 5–18.

Sevaldson, Birger. 2011. "GIGA-Mapping: Visualisation for Complexity and Systems Thinking in Design." Nordes 2011: 4th Nordic Design Research Conference, Helsinki.

Song, Junhua. 2023. "Kechixu fazhan linian yu feiwuzhi wenhua yichan xitongxing baohu [The idea of sustainable development and the systematic safeguarding of intangible cultural heritage]." *Wenhua Yichan* (3): 1–8. (in Chinese)

UNESCO. 2003. *Convention for the Safeguarding of the Intangible Cultural Heritage*. Paris: UNESCO.

Walker, Stuart. 2011. *The Spirit of Design: Objects, Environment and Meaning*. London: Earthscan.

Walker, Stuart. 2014. *Designing Sustainability: Making Radical Changes in a Material World*. London: Routledge.

Zhan, Xiaofang, Stuart Walker, Ricardo Hernandez-Pardo, and Martyn Evans. 2017. "Craft and Sustainability: Potential for Design Intervention in Crafts in the Yangtze River Delta, China." *The Design Journal* 20 (sup1): S2919–S2934. <https://doi.org/10.1080/14606925.2017.1352802>.

Zhang, Yuwei. 2020. "'Mama zhizao': Zhuli feiyi jiyi zouxiang shanwai da wutai ['Mama Makes': Helping ICH skills toward a larger stage]." *People's Daily Online*, 25 August 2020. <http://pic.people.com.cn/n1/2020/0825/c433146-31836108.html>. (in Chinese)

Zhu, Shangshang, and Shijian Luo. 2013. "Chanpin sheji zhong jiyu sheji fuhaoxue de wenwu yuansu zaizao [Re-creation of cultural-relic elements in product design based on design semiotics]." *Zhejiang Daxue Xuebao (Gongxue Ban)* 47 (11): 2065–2072. (in Chinese)

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Yixin Long is a graduate student at the School of Arts, Soochow University. Her research concerns folk art and the innovative transmission of cultural heritage, with particular attention to how minority textile practices can enter contemporary life without being reduced to portable ornament. This paper grows out of fieldwork in Danzhai and from a longer interest in the meeting of Eastern design ethics with present-day making.



Cinema Across Cultures: Understanding Differences Through Film

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Abstract

This research explores how *Parasite*, *In the Mood for Love*, and *The Intouchables* use cinematic techniques to convey cultural differences and invite viewers to engage with unfamiliar perspectives. The chosen films come from three different cultural contexts: *Parasite* from South Korea, *In the Mood for Love* from Hong Kong, and *The Intouchables* from France. This topic is important because films do not only tell stories through plot, but also present culture through environment, behavior, language, sound, wardrobe, visual style, and imagery.

I used a qualitative comparative film case study approach. The analysis was organized around four shared categories: environment, communication and social rules, visual techniques, and character perspective. These categories were applied consistently across the three films to compare how each constructs cultural difference and may invite viewers to engage with unfamiliar perspectives.

The findings show that the three films convey cultural differences in various ways. *Parasite* presents Korean class inequality through housing, social hierarchy, and family survival. *In the Mood for Love* presents Hong Kong's social restraint through silence, wardrobe, shared living spaces, and repeated visual patterns. *The Intouchables* presents French class differences, disability, race and friendship through humor, direct communication, and contrasting social environments. Overall, this research suggests that cinema can potentially facilitate intercultural understanding by presenting cultural differences through emotionally and visually accessible forms rather than presenting them as the same.

Keywords

Intercultural Understanding; Cultural Difference; Film Analysis; Visual Storytelling; Audience Empathy; Cross-Cultural Cinema

Introduction

Film is an important field for exploring how cultural perspectives are represented and made accessible to viewers. Film does not only tell stories, but also presents culture through environment, behavior, language, sound, wardrobe, and visuals. I am interested in this question because films can make unfamiliar cultures relatable while still preserving the details that make each culture unique.

My personal experience also connects to this research question since I have lived and studied across different cultural environments including Korea, China, and France throughout my childhood. This has led me to often experience how people from different backgrounds can misunderstand each other, even when they are trying to communicate. At the same time, I have also seen how stories and shared emotional experiences can help people understand perspectives that are different from their own. This made me interested in how film can act as a bridge, connecting cultures without erasing the differences between them.

The main concepts explored are cultural differences and understanding, narrative perspective, and audience empathy. Although cultural differences and understanding might seem like similar ideas, cultural differences refer to the specific values, behaviors, social expectations, and environments that shape the characters' lives. On the other hand, cultural understanding indicates the audience's ability to recognize and interpret perspectives different from their own. Narrative perspective and potential audience empathy are important because they help explain how films position viewers to engage emotionally with characters whose cultural backgrounds or social situations may be unfamiliar.

The main research question guiding this study is: **How do *Parasite*, *In the Mood for Love*, and *The Intouchables* use cinematic techniques to convey cultural differences and invite viewers to engage with unfamiliar perspectives?** This study argues that the three films convey cultural differences



through distinct uses of environment, communication and social rules, visual techniques, and character perspective, while potentially inviting viewers to engage with unfamiliar perspectives without presenting different cultures as the same.

Literature Review

Cinema may facilitate cross-cultural understanding by allowing audiences to enter unfamiliar cultural situations, emotionally connect with characters, and interpret perspectives different from their own. Deardorff's (2006) article defines intercultural competence as more than simply learning facts about another culture. She argues that understanding another culture also involves being able to interpret different perspectives and communicate across cultural differences. This framework can help explain how films may encourage engagement with characters from unfamiliar cultural backgrounds. Green and Brock (2000) explain why stories can affect audiences emotionally. Their concept of narrative transportation suggests that audiences can become absorbed in a story through attention, imagery, and emotion. This provides a framework for considering how narrative engagement may support viewers in interpreting characters from cultures different from their own. Gao et al. (2024) focus on cross-cultural film understanding and cultural distance. Their study shows that audiences may experience foreign films differently depending on factors such as setting, translation, non-verbal expression, visuals, music, plot, theme, and ending. This is relevant to my research because it demonstrates that cultural distance can influence how foreign films are interpreted.

While these sources provide frameworks for understanding audience engagement and intercultural interpretation, other research examines how films construct cultural meaning through cinematic form. The potential for audience empathy may come not only from narrative content, but also from visual and non-verbal details that guide viewers toward possible cultural meanings.

Films convey cultural differences not only through dialogue, but also through visual details, non-verbal behavior, environment, wardrobe, time, and cinematic style. Kiaer and Kim (2022) argue that foreign-language film viewers can become "multimodal translators" (p. 2), interpreting cultural meaning through both verbal and non-verbal elements. This connects with *Parasite*, where hierarchy, politeness, social class, posture, and social interaction may not be fully communicated through dialogue or subtitles alone. Sutandio (2020) argues that visual signs, cinematography, and mise-en-scène in *In the Mood for Love* support the theme of restraint. Tight spaces, wardrobe, repetition, and visual symbols can therefore position viewers to perceive the characters' emotional and social restrictions. Nakama (2009) connects Wong Kar Wai's films to temporality, memory, identity, and Hong Kong's cultural uncertainty. This is relevant to *In the Mood for Love*, which uses time, repetition, nostalgia, and memory to create a culturally specific representation of 1960s Hong Kong.

Research focused on the individual films provides further support for these ideas. Lim's (2019) interview with Bong Joon-ho connects *Parasite* to family, class, and environment. Bong explains that class is a theme that "penetrates our times" and discusses his own experience tutoring in a wealthy home. He also emphasizes his attention to environment and spatial design, which is reflected in the film's use of the Park house, the Kim family's semi-basement, stairs, and underground spaces. Ridgeway-Diaz et al. (2020) further connect *Parasite* to repression and hidden social tensions, providing a framework for interpreting the film's class anxiety and conflicts beneath everyday family life.

Wigley's (2025) interview with Wong Kar Wai supports interpretations of restraint, silence, hidden emotion, and visual storytelling in *In the Mood for Love*. Because Wong discusses the film retrospectively, the interview also provides insight into the director's approach to visual and emotional restraint. Fişek (2018) examines *The Intouchables* through race and class in contemporary French society and discusses how interpretations of the film can differ across cultural contexts. This is especially relevant because it demonstrates that cultural representation does not automatically produce the same response among all viewers.



Existing research therefore provides several useful but separate approaches to understanding the relationship between cinema and cultural difference. Deardorff's (2006) framework provides a way to define intercultural understanding, although this study applies the concept to film analysis rather than testing intercultural competence among actual film audiences. Green and Brock's (2000) concept of narrative transportation provides a framework for considering emotional engagement, while Kiaer and Kim (2022) demonstrate the importance of verbal and non-verbal interpretation. Gao et al. (2024) provides audience-based evidence that cultural distance can shape the reception of foreign cinema, although their study focuses on *Silenced* rather than the three films examined here.

At the same time, research on *Parasite*, *In the Mood for Love*, and *The Intouchables* generally examines the films individually rather than comparing how different cinematic forms construct cultural difference. Existing studies therefore tend to examine audience response, intercultural understanding, or individual film techniques separately.

This study addresses that gap by bringing these approaches together through a comparative textual analysis of three culturally and generically distinct films: *Parasite*, *In the Mood for Love*, and *The Intouchables*. It compares how the films use environment, communication and social rules, visual techniques, and character perspective to construct cultural difference and potentially invite viewers to engage with unfamiliar perspectives.

Methods

This research uses a qualitative comparative film case study approach to analyze *Parasite*, *In the Mood for Love*, and *The Intouchables* as culturally specific works. Rather than using numerical data or measuring audience responses, the study focuses on how each film constructs cultural meaning through environment, communication and social rules, visual techniques, and character perspective.

The three films were selected as deliberately contrasting cinematic cases rather than as equivalent representations of three national cultures. *Parasite* is a South Korean class thriller that uses social space and family conflict to explore inequality; *In the Mood for Love* is a Hong Kong art-house romance that uses restraint, repetition, and visual style to represent social expectations; and *The Intouchables* is a French comedy that approaches class, race, disability, and social difference through humor and friendship. Their differences in genre, tone, and cultural context make them useful for comparing how distinct forms of cinema represent cultural difference through environment, communication and social rules, visual techniques, and character perspective. *The Intouchables* is also treated as a more contested cultural representation because its depiction of race, class, and disability has produced different interpretations across cultural contexts.

The analysis was organized around four shared categories: environment, communication and social rules, visual techniques, and character perspective. These categories were applied to all three films so that similarities and differences could be compared consistently. Environment was used to examine how spaces reflect social structures; communication focused on dialogue, silence, humor, body language, and social expectations; visual techniques included framing, camera movement, wardrobe, sound, and spatial contrast; and character perspective examined how the films represent experiences such as class pressure, restraint, disability, race, and social belonging.

Scenes were selected when they met at least one of three criteria: they clearly represented a cultural or social difference, revealed conflict between characters or social groups, or significantly developed the representation of a character's social position or perspective. Six primary focal scenes were examined in detail: three from *Parasite*, two from *In the Mood for Love*, and one from *The Intouchables*. Additional scenes were used as supporting examples when they reinforced patterns identified in the focal scenes.



Each focal scene was examined using the same process. First, I identified the cultural or social issue represented in the scene. Second, I analyzed the cinematic choices used to construct that representation, such as setting, framing, sound, costume, dialogue, or performance. Third, I considered how these choices shaped the representation of the characters and their relationships. Finally, I compared the findings across the three films to identify similarities and differences in how cultural experiences were represented.

This method allows the films to be compared systematically without treating their cultural contexts as identical. It also keeps the findings focused on what can be demonstrated through textual film analysis: what the films represent, how cinematic form constructs that representation, and how those choices may invite viewers to interpret unfamiliar perspectives.

Results and Discussion

This research shows that *Parasite*, *In the Mood for Love*, and *The Intouchables* convey cultural differences through environment, communication, visual techniques, and character perspective. Although the three films come from different cultural backgrounds, they each make culture visible through everyday details and cinematic form. Cultural difference is not only expressed through national identity, language, or setting. It is also expressed through characters' movement within their environments and their responses to social expectations. The films do not erase the differences between Korean, Hong Kong, and French societies. Instead, they preserve cultural specificity while presenting emotional experiences that viewers may recognize or engage with.

Across the three films, cultural differences are presented in ways that may make unfamiliar perspectives more accessible to viewers. *Parasite* presents Korean class inequality through housing, family survival, education pressure, and formal social behaviors. *In the Mood for Love* presents Hong Kong social restraint through silence, costume, tight spaces, and repeated visual patterns. *The Intouchables* presents differences involving class, race, disability, humor, and friendship within French society. Rather than directly explaining each cultural context, the films invite viewers to observe how culture shapes the characters' lives.

In *Parasite*, the Kim family is a lower-income family living in a semi-basement apartment, while the Park family is wealthy and lives in a modern mansion. Much of the film's conflict comes from the Kim family entering the Park household through service jobs, which exposes the class gap between them. *In the Mood for Love* develops emotional connection through Mr. Chow and Mrs. Chan, married neighbors in 1960s Hong Kong, after suspecting that their spouses are having an affair. Their relationship is shaped by social pressure, reputation, and emotional restraint. In *The Intouchables*, Philippe is a wealthy disabled aristocrat, while Driss is a working-class caregiver from a different racial and social background. Their friendship becomes the main way the film explores class, disability, race, humor, and understanding.

Environment & Cultural Differences

Environment is one of the most important ways the three films communicate cultural differences. In all three films, setting is not just a background. It becomes a social system that shows who has power and who is restricted. The settings reveal cultural values and social divisions.

In *Parasite*, the environment is central to the film's portrayal of Korean class inequality. The Kim family's semi-basement apartment immediately establishes their social position. The apartment is partly underground, cramped, and exposed to the street (figure 1a).

Figure 1a – The Kim family's semi-basement window positions the household below street level (00:04:46).

The family looks outward through a low window, meaning they are physically close to public dirt, insects, smoke, and flooding. This environment shows that poverty is not only an economic condition, but a daily



physical experience. By contrast, the Park family's house is spacious, elevated, private, and luxuriously designed. The rich home is separated from the street and from the instability outside. Bong Joon-ho's interview (Lim, 2019) supports this because he directly connects *Parasite* to family, class, and environment, explaining that class is a theme that runs through contemporary life and that he is highly conscious of spatial design in his films.

The vertical structure of *Parasite* is especially important. Characters are often moving upward or downward: up the hill to the Park house, down to the Kim apartment, and even farther down into the hidden bunker.

Figure 1b – The Park family's elevated house visually associates wealth with height and separation (00:12:32).

Figure 1c – The hidden bunker extends the film's class hierarchy further underground (01:06:59).

This vertical movement visualizes class hierarchy. The wealthy family lives above, the poor below, and the hidden man in the bunker exists even lower, almost erased from society. The film therefore conveys cultural differences through the environment rather than direct explanation. International viewers may not know every detail of Korean housing inequality, but the visual contrast between the semi-basement and the mansion offers a clear visual representation of this social division. The film uses architecture to make the Korean class structure visible.

The environment also shapes how the characters behave. In the Park house, the Kim family must perform politeness and professionalism. They must hide their real family relationships and adjust themselves to the expectations of the wealthy household. However, in the semi-basement, they speak freely, argue openly, and reveal their desperation. The change in environment affects their performance of identity. This supports the idea that cultural differences are not only shown through objects or locations, but through how people adapt themselves to social spaces.

In the Mood for Love has an environment that works differently. Instead of showing class through vertical space, Wong Kar Wai uses narrow interiors, corridors, rented rooms, and shared neighborhoods to show social restraint. The film is set largely in cramped apartments and hallways where privacy is almost impossible. Mr. Chow and Mrs. Chan live close to each other, and their shared spaces create social pressure. Neighbors are always nearby, and the proximity affects the characters' behavior in being less expressive. Their emotional connection develops in a world where they cannot openly express their feelings.

Figure 2a – The narrow shared interior reflects the characters' limited privacy and social restraint (00:24:42).

Sutandio's (2020) analysis argues that *In the Mood for Love* uses cinematography and mise-en-scène to support the idea of restraint. The article specifically identifies cramped and shallow spaces, wardrobe, and repetition as visual signs that communicate emotional limitations. This is clearly visible in the film's use of narrow hallways and small rooms. The characters often pass each other in spaces so tight that they almost touch, but the social rules around them prevent emotional or physical openness. The setting therefore communicates both desire and limitation at the same time.

The Hong Kong environment of *In the Mood for Love* also conveys cultural differences through social pressures from the community. The characters are not individuals acting only according to personal desires, but are part of a social world where reputation matters. The rented rooms, shared meals, and crowded apartment structure create an environment in which private behaviors can easily become public. This context invites viewers to interpret the characters' restraint as partly shaped by the social environment surrounding them. Their restraint is not only personal, but it is shaped by the social environment around them.



In *The Intouchables*, the environment conveys cultural difference through the contrast between Philippe's wealthy Parisian mansion and Driss's working-class neighborhood. Philippe's home is elegant and quiet and associated with inherited wealth. Driss's environment is crowded, noisy, and shaped by family responsibility and economic pressure. The film uses these contrasting spaces to present differences in class, race, and social opportunity within French society. Unlike *Parasite*, which gradually turns class conflict into thriller and tragedy, *The Intouchables* often uses comedy and warmth to show how these different social worlds interact.

The mansion in *The Intouchables* becomes a meeting point between two different social worlds. Philippe belongs to an elite environment of art, music, wealth, and formal care. Driss enters this space as someone who does not fully follow its rules. His directness disrupts the formality of Philippe's world, which brings energy and honesty into it. The contrast encourages viewers to consider both spaces differently: Philippe's mansion may appear comfortable, while being emotionally limiting. On the other hand, Driss's neighborhood may appear chaotic, but it is also connected to family, survival, and identity. Fişek's (2018) article on *The Intouchables* examines the film through race and performance in contemporary France, showing that the film's meaning depends partly on how audiences interpret Driss's performance across different cultural contexts.

Across the three films, the environment becomes a way of translating cultural differences. *Parasite* uses the environment to show Korean class hierarchy. *In the Mood for Love* uses cramped interiors to show Hong Kong's social restraint. *The Intouchables* uses contrasting French social spaces to show class, disability, and race. These environments make different forms of social pressure visible, potentially making unfamiliar cultural perspectives more accessible to viewers.

Communication & Social Rules

Communication is another major way the films convey cultural differences. The characters do not only communicate through what they say. They also communicate through silence, politeness, humor, body language, and indirectness. These forms of communication reveal the social rules of each culture.

In *Parasite*, communication is shaped by hierarchy. The Kim family must speak differently when interacting with the Park family than when speaking among themselves. They must appear respectful, professional, and controlled, even when they are manipulating the situation. Korean honorific speech and social hierarchy are important here because they structure relationships between employers and employees, older and younger people, and people of different social status. Kiaer and Kim's (2022) work on Korean film explains that foreign language film viewers often become "multimodal translators" because Korean cultural meanings are not always fully translated through subtitles. They argue that Korean films contain verbal and non-verbal meanings that may be difficult for English-speaking viewers to interpret without cultural context.

The film's class critique is not only in the plot but also in small moments of conversations or politeness. For example, the Kim family must lower themselves socially when interacting with the Parks, even when they are secretly controlling the situation. Their politeness is strategic, but it also reflects a real social structure. The scene presents class difference as not only a matter of wealth, but also of who must constantly regulate their behavior.

The concept of smell in *Parasite* also functions like communication, even though it is not a spoken language. Mr. Park repeatedly comments on Mr. Kim's smell, describing it as something that crosses a line. This becomes one of the most painful forms of class communication in the film. Body odor marks the poor body as socially unacceptable, even when the poor character is performing his job correctly. Mr. Kim understands that he is being judged not only for his work, but for something attached to his living conditions and class identity. This presents the emotional consequences of class difference through an everyday indicator.

In the Mood for Love presents communication in an even more indirect way. The film is built around what characters cannot say. Mr. Chow and Mrs. Chan rarely express their desires openly. Instead, their emotions appear through pauses, glances, repeated meetings, and silence. This form of communication reflects a social world where reputation and restraint shape behavior. The characters know that acting



openly on their feelings would make them resemble their unfaithful spouses, so they define themselves through self-control.

Wong Kar-wai's BFI (2025) interview is useful because it frames *In the Mood for Love* as a film of desire and restraint, where meaning often appears through what is hidden or unsaid. The film's dialogue is often minimal, and many of its most important emotional moments happen without direct confession. For example, when the characters rehearse how their spouses may have started the affair, they are also rehearsing their own possible relationship. Their role-playing blurs the line between investigation and desire. They speak indirectly because direct speech would break the social boundary that holds them back.

In the Mood for Love shows that sound is therefore not empty. It is a cultural and emotional form of communication. The film invites viewers to read silence as pressure, longing, fear, and self-control. For international viewers, this indirect form of communication may provide access to a social perspective that is culturally unfamiliar. Instead of presenting love through open confession, the film presents it through restraint. Meaning therefore emerges not from direct explanation, but from pauses, gestures, repetition, and what remains unsaid.

In *The Intouchables*, communication is more direct and often humorous. Driss speaks directly to Philippe and does not treat him with the careful politeness that others use around him. At first, this directness appears inappropriate within Philippe's formal upper-class environment. However, it becomes the base of their friendship. Driss's humor allows Philippe to be seen as a person rather than only as a disabled man who must be treated with care. This communication style may encourage empathy through contrast.

The film's use of humor raises questions. Driss's performance can seem liberating because he refuses stiff social rules, but it also risks relying on racial and class stereotypes by presenting him mainly through energy, humor, and physical confidence. This is why *The Intouchables* is important: it does not only show cultural difference as something positive and easily resolved. It also shows that audience understanding can be complicated. Viewers may feel empathy for Philippe and Driss while also questioning how race, class, and disability are represented. Fişek's (2018) discussion of race and performance helps support this point because the article argues that the film's reception depends on different cultural histories of race and performance.

Together, the films show that communication reveals culture in different ways. *Parasite* uses politeness and class-coded language. *In the Mood for Love* uses silence and indirect emotion. *The Intouchables* uses humor and direct communication. Each film shows that social rules influence not only what characters express, but also what they suppress.

Visual Techniques & Viewer Positioning

Visual techniques are central to how the three films position viewers in relation to unfamiliar cultural perspectives. The films do not depend only on dialogue or plot alone. They use framing, camera movement, color, wardrobe, repeated musical themes, and spatial contrast to make cultural differences emotionally relatable.

In *Parasite*, one of the most important visual techniques is vertical framing. The film repeatedly organizes characters through height and depth. The Parks are associated with elevated areas, sunlight, open rooms, and clean interiors. In contrast, the Kims are associated with low areas, darkness, disorganized rooms, and closeness to the street. This contrast visually establishes class inequality before it is directly discussed. The visual structure makes social inequality feel physical.

The controlled camera movement in *Parasite* also shapes how its class structure is revealed. Bong Joon-ho's style often feels precise and organized, which matches the film's careful social structure. The camera guides the audience through spaces in a way that reveals how the house works. The Park house appears open and beautiful, while hiding secrets as the discovery of the underground bunker changes the meaning of the house. What first appears to be a symbol of wealth becomes a layered social structure, with hidden poverty right underneath luxury.



This visual revelation recontextualizes what has already been shown. The wealthy family does not know what exists underneath them, just as they do not fully understand the lives of people who serve them. The editorial by Ridgeway-Diaz et al. (2020) supports this idea by discussing repression in *Parasite*, especially the idea that what is hidden or blocked from awareness eventually returns. In the film, the repressed social reality is not only psychological but spatial. The bunker is the hidden underside of class society.

In the Mood for Love's visual techniques work more through repetition and obstruction. The film uses slow motion, mirrors, narrow frames, repeated music, and wardrobe to create emotional restraint. Sutandio's (2020) article especially identifies visual signs in the film that support and amplify the theme of restraint, including cinematography, mise-en-scène, obstructed shots, and repeated elements.

Wardrobe is one of the clearest examples. Mrs. Chan's cheongsam is visually beautiful, but limits movements. The dress becomes more than clothing as it becomes a sign of elegance and social identity. Sutandio (2020) argues that the cheongsam shifts from a symbol of Chinese beauty into a symbol of limitation because of how tightly it controls the body. The wardrobe communicates a social world in which emotion is controlled through appearance and posture, potentially making that system of restraint accessible even to viewers unfamiliar with its cultural context.

Figure 2b – Mrs. Chan's cheongsam and framing emphasize controlled appearance and emotional restraint (00:47:36).

The repeated musical theme also shapes the film's representation of emotional restraint. The music often appears during moments of slow movement or emotional tension, guiding the audience into the characters' restrained desire. Because the characters rarely confess their emotions directly, the music functions as an emotional substitute for what the characters cannot say directly. Sutandio (2020) argues that the soundtrack helps read the restrained atmosphere of the film and contributes to the audience's experience of the characters' emotional state.

Mirrors and obstructed shots also create meaning. The characters are often seen through doorways, windows, curtains, or reflections. This visual style creates a sense of privacy, incompleteness, and forbidden observation. The camera does not give full access. Instead, it places the viewer in a position of partial understanding. This matches the characters' situation that they also cannot fully access or express their feelings. The visual technique therefore positions the viewer to perceive restraint through limited visual access rather than simply observe it as a narrative theme.

Nakama's (2009) article adds another layer by connecting Wong Kar-wai's use of time, repetition, and identity to Hong Kong's cultural uncertainty. The article argues that Wong's films often move through time in cycles rather than simple lines, creating characters who are fixed in place but wandering through memory and temporal space. This is useful in understanding why *In the Mood for Love* feels nostalgic and suspended. The film creates a mood of memory, loss, and uncertainty instead of only telling a love story. The film therefore invites viewers to engage with aspects of its Hong Kong cultural context through atmosphere rather than direct explanation.

In *The Intouchables*, visual techniques are more direct and accessible. The film often contrasts Philippe's wealthy, controlled environment with Driss's more energetic personality. The contrast between Philippe's restricted mobility and Driss's physical expressiveness visually distinguishes their social positions and personalities. Philippe has social and economic power but limited physical mobility. Conversely, Driss has physical freedom and humor, but less social and economic power. The film therefore visually places their differences side by side, acting as each other's foil.

Music also becomes important in *The Intouchables*. The contrast between classical music and popular music reflects the difference between Philippe's elite cultural world and Driss's background. Even though these musical differences are mainly used for comedy, they also show how culture is connected to class. When the characters share or challenge each other's music, the film suggests that understanding can develop through cultural exchange. However, this exchange is not equal in every aspect because Philippe still holds wealth and power. This makes the film useful for discussing both empathy and inequality.



Across the three films, visual techniques make culturally specific perspectives visible without relying entirely on direct explanation. *Parasite* uses vertical space and controlled framing to show class pressure. *In the Mood for Love* uses wardrobe, slow motion, music and obstruction to show restraint. *The Intouchables* uses contrast, performance, music, and physicality to show class, race, and disability. These techniques make cultural differences visible and emotionally understandable.

Character Perspective & Potential Empathy

The final major finding is that all three films use character perspective to create opportunities for potential empathy toward characters whose experiences may be unfamiliar to viewers. However, the basis for this potential empathy differs across the films. *Parasite* emphasizes pressure and desperation, *In the Mood for Love* emphasizes restraint and longing, and *The Intouchables* emphasizes humor, friendship, and social contrast.

In *Parasite*, the narrative encourages viewers to consider the Kim family's desperation even when their actions become morally questionable. The family lies, manipulates, and invades another household, but we understand their economic pressure which shapes their behavior. Instead of being presented as useless or harmful beings to society, they are shown as people trying to survive inside an unequal system. By connecting their morally questionable actions to economic pressure, the film may encourage viewers to interpret their deception within the broader context of inequality.

The hidden bunker couple introduces another potential point of empathy after their existence is revealed. At first, the main conflict seems to be between the Kim family and the Park family. However, the discovery of the bunker introduces another level of inequality. The Kims, who seemed to be at the bottom, are not actually the lowest. This complicates the film's initial class structure by showing members of the underclass competing against one another for survival. The conflict suggests that inequality can divide people who might otherwise share common interests.

This perspective is important to the research question because the film does not simply present information about Korean society. Instead, it uses the Kim family's experiences to place class pressure within a specific Korean social context while also connecting it to broader forms of inequality. The cultural details remain specific, while emotions such as pressure, shame, and desperation may still provide points of engagement for viewers from different backgrounds.

In the Mood for Love creates opportunities for empathy through emotional restraint. The film invites empathy with Mr. Chow and Mrs. Chan precisely through their inability to express themselves openly. Their desire is shaped by social rules, reputation, and their own moral boundaries. They refuse to become like their spouses, even though their restraint causes pain. The audience is invited to empathize with what remains unspoken.

This potential for empathy depends on patience and observation. The film does not give the viewer a direct emotional explanation. Instead, it directs attention toward repetition, wardrobe, silence, and small movements. This is important to the research question because it shows how cinematic form can invite viewers to engage with an unfamiliar perspective without directly explaining it. A viewer does not need to belong to 1960s Hong Kong society to understand the feeling of wanting something but being unable to achieve it. The film preserves cultural difference while making the emotional conflict recognizable.

Nakama's (2009) discussion of time and identity helps explain why this empathy feels connected to memory. The characters seem caught between what happened, what could have happened, and what cannot happen. Their relationship becomes something remembered almost as a souvenir, creating a reflective form of empathy. As a result, their relationship can be interpreted as something shaped by memory, regret, and possibilities that were never fully realized.

In *The Intouchables*, the relationship between Philippe and Driss creates opportunities for empathy. The film invites viewers to consider Philippe beyond his disability by emphasizing his personality, loneliness, and relationships. Driss's refusal to treat Philippe only with pity becomes important because it allows



Philippe not to be seen as a disabled patient in need of aid. Their friendship provides narrative access to Philippe's loneliness and Driss's own need for opportunity and recognition.

Figure 3 – Philippe and Driss are positioned together despite their contrasting social backgrounds (00:31:34).

At the same time, *The Intouchables* must be discussed critically. The film may create opportunities for understanding by showing friendship across class, race, and disability, while at the same time simplifying some of these social differences through comedy. Driss is often presented as energetic, physical, and humorous, whereas Philippe is associated with wealth and seriousness. This contrast makes the film accessible. Fişek's (2018) article is useful because it examines how race and performance shape different interpretations of the film in contemporary France.

While all three films are important to the paper, *The Intouchables* adds a different perspective because it shows that intercultural understanding is not always simple or complete. Unlike *Parasite* and *In the Mood for Love*, which focus more on class pressure and emotional restraint, *The Intouchables* connects cultural differences to race, disability, class, humor, and performance at the same time. This makes the film especially useful because it creates the possibility of empathy with Philippe and Driss while also inviting viewers to question how social differences are represented. Therefore, the film strengthens the argument by showing that cinema can open a space for cross-cultural understanding, but that understanding still depends on how audiences interpret the film's representation of cultural difference.

Summary

Overall, there are several films which create empathy; nonetheless, these three films suggest that potential intercultural understanding depends partly on how viewers interpret cultural signs. Environment, silence, humor, wardrobe, and body language do not explain culture directly, but they direct attention toward how culture shapes emotion and behavior. This means cinema can become a bridge between different perspectives, but the viewer still has to actively question what is being shown. Therefore, the films do more than represent Korean, Chinese, and French cultural contexts. They show that intercultural understanding is a process of observation, interpretation, and emotional response.

Conclusion

My research suggests that the potential for intercultural understanding in cinema does not come simply from showing another culture on screen. Instead, films can invite viewers to observe how culture shapes emotion, behavior, relationships, and social pressure. In the three films, cultural differences are communicated through details such as space, silence, wardrobe, humor, body language, and visual composition. These elements can make unfamiliar perspectives more accessible without reducing each culture to a simple explanation.

A key finding is that film can make cultural differences more accessible while still preserving their cultural specificity. Viewers are not asked to ignore the differences between Korean, Hong Kong, and French social contexts. Rather, the films encourage viewers to interpret those differences through emotional experiences such as pressure, restraint, loneliness, dignity, and friendship. This suggests that cinema can provide a space in which viewers encounter and interpret perspectives beyond their own.

However, this research also shows that film does not automatically create complete cross-cultural understanding. Viewers still bring their own cultural backgrounds and assumptions into the way they interpret a film. For this reason, future research could focus on how different audiences respond to the same culturally specific films. This would help further explore not only how films represent culture, but also how audiences actively create meaning from what they see.

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References

- Deardorff, D. K. (2006). Identification and assessment of intercultural competence as a student outcome of internationalization. *Journal of Studies in International Education*, 10(3), 241–266. <https://doi.org/10.1177/1028315306287002>
- Fişek, E. (2018). Rethinking *Intouchables*: Race and performance in contemporary France. *French Cultural Studies*, 29(2), 190–205. <https://doi.org/10.1177/0957155818755607>
- Gao, X., Hamed, M. A., & Wang, C. (2024). Cultural distance perceived by Chinese audiences in the Korean film *Silenced*: A study of cross-cultural receptions in film content elements. *Frontiers in Communication*, 9, 1306309. <https://doi.org/10.3389/fcomm.2024.1306309>
- Green, M. C., & Brock, T. C. (2000). The role of transportation in the persuasiveness of public narratives. *Journal of Personality and Social Psychology*, 79(5), 701–721. <https://doi.org/10.1037/0022-3514.79.5.701>
- Kiaer, J., & Kim, L. (2022). *Understanding Korean film: A cross-cultural perspective*. Routledge.
- Lim, D. (2019, November 19). Bong Joon Ho on family and class in *Parasite*, collecting films, and *Memories of Murder*. *Film at Lincoln Center*.
- Nakama, J. (2009). Time after time: Exploring temporality and identity in Wong Kar-wai's *Days of Being Wild*, *In the Mood for Love*, and *2046*. *PSU McNair Scholars Online Journal*, 3(1), Article 18. <https://doi.org/10.15760/mcnair.2009.127>
- Ridgeway-Diaz, J., Truong, T. T., & Gabbard, G. O. (2020). Return of the repressed: Bong Joon-Ho's *Parasite*. *Academic Psychiatry*, 44(6), 792–794. <https://doi.org/10.1007/s40596-020-01309-7>
- Sutandio, A. (2020). Restraining the mood for love: A semiotic analysis of Wong Kar Wai's *In the Mood for Love*. *Capture: Jurnal Seni Media Rekam*, 12(1), 1–12. <https://doi.org/10.33153/capture.v12i1.3086>
- Wigley, S. (2025, May 20). Wong Kar Wai on *In the Mood for Love* at 25 – a new interview: “Can an algorithm understand the weight of a glance between two people?” *Sight and Sound*.

Authors

Junsoo Lee is a student at the International School of Beijing. This paper examines how films represent cultural difference and how cinematic form may invite viewers to engage with unfamiliar perspectives.



Statehood As Belief: From The Floor Tile To The Historical Dynamics Of Institutional Elasticity

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Abstract

This paper starts with a classroom thought experiment. I declared a single floor tile an independent nation, with a hamster cage as its prison and a wooden stick as its military, and asked my classmates to recognize each other's "tile nations." The scene is an analogy, not a test of Engels or Weber. It shows how belief and mutual recognition can make a small, artificial order feel real.

Building on this, the paper proposes a Balance Theory of Institutions: institutions work like a scale connecting decision-makers and ordinary people. They transmit commands downward and feedback upward, but the scale always tilts toward those who hold the power of definition. The paper then develops a Triadic Model: any historical event depends on motive, condition, and institution—none can be absent.

Re-examining Marx's theory through this framework reveals three tensions. The paper argues that idealism, materialism, and institutionalism each capture one dimension of truth, and the Triadic Model stitches them together. When institutions are too strong, dynastic cycles follow; when too weak, chaos; only when they remain elastic can conditions accumulate. History is not a machine; it is a scale—tilted by those who shape belief, read by those who bear the consequences.

Keywords

State legitimacy; collective belief; balance theory; triadic model; institutional elasticity; Marxian tensions

Introduction

What is the state? Every Chinese high school student can recite the textbook answer: the state is the product of irreconcilable class contradictions and an instrument of class rule. This definition did not emerge from nowhere. Engels (1884) wrote that the state is "a power seemingly standing above society... arisen out of society but placing itself above it, and increasingly alienating itself from it." He further concluded that the state is "in all typical periods... the state of the ruling class, and in all cases essentially a machine for the oppression of the oppressed classes." Weber (1946) offered a more neutral formulation: the state is "a human community that (successfully) claims the monopoly of the legitimate use of physical force within a given territory." Both definitions converge on one direction: the state is an objective entity, sustained by material force—class relations or violence. They tell us what the state does and what it uses, but they do not tell us why people believe it is legitimate.

Research on state theory has broadly followed three paths. The materialist tradition asks whose interests the state serves; the contractarian tradition asks whence the state's authority derives; the idealist tradition asks how the state is imagined and maintained. Yet each path captures only one facet of the state; none provides a mechanism that connects them. March and Olsen (1984) treat institutions as "relatively enduring structures, rules, and conventions of political life," providing theoretical support for "institutions as connecting mechanisms." Thelen (1999) further points out that institutions are not



immutable "locked-in" states but are continually reinterpreted and enforced over time. This paper seeks to fill precisely this gap—the "missing middle."

After the Introduction, the argument is set out in seven sections. Section 1 describes the thought experiment. Section 2 proposes the Balance Theory. Section 3 develops the Triadic Model. Section 4 engages with philosophical traditions. Section 5 examines Marx through three tensions. Section 6 synthesizes idealism, materialism, and institutionalism. Section 7 illustrates the theory through cases. The Conclusion summarizes the argument.

This is a theoretical essay. It combines a classroom thought experiment with historically illustrated cases. The cases were chosen because they contrast sharply in institutional elasticity: the Chinese and British reforms in the late twentieth century, and Gu Jiawei's 2009 visit to Zhongnanhai. I do not treat these cases as a formal test of the Triadic Model; they are illustrations meant to show how the model can be used.

Results and Discussion

1. The Thought Experiment: Building a Nation on a Floor Tile and "I Oppress Myself"

I chose a single floor tile in my classroom as my "territory." Why a tile? Because it is ordinary enough that any student could claim one. My territory measured roughly one square meter, its boundaries clearly marked with chalk. I placed a wooden stick beside the tile—my "state military"—and set a hamster cage in its center—my "state prison." Then I stood up and addressed the class: "I declare this tile my nation. I formally recognize each of your 'tile nations'—provided that you recognize mine." One by one, my classmates followed suit. We reached an informal agreement: mutual recognition of sovereignty, mutual non-aggression.

When the experiment concluded, I observed three things. First, statehood can be declared. Second, statehood requires recognition to acquire legitimacy. Third, statehood is, at its core, a collective belief. More significantly, the experiment exposed a boundary condition in the Marx-Engels framework: when a state shrinks to one person, class oppression disappears—yet the state remains. I am both head of state and sole citizen; both oppressor and oppressed. I have become my own oppressor—I oppress myself.

This sounds absurd, but it hits a blind spot in Marx's theory. Marx and Engels defined whom the state serves, but they did not define whom it serves when the state consists of a single individual. According to their definition, the state requires two classes: one that rules, one that is ruled. But in the tile nation, there is only me. If the state must be an instrument of class oppression, then I am now both the ruling class and the ruled—a logical contradiction. This contradiction is not a refutation of Marx but a refinement of him: Marx explained what the state is when it is large; he did not explain what it is when it is small.

Weber offered another perspective. In *Politics as a Vocation*, he wrote: the state is "a human community that (successfully) claims the monopoly of the legitimate use of physical force within a given territory" (Weber, 1946). Under Weber's formulation, my "stick army" and "cage prison" already constitute a complete system of monopolized violence—no second class is required. Anderson (1983) went further. In *Imagined Communities*, he defined the nation as "an imagined political community." In my experiment, the tile became my territory only because my classmates and I treated it as one. When we recognized one another's tile nations, we were not engaging in coercion or contract; we were participating in an act of collective imagination. The belief became a shared reality because others took it up.

I should be clear about what this experiment can and cannot show. It is an analogy, not a boundary test of Engels or Weber. The classroom already sits inside a school and a state; my classmates' recognition is not recognition by other states, and a stick and a hamster cage are not a monopoly of



legitimate force. What the scene illustrates is how belief and mutual recognition can make a small, artificial order feel real. It does not show that a historical state can shrink to one person. Nor does it show that a state can be created by fiat. What it shows is that even a small, artificial order depends on mutual recognition—not on force alone.

Yet belief does not exist in a vacuum. It must be transmitted and sustained. The mechanism that performs this function is the institution. To understand why the state can exist on belief, therefore, we must understand how institutions transmit belief. This leads to the Balance Theory.

2. The Balance Theory: Institutions as a Scale

The Balance Theory of Institutions began with a simple observation: institutions are not neutral rules. They are transmission mechanisms. They connect decision-makers at one end and ordinary people at the other. What matters is not what an institution “stipulates” but what it “transmits.”

In the tile nation experiment, I set up a small institution through my own “declaration” and the class’s “recognition.” It occupied one square meter. Still, it did two things any institution does: it carried the belief “this is my country” to the whole class, and it turned that belief into something we all acknowledged. Institutions, at bottom, are connecting devices.

The image of a scale came later. I did not see it in the classroom. I saw it when I looked at the Chinese and British reforms. Both countries faced similar problems—state-owned enterprises in crisis. China used administrative decrees. Britain used parliamentary legislation. Different tools, similar results: workers were laid off, communities broke apart. The weight fell on ordinary people. Decision-makers were not the ones who paid. The scale tilts toward those who hold the power of definition.

“Scalar,” in English, usually means a quantity without direction, such as temperature or mass. What this paper describes is a balance: a scale that tilts. The name used here is therefore Balance Theory.

Why does it tilt? Because institutions are never neutral. The direction of the tilt depends on who sits at the “defining” end. When decision-makers are at one end and ordinary people at the other, the scale naturally leans toward the decision-makers. The design, the implementation, the interpretation—all are controlled by those who hold the power of definition. Whoever defines “legitimate” decides which way the institution leans.

But the scale is not only a one-way instrument of oppression. It also carries feedback. Commands go down; reactions come back up. Reform can produce table-pounding at the top and job-loss at the bottom at the same time. That is the scale transmitting weight from both ends.

Why a scale and not a seesaw? A seesaw is symmetrical. A scale implies weighing. In theory, decision-makers are supposed to balance the two ends—efficiency vs. equity, capital vs. labor, reform vs. stability. In practice, the tilt is set by whoever controls the definition of “legitimate.” The scale is not neutral. Its tilt is already preset.

Yet the feedback valve is not always closed. In February 2009, Gu Jiawei, a 23-year-old migrant worker who had just lost his job in Zhejiang, was invited into Zhongnanhai to speak to Premier Wen Jiabao about the draft Government Work Report. He made three requests: a portable pension system, service centers for migrant workers, and unified labor training. Wen Jiabao said his suggestions were “very important.” Less than a month later, they appeared in the official report. A laid-off worker’s voice became part of national policy.

That shows the valve can open. It does not change the overall tilt. Whether feedback travels depends on whether the institution leaves an interface open and whether decision-makers choose to open it. The scale still leans toward decision-makers. The feedback valve remains in their hands.



One more thing. "Elasticity" is a metaphor, not a law. When I say Rome was too rigid, or that Britain after 1688 was elastic, I am describing outcomes after the fact. The metaphor helps organize cases. It does not predict collapses in advance. What it does help explain is why similar material conditions can produce different reform paths—because the institutional scale transmits different weights.

3. The Triadic Model: Motive, Condition, and Institution

The Balance Theory explains how institutions transmit. It does not explain where institutions come from, why some are overthrown while others endure, or who sets the tilt of the scale. These questions need a second framework. I call it the Triadic Model.

The Triadic Model says that any historical event depends on three things: motive, condition, and institution. Motive is whether people want to do something. Condition is whether they can do it. Institution here means the rules, enforcement mechanisms, and feedback channels that decide how commands travel downward and how reactions travel upward. None of the three can be missing. I write it as: $\text{Success} = \text{Motive} \times \text{Condition} \times \text{Institution}$. If any factor is zero, the result is zero.

The model is not a copy of Marx's historical materialism. Marx puts condition first—the economic base determines the superstructure. The Triadic Model treats condition as one of three. Without motive, even good conditions do not lead to action. Without institution, even good conditions do not allow action. The model also differs from idealism. Idealism puts motive first—consciousness determines existence. The Triadic Model says motive is one of three. Without conditions, wanting alone is useless. Without institutions, wanting alone cannot travel.

I also need to subdivide "condition." It is not a single bag. It includes at least: technological condition, material condition, human condition, organizational condition, environmental condition, and historical condition. These can turn into one another. But separating them helps when analyzing a specific event.

The Triadic Model is useful because it can explain why similar conditions produce different outcomes under different institutions. When motive, condition, and institution all reach a critical point, revolution breaks out. When institutions stay elastic—able to adjust and absorb feedback—motive and condition can accumulate without overthrowing the system. The system corrects itself instead. I will illustrate this logic in Section 7.

4. Philosophical Dialogue: Engaging with Three Traditions

Before I criticize Marx, I need to say where this paper sits. Materialism captures the state's material face: violence, economic base, class interest. It explains where the state comes from but not why it persists. When the state shrinks to one person, class relations disappear—yet the state remains. Materialism cannot explain why this "one-person state" can still be called a state.

Contractarianism captures the state's consent face: Locke's "consent," Rousseau's "general will" (Rousseau, 1762). It explains where legitimacy comes from but not how institutions carry consent. In the tile nation experiment, my classmates and I did give mutual recognition. But that recognition worked not because it was a "contract." It worked because an informal institution carried it—mutual recognition of sovereignty, mutual non-aggression. Contractarianism misses this transmission mechanism.

Idealism captures the state's belief face: Hegel's "ethical idea" (Hegel, 1991), Anderson's "imagined community" (Anderson, 1983). It explains meaning but not the role of matter and institutions. When my classmates and I believed the tile was a "state," we were imagining something together. But the imagining lasted because of material conditions—the tile, the classroom, the chalk—and because of the institution of mutual recognition. Idealism misses both the material base and the institutional transmission.



The Balance Theory is a synthesis. Institutions are the glue connecting matter, consent, and belief. The state is not just a machine, not just a contract, not just an idea. It is all three. What binds them is institutions. Institutions carry the decision-maker's will into the worker's reality. They channel the general will into specific laws. They turn abstract ideas into lived belief.

"I oppress myself" is not a refutation of Marx. It is a refinement. Marx explained what the state is when it is large. The Balance Theory explains what it is when it is small.

5. Three Tensions in Marx's Theory

A more careful reading of Marx suggests three tensions. These are places where his theory, as it is usually taught, runs into trouble under certain conditions.

Tension 1: Between economic base and superstructure, there is an institutional layer.

Marx says the economic base determines the superstructure. That claim is powerful for capitalism. Applied to other periods, it needs qualification.

The High Qing is one example. According to Maddison (2007), China's GDP accounted for roughly 32.9 percent of the world total in 1820. The economic base was strong. Yet intellectual life was thin. Literary inquisitions, the eight-legged essay, and maritime prohibitions pressed hard on cultural production. Apart from *Dream of the Red Chamber* and *The Scholars*, little comparable work appeared.

Engels later qualified the claim. In his 1890 letter to Joseph Bloch, he wrote that the economic factor is not the sole determining one, and that the superstructure reacts back on the economic base. He also accepted that he and Marx were partly responsible when younger readers overstated the economic side. The High Qing example does not show that economics is unimportant. It shows that an institutional layer sits between the economy and culture.

Tension 2: Capitalism's "inevitable collapse" was postponed by institutional elasticity.

In *The Communist Manifesto*, Marx argues that capitalism is doomed. His reasoning is that crises recur, workers grow poorer, and revolution follows.

That description fit much of the nineteenth century, when many workers lived near subsistence.

Capitalism later changed. Welfare systems, trade unions, suffrage, minimum wages, and universal healthcare were added one after another. Workers did not become poorer to the point of desperation, and the motive for rebellion weakened. Capitalism did not collapse. It absorbed parts of Marx's critique and extended its own life.

This is not a claim that Marx was wrong. He saw the internal contradictions. He did not fully anticipate that institutions could adjust themselves. When institutions remain elastic, contradictions can be absorbed instead of exploding.

Tension 3: "To each according to need" assumes that needs can be historically satisfied.

In the *Critique of the Gotha Programme*, Marx says the higher phase of communism will distribute "to each according to need." He treats "need" as something that can be met. But he does not unpack it: where do needs come from? Do they change?

Marx assumes that needs can be historically satisfied. He does not show that this assumption must hold. If needs keep expanding, "to each according to need" names a condition that may never arrive.



These three tensions do not mean Marx “missed” motive and institution. More precisely: his theory is strong for large-scale, long-term history, but weak for small-scale, short-term change. His “economic base determines superstructure” works under capitalism but needs qualification elsewhere. His “inevitable collapse” needs the variable of institutional elasticity. His “to each according to need” needs to confront the historicity of needs.

The Triadic Model—motive, condition, institution—can fill these gaps. But it does not overthrow Marx. It places him inside a larger frame. His insights remain central. They just no longer carry the whole argument alone.

6. *Synthesis: Idealism, Materialism, and the Triadic Model*

The three tensions above point in the same direction. Marx put his weight on “condition.” He had less to say about motive and institution. The Triadic Model is meant to hold all three.

I want to be careful here. I am not saying materialism is wrong. The materialist tradition forces a question that is hard to dodge: who benefits from existing institutions? Marx’s answer—the bourgeoisie—remains one of the sharpest tools in political economy. The problem is not the question. The problem is when the answer becomes the only answer. When that happens, the tool loses its edge.

The High Qing shows what I mean. When institutions are strong enough, they can run on their own, almost independent of the economic base. They can crush a society’s cultural production into a desert. That does not mean the economy is unimportant. It means the economy is not everything.

Idealism has its own strength. It reminds us that people are not machines pushed by material conditions. When I declared in class that “this tile is a state,” I was not reflecting some material necessity. I was making meaning. Anderson’s (1983) “imagined community” is powerful because he saw that belief itself is productive. But idealism often makes belief sound too easy. It can sound as if changing one’s mind would change the world. The tile nation worked not only because I believed. It worked because there was a tile, a classroom, and classmates willing to go along.

Institutionalism fills the gap between belief and reality. Institutions are not just rules. They are sets of transmission mechanisms that turn belief into action and commands into consequences. But institutionalism often treats institutions as neutral—as if they were just “rules of the game.” The Balance Theory breaks that illusion. Institutions always have a direction. And that direction depends on who holds the power of definition.

Institutions are plastic because they have to carry both motive and condition. When both are changing, institutions that do not change lose their capacity to transmit. If they change too fast, they lose stability. That is a tension, not a paradox.

The “I oppress myself” absurdity is not a refutation of Marx. It is a refinement. Marx explained what the state is when it is large. The Balance Theory tries to explain what it is when it is small.

7. *Case Illustrations: From Command to Feedback, From Rigidity to Elasticity*

Section 6 argued that when motive, condition, and institution all reach a critical point, revolution breaks out. When institutions stay elastic, they can absorb pressure instead of breaking. The cases below illustrate this logic. They do not test it. I am not trying to verify the model. I am showing how it can be used.

The Chinese and British reforms are the main examples. Zhu Rongji’s SOE reform had a clear motive, used administrative decree, and met ripe conditions. According to Chinese official statistics, around 40 million workers were laid off between 1995 and 2002 (National Bureau of Statistics, 2003). Thatcher’s privatization (Thatcher, 1993) was equally clear in motive, used parliamentary legislation,



and met similar conditions. The result was the collapse of working-class communities (Jones, 2011). Different tools, similar weight. The scale tilted toward the decision-maker in both cases.

The feedback channel sometimes opens, as in Gu Jiawei's 2009 visit to Zhongnanhai, described above (Government Work Report, 2009). Feedback can travel upward. That does not make the scale neutral. The valve still sits in the decision-maker's hands.

What about the broader pattern? Rome, the Glorious Revolution, American independence, the Soviet collapse, Tocqueville's paradox—each of these could be described as too much or too little elasticity. But that description comes after the fact. I am not claiming the metaphor predicts collapse in advance. It helps organize the cases. That is all.

One more qualification. The five civilizational examples I mentioned earlier—Rome, 1688, 1776, 1991, 1789—are not all given equal weight. I mention them to show the range of the metaphor. I do not claim they all fit neatly. Rome was not Britain. The Soviet Union was not France. The point is not to explain every collapse. The point is to show that the same logic—elasticity matters—can be seen across different times and places. That is an illustration, not a proof.

Conclusion

The paper began with a classroom experiment: a floor tile declared a nation. The experiment showed that belief and mutual recognition can make a small order feel real—but not that a state can shrink to one person.

That gap led to the Balance Theory: institutions are transmission mechanisms that carry commands downward and feedback upward, yet the scale tilts toward those who define legitimacy. The Triadic Model then added motive and condition to the analysis: any historical event depends on all three.

Reading Marx through this frame revealed three tensions: the institutional layer between economic base and superstructure, the postponement of capitalism's collapse by institutional elasticity, and the unproven assumption that needs can be historically satisfied. These tensions do not refute Marx; they mark the limits of his theory for small-scale, short-term change.

The Chinese and British reforms illustrated how the scale tilts toward decision-makers. Gu Jiawei's 2009 visit to Zhongnanhai showed that feedback can sometimes travel upward. These cases illustrate the model; they do not test it.

History is not a machine. It is a scale—tilted by those who shape belief, read by those who live with the consequences. A tile remains a tile. But when enough people treat it as a state, it becomes one—in the limited sense of mutual recognition among participants.

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References

Anderson, B. (1983). *Imagined communities: Reflections on the origin and spread of nationalism*. Verso.

Engels, F. (1884). *The origin of the family, private property and the state*. Hottingen, Zurich.

Engels, F. (1891). Introduction to Marx's *The civil war in France*. In K. Marx, *The civil war in France*. International Publishers.



Government Work Report. (2009). *Report on the work of the government*. Second Session of the Eleventh National People's Congress.

Hegel, G. W. F. (1991). *Elements of the philosophy of right* (A. W. Wood, Ed.; H. B. Nisbet, Trans.). Cambridge University Press.

Jones, O. (2011). *Chavs: The demonization of the working class*. Verso.

Locke, J. (1690). *Second treatise of government*. Awnsham Churchill.

Maddison, A. (2007). *Contours of the world economy, 1–2030 AD: Essays in macro-economic history*. Oxford University Press.

March, J. G., & Olsen, J. P. (1984). The new institutionalism: Organizational factors in political life. *American Political Science Review*, 78(3), 734–749.

Marx, K., & Engels, F. (1848/1998). *The communist manifesto*. Penguin.

National Bureau of Statistics of China. (2003). *China statistical yearbook 2003*. China Statistics Press.

Rousseau, J.-J. (1762). *The social contract*. Penguin.

Thatcher, M. (1993). *The downing street years*. HarperCollins.

Thelen, K. (1999). Historical institutionalism in comparative politics. *Annual Review of Political Science*, 2, 369–404.

Weber, M. (1946). Politics as a vocation. In H. H. Gerth & C. W. Mills (Eds.), *From Max Weber: Essays in sociology* (pp. 77–128). Oxford University Press.

Zhu, R. (2011). *Selected speeches of Zhu Rongji*. People's Publishing House.

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Toward Music Medicine: A Framework for Music Features and Alzheimer's Disease

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Abstract

The incidence of Alzheimer's disease (AD) is rising rapidly, yet there aren't definitive diagnostic methods or effective interventions that can treat AD. Growing evidence shows that music can influence the brain in a positive way, but music has often been treated as an undifferentiated whole, rather than examining its individual acoustic features. This review bridges disconnected literatures to examine how isolated acoustic features can influence biological mechanisms related to AD. We first review non-AD evidence, spanning from neuroimaging, clinical disorders (anxiety, depression, and epilepsy), and cellular/rodent models, proposing that individual acoustic features may produce differential neural and physiological effects. We then synthesize AD-relevant biological pathways, including A β and tau pathology, BDNF signaling, gene regulation via miR-132, and gamma oscillations. Finally, we propose three feature-pathway frameworks linking specific acoustic features to these biological pathways implied in AD. The evidence support levels of each pathway are asymmetrical, with rhythm showing the most direct evidence, while frameworks linking rhythm to BDNF and timbre to gamma oscillations remain more indirect and inferential. These frameworks are intended as a hypothetical conceptual map to guide future feature-isolation studies that aim toward developing more precise, non-pharmacological music interventions for AD.

Keywords

Music medicine; acoustic feature; Alzheimer's disease; music-based-interventions; music therapy; precision medicine

Introduction

Alzheimer's disease (AD) is a common neurodegenerative disease among older populations that affects 11% of the population over the age of 65 and nearly half of people aged 85 years and older [1]. However, despite this prevalence, there are currently no definitive diagnostic tools or effective preventive and therapeutic interventions for AD [1].

At the same time, there is currently a growing interest in non-pharmacological approaches for AD, particularly music-based-interventions (MBI) [2]. Broadly categorized into active music therapy and receptive music medicine [3], MBIs, as well as acoustic stimuli like natural sounds, rhythmic drumming, and lullabies, have demonstrated cognitive, emotional, and social benefits across neurodegenerative populations [4,5]. Notably, many studies report that AD patients, who normally have challenges in memory recall, can still recognize familiar melodies [6,7,8,4]. Some studies also report that listening to unfamiliar music can also enhance episodic memory recall in AD patients [9,10,4].

However, although recent research has evaluated the genomic, epigenetic, biological and chemical changes induced by music on the brain, most have treated music as an undifferentiated whole [11,5,12], preventing the advancement of MBIs toward standardized, clinical prescription. Existing studies have generally categorized MBIs by intervention type or simply examined complete musical stimuli rather than individual musical features, masking the exact mechanisms at play [12,13].

However, music is, in fact, a multidimensional stimulus and can be divided into three fundamental categories: melody, harmony, and rhythm [14]. Melody refers to the pattern of pitched sounds; harmony refers to the combination of pitched sounds that forms chords; and rhythm refers to the structural arrangement of sounds [14]. The pitch itself is defined by fundamental frequencies. Timbre and tonality are also acoustic features of music, with timbre referring to the quality or color of the sound, and tonality referring to the organization of melody and harmony, giving music a certain direction [14].

The emerging field of sensogenomics, the study of how sensory stimuli influence gene expression and the genome [11] suggests that isolating these features is crucial. Overlapping yet distinct neural networks seem to process individual musical constituents [14,15]. Furthermore, several genes seem to be implicated in both music-related processes and AD [5]. To move toward prescribed, clinically standardized uses of music, we must move beyond asking if music works to how and which isolated features of music produce neurobiological effects.

In this review, we aim to bridge the disconnected literatures of feature-isolation research and AD molecular neuroscience by constructing feature-pathway frameworks that identify candidate relationships and highlight gaps for future experimental testing (Figure 1).

Figure 1. Conceptual framework and structural outline of the review. The review progresses from evidence that individual features of music can produce differential effects in non-AD contexts, to biological pathways implicated in AD, and finally to three proposed feature-pathway frameworks. An adjacent mechanism involving whole music exposure and miR-132 is considered separately because it does not isolate a specific acoustic feature. The overall framework identifies candidate relationships between specific acoustic features and AD-related biological mechanisms while distinguishing these hypotheses from broader whole music effects. The review may serve as a potential hypothesis map for future work related to developing precision music medicine for AD.

We will first look into how music and its specific features affect the brain in a non-AD context, investigating whether different acoustic features actually have differential effects. Then, the review will provide a synthesis of current research on AD-related biological pathways. The specific acoustic features and AD-related pathways will be associated in a framework. To construct these frameworks, a literature search was conducted through Google Scholar using keywords including “acoustic features of music,” “AD,” and “music-based-interventions.” Studies were selected based on their relevance to at least one of these components: (1) the effects of specific acoustic features of music, (2) biological pathways related to AD, (3) clinical effects of music-based-interventions. Studies that isolated or quantified acoustic features, directly measured biological or clinical outcomes, or provided evidence connecting music exposure to AD-related pathways were prioritized. Because direct studies linking individual music features to AD-related biological

pathways were limited, evidence from non-AD clinical populations, cellular and animal models, and related sensory stimulation studies were also considered when it provided relevant evidence. Studies examining the wider effect of music were utilized to establish a broader context, including the adjacent relationship between whole music exposure and miR-132, rather than as evidence for feature-specific framework. The three pathways were selected based on the availability of evidence connecting both sides of the framework: music features and AD-related biological pathways. Other AD mechanisms were excluded when relevant music-feature evidence was insufficient.

Results and Discussion

Differential Biological Modulation in Non-AD Context

Whole Brain

Before turning to AD-specific pathways, we first ask whether isolated features are indeed processed differentially in the brain through exploring non-AD evidence.

Alluri et al. [16] scanned the participants' brains with fMRI while they were listening to the Adios Nonino, a tango by Astor Piazzolla. Alluri and colleagues computationally extracted and selected six acoustic components that represented the main timbral, tonal, and rhythmic features of the piece. The team noted that each feature activated different, hardly overlapping regions of the brain. Timbral features activated mainly perceptual and default mode areas of the cerebrum, and cognitive areas of the cerebellum [16]. Timbral features also showed correlation with the temporal lobe, mostly when there were quick passages and complex melodies with several pitches and instruments being played [16]. On the other hand, tonal and rhythmic features engaged subcortical emotion-related structures as well as cognitive and somatomotor cerebrocortical areas [16]. These functional dissociations among acoustic features shown through computational audio analysis and brain imaging provide empirical support for the idea that individual features of music can be isolated and target specific neural regions.

Focusing specifically on rhythm, Grahn and Brett [17] made participants reproduce different types of rhythmic sequences: metric simple (the rhythms are separated in integer ratio intervals, and the accents happen at regular intervals), metric complex (the rhythms are separated in integer ratio intervals like metric simple rhythm, but accents happen irregularly), and nonmetric rhythms (the rhythms are separated in non-integer ratio intervals, and accents happen irregularly). Participants reproduced metric simple rhythms more accurately, suggesting that integer ratio intervals and regular accent intervals may induce internal beat perception [17]. For rhythms with simple integer ratios, people often perceived a pulse (around 1.5–2.5 Hz) and spontaneously moved along [15]. Neuroimaging (fMRI) further revealed that listening to metric simple rhythms increases activity across regions involved in both auditory and motor processing, such as the basal ganglia, anterior superior temporal gyri, left inferior frontal gyrus, and the pre-SMA/SMA (supplementary motor areas), more than the other rhythms, while areas like cerebellum and premotor cortex show similar activity level across all rhythm types [17]. These

findings demonstrate that mathematically different rhythms both differently and similarly engage neural circuits related to movement.

Similar to rhythms, melodies can also be mathematically quantified through the ratio of distances between consecutive pitches, known as melodic intervals [15]. Intervals based on simple ratios, such as a fifth, 3:2, generate stronger memory traces than intervals based on complex ratios, such as a tritone, 45:32 [15].

The mechanism behind how these different features produce differential neural effects could be explained by Neural Resonance Theory (NRT) [15]. According to NRT, neural oscillations synchronize and resonate with external stimuli to form stable patterns [15]. Furthermore, through attunement, neural circuits continuously adapt and align themselves to the environmental stimulus (in this case, musical patterns) over time, enabling the brain to process them more efficiently and flexibly [15].

In summary, as musical features, such as rhythm and melody, can be quantified, and neural circuits can synchronize themselves with the different musical stimulus via NRT, isolated musical features could predictably target and modulate specific brain networks.

Clinical Disorders

We now turn to clinical disorders and examine whether this feature-specific neural engagement translates to differential effects on disease-relevant symptoms.

Anxiety

Luo et al. [18] investigated the effect of tonality (major and minor key) and timbre (violin and piano) on anxiety. Among the anxiety group, major-key violin music showed the greatest anxiety reduction effect, along with gamma-band alterations and engagement of prefrontal circuits [18]. On the other hand, for the control group, minor-key piano music significantly reduced gamma waves [18]. This suggests that acoustic features may differentially affect individuals with different clinical conditions.

Luo and colleagues suggest that this anxiety reduction effect on individuals reporting anxiety symptoms may have been due to violin timbre, which is shown to be rougher and has greater frequency density than piano. Auditory roughness can cognitively be perceived as a threat or salient cue, and this may have triggered defensive responses and captured attention, possibly helping alleviate anxiety symptoms by redirecting attention from internal thoughts that evoke anxiety [18].

This study by Luo et al. [18] thus suggests how the specific physical and acoustic characteristics of timbre and tonality can induce anxiety-specific therapeutic effects.

Depression

Cheng et al. [19] studied the effects of different music genres (light, classical, atonal composition, and rock music) using mice with chronic unpredictable mild stress (CUMS)

(CUMS can create depression like behaviors in mice). Exposure to light and classical music increased sucrose preference and reduced immobility time, suggesting an improvement of depression-like behaviors, while atonal composition and rock music did not show these effects [19]. This suggests that specific tonality, rhythm, and roughness constituting a genre were significant in inducing these antidepressant effects.

From a biochemical perspective, music shown to have antidepressant effects also showed enhanced Brain-Derived Neurotrophic Factor (BDNF) signaling, synaptic proteins, and neurogenesis [19,20].

Furthermore, on a neural-circuit level, these features seem to interact with cortical rhythms, especially gamma oscillations. Gamma oscillation and high gamma oscillations have emerged as biomarkers for major depression, with therapeutic recovery in both human treatments and animal models being linked to gamma power alterations [21]. In fact, many treatments, both pharmacological and non-pharmacological, alter gamma oscillations, and changes in gamma have been associated with recovery in animal models [21]. Given that major-key violin music modulates gamma oscillations [18], and neural circuits resonate with external stimulus via NRT [15], it may be possible that specific acoustic features of music could alleviate depressive symptoms in a similar way pharmacological treatments do.

However, one confounding factor is that depression is not uniformly linked with a simple increase or decrease in gamma power. For instance, serotonergic drugs suppress gamma, while noradrenergic drugs increase gamma power [21]. This divergence suggests that individual depressive states may be characterized by distinct circuit-level dysregulations, connecting to why certain patients respond to specific drugs while others do not [21]. These findings again highlight the necessity of individualized music medicine that can be precisely targeted to the individual's unique profile.

Epilepsy

Štillová et al. [22] investigated the effects of musical features on epileptiform discharge (ED) by playing Mozart's Sonata for Two Pianos K. 448 and Haydn's Symphony No. 94 to epileptic patients. The acoustic features of the pieces, the rhythmic, dynamic, and timbre musical features, were parameterized and analyzed [22].

In general terms, listening to Mozart's piece decreased EDs by 32%, while listening to Haydn's piece increased EDs by 45% [22]. When discussing the beneficial effects of music, many theories propose an explanation with the activation of the cerebral reward system [22]. However, as patients did not report any significant preference to the compositions, it is unlikely that one specific composition caused a differential level in pleasure and thus a difference in the level of released dopamine [22]. Instead, the different physical features of each composition may have affected EDs through affecting brain oscillations [22]. Computational audio analysis also revealed that Mozart's K. 448

features a more harmonic spectrum, lower and more stable auditory roughness, and a higher long-term periodicity. These specific musical features, particularly the periodicity and repetition, may resonate with brain oscillations and suppress abnormal discharges [22]. Importantly, Štillová et al. [22] noted that K. 545, another piece by Mozart also shown to have antiepileptic effect, shares similar spectrogram characteristics with K. 448. This structural resemblance strongly suggests that the antiepileptic effect may be driven by specific acoustic features (in this case, a group of specific elements) within a sound.

In addition, the acoustic elements that seemed to be correlated with decrease in EDs were different for men and women [22]. Men and women were each sensitive to different acoustic elements; for instance, men were sensitive to dissonance and high-frequency parts, while women were more sensitive to dynamics [22]. Although this research does not clearly show specifically which musical element leads to a decrease or increase in EDs, or rather if the change is an emergent outcome of several acoustic elements combined, it suggests that certain acoustic features can modulate brain activity and highlights the necessity of designing feature-optimized, sex-specific musical interventions for neurological disorders.

Experimental Models

Cellular Models

Experiments with cellular models have also shown how acoustic features of music can influence models that lack auditory systems. In a study by Ramírez-Rivera and Bernal [23], AGS gastric cancer cells were exposed to metal and classical music. The study showed that proliferation of AGS gastric cancer cells increased in metal music [23]. Music seems to also be able to induce changes in gene expression associated with apoptosis and cell-cycle control, while these changes are slightly different for each genre [23]. Although the mechanisms are not completely understood yet, the frequencies and amplitudes composing the specific genre may have differentially affected gene expression, which in turn may have led to changes in proliferation of cells. Indeed, Brun and Exbrayat [24] suggest that fluids in cells are sensitive to pressure changes, which can also be caused by sound waves. These studies suggest that some features of music, such as frequency and amplitude, can act as physical stimuli and affect cells, even without going through the auditory cognition process.

Rodent models

A study by Zhang et al. [25] compared the effect of classical music (Mozart K. 448), white noise, and control (silence) in mice. While exposure to Mozart's K. 448 increased body weight, positively affected the composition of gut microbiota and immune responses, white noise had the opposite effect [25]. Although the specific elements constituting K. 448 was not the main focus of the study, this study shows how a very specific type of

sound (white noise) can differentially modulate stress pathways and gut-brain axis function.

Together, evidence from neuroimaging, clinical studies, and cellular/rodent models suggests that music, a stimulus constituted of multiple sub-features, does not act uniformly; instead, the isolated features may engage distinct neural and molecular mechanisms. We now turn to the specific biological pathways implicated in AD, before asking whether these feature-specific effects observed in non-AD contexts can be extended to AD-related mechanisms.

AD Related Pathways

Figure 2. Biological pathways implicated in Alzheimer's disease considered in this review. The diagram summarizes four pathways selected due to their relevance to both music-related research and AD biology: A β and tau pathology, BDNF, miR-132, and gamma oscillations. Arrows indicate the proposed direction of biological relationships discussed in the text. The red color represents negative outcomes that may be related to worsening of AD. The green color represents positive outcomes that may be related to potential improvement or prevention of neurodegenerative changes in AD. The figure summarizes AD mechanisms in current literature.

A β and Tau Pathology

Broadly, AD pathology is characterized by the aggregation of two proteins, A β and tau [1]. These proteins respectively form insoluble, extracellular A β plaques and intracellular neurofibrillary tangles (NFT) [1,26].

A β plaques form due to an abnormal cleavage of amyloid precursor proteins (APP) [27] (Figure 2). Normally, APP is cut by α -secretase and produces harmless fragments; however, when APP is processed by β -secretase and γ -secretase, amyloid beta peptides are released, eventually developing larger plaques [27]. On the other hand, tau is a microtubule associated protein that is normally involved in stabilizing microtubules and promoting axonal growth [28]. It also has a low tendency to aggregate and form tangles, as it is highly soluble [28]. However, when tau becomes abnormally phosphorylated, the binding affinity of tau to microtubules decreases and causes tau to be detached from microtubules [28]. An increase of these phosphorylated tau seems to be associated with an increase in tau aggregation, ultimately leading to the formation of NFT [28].

The accumulation of A β plaques and NFT can trigger inflammation and lead to neuronal death, contributing to the development of AD [1,26]. The accumulation of A β in the brain is considered as an early toxic event in AD pathogenesis, preceding more advanced neurodegenerative changes [13].

The main cause of AD seems to be the failure to remove A β peptide from the brain tissue [26]. However, the problem is that these pathways start a positive feedback relationship and worsen over time. Inflammation initiated by A β plaques and NFT can activate microglia, impair neural function, and worsen the accumulation of A β [29]. In addition, A β

and tau themselves also seem to be related. It is shown that reducing tau can lead to decreased A β pathology and toxicity in mice [30].

BDNF

Brain-Derived Neurotrophic Factor, BDNF, is one of the neurotrophic factors that is often discussed in music and AD-related literature. BDNF plays an important role in neuronal survival and growth, and regulates neuronal plasticity, which is important for learning and memory [31,1]. Although the exact mechanisms are yet unknown, depletion of BDNF has been associated with tau phosphorylation, A β accumulation, neuroinflammation, and neuronal apoptosis [1], which are all pathways involved in AD pathology (Figure 2). As AD progressed, BDNF levels in the brain, blood, and cerebrospinal fluid decreased, while an increase in serum levels of BDNF was associated with an improvement in cognitive functions among AD patients [1]. Although most research related to BDNF and AD is correlational, increasing research suggests that there may be a link between BDNF and AD.

miR-132

MicroRNAs are non-coding RNAs that usually regulate gene expression at a post-transcriptional level, while some also play an important role in neural development, differentiation and maturation [32]. Among all the microRNAs, miR-132 is one of the most abundant in the brain [32]. Interestingly, miR-132 may be involved in the progression of both A β and tau pathology, with the decrease in level of miR-132 also showing potential as a biomarker for AD [32,30,33,34].

In mice models, a deficiency in miR-132 led to increased expression, phosphorylation and aggregation of tau proteins, with miR-132 targeting tau mRNA to regulate its expression [33,35] (Figure 2). Beyond its role in tau regulation, miR-132 is also implicated in A β . In a study by Hernandez-Rapp et al. [30], genetically deleting miR-132 in triple transgenic mice increased A β production and senile plaque deposition. This suggests that miR-132 may normally contribute to suppressing abnormal A β metabolism.

Indeed, in a study by Walgrave et al. [34], restoring miR-132 into the hippocampus of AD mice model improved neurogenesis and memory deficits. On the other hand, overexpression of miR-132 also led to worsened performance in a task related to adult hippocampal neurogenesis [34]. It seems that miR-132 levels must be kept within a certain range, and that an abnormal increase or decrease can lead to progression of AD.

Neural Oscillations

Gamma oscillations are another pathway of interest, as their disruption is a prominent feature across many neurodegenerative diseases and thus may directly contribute to cognitive deficits observed in these conditions [36].

Gamma oscillations are known to support long-term memory formation, attention, and working memory [37,38,39,40,41,36]. A loss of gamma band synchronization has been reported in AD, perhaps due to this important role gamma oscillations play in many cognitive functions [42,36] (Figure 2).

This pathway has also been targeted as a therapeutic approach. Iaccarino et al. [43] explored the usage of visual stimulation on driving gamma range oscillations by exposing mice to lights flickering at 40 Hz. They found that 40 Hz light flicker may create 40 Hz oscillations in the visual cortex [43]. 40 Hz flicker resulted in an increase in microglial A β uptake, significantly reduced A β 1-40 and A β 1-42 levels, and reduced tau phosphorylation [43]. Interestingly, light flicker at other frequencies or random flicker did not significantly reduce A β levels compared to controls (dark and light), suggesting that 40 Hz flicker may modulate gamma oscillations and start an overall neuroprotective response [43]. Similarly, Yi et al. [44] observed reduced A β plaque deposition and increased plaque related microglial activity in mice models after a transcranial ultrasound stimulation (TUS) at 40 Hz. Yi and colleagues also observed enhanced gamma oscillations in the hippocampus after the treatment, suggesting that external stimuli of 40 Hz may alter neural oscillations.

Main Feature-Pathway-AD Frameworks

Figure 3. Proposed feature-pathway frameworks linking music-related stimuli with AD. The three feature-pathways frameworks are presented in descending order of evidentiary strength: Framework A, rhythm-A β Pathology; Framework B, rhythm-BDNF; and Framework C, timbre-gamma oscillations. Gray boxes indicate the level and source of evidence supporting each specific link within the pathways. Framework A represents the most direct pathway, supported by an AD rodent model (APP/PS1 mice) that tested isolated musical rhythm. Framework B bridges evidence from animal and non-AD human models (showing music/rhythm induced BDNF enhancement) with general AD literature (linking BDNF to reduced A β , tau phosphorylation, neuroinflammation, and neuronal apoptosis). Framework C is an inferred framework combining non-AD human studies on musical timbre and gamma modulation with general AD and 40 Hz stimulation literature. The arrows represent proposed or hypothesized relationships rather than established causal pathways.

General Music and AD-Related Pathways

Several research has shown that music as an undifferentiated whole engages A β /tau relevant, BDNF, gene-regulatory, and gamma-oscillatory pathways.

This section attempts to narrow from general music exposure to specific feature-pathway frameworks. To the best of the author's knowledge, there aren't many studies experimentally testing the exact feature-pathway framework this review suggests. Thus, the frameworks are hypothetical and ordered from most direct evidence to most inferential, A, B, and C (Figure 3).

A. Rhythm-A β Pathology-AD

This framework connecting rhythmical features, A β pathology, and AD is the one with the most direct evidence. Unlike the majority of studies investigating the effect of music on the brain, Li et al. [29] tested the rhythm component of the widely used Mozart's K. 448. The musical notes in K. 448 were all changed to the same note (Middle C), while the original rhythm, tempo, dynamics, and timbre were preserved. Although there were some limitations in this study, it is the only study referenced in this paper that most resembles feature-isolation experiments. This edited extract was played to mice models (APP/PS1 mice) from 20:00 to 00:00, 4 hours every day for 6 months [29]. In order to obtain a better measurement of the potential effect of musical rhythm exposure on mice, the rhythm was played during mice's natural peak activity during dark phase, when mice's perception of auditory stimuli and responsiveness are normally enhanced. The study found a reduction in the area of A β plaques in the hippocampus and enhanced performance on cognitive behavioral tests, such as the Morris Water Maze, after long-term musical rhythm exposure [29].

Furthermore, an inhibition of abnormal proliferation of microglia in the hippocampus and reduction of inflammatory factors in the serum of AD mice were observed. As discussed in the previous section, an increase in A β plaques may contribute to the development of AD [1]. Abnormal proliferation of microglia, which can also be accelerated by the increase in A β plaques, can contribute to further inflammation in the brain [1].

Thus, if listening to Mozart's K. 448 rhythm leads to a reduction in A β plaques, inhibition of proliferation of microglia, and reduction of inflammation, this suggests that rhythm may potentially be able to slow neurodegeneration, or improve cognitive functions through the A β pathology pathway.

Li et al. [29] attempts to explain this mechanism of rhythm on A β pathology by stating that music is a more ecological stimulus than the monotonous 40 Hz used in prior AD research, and that classical compositions, including K. 448 has a unique 1/f rhythm spectrum that shares structural similarities with physiological rhythms in the body.

This proposal is worth sitting alongside a separate body of evidence on repetitive sensory stimulation and A β pathology. Iaccarino et al. [43], Yi et al. [44], and Lv et al. [45] each used different modes of stimulation: visual flicker in Iaccarino et al. [43], ultrasound in Yi et al. [44], and electrical in Lv et al. [45]. These different modes were all delivered at 40 Hz, and each showed a reduction in A β plaque deposition and increase in microglial activity associated with plaque.

It is important to note that these findings should not be directly equated with the effects of musical rhythm. A 40 Hz stimulus repeats 40 times per second, whereas musical rhythm is generally measured in beats per minute and is usually at a slower temporal scale. For instance, a tempo of 120 beats per minute corresponds to only 2 beats per second. Furthermore, none of these three studies used music.

Nevertheless, the convergence of these studies raises a broader question of whether precisely structured repetitive stimulation, rather than specifically 40 Hz, may contribute to A β and microglial responses. In this context, the repetitive temporal structure of music may be worth investigating as a potentially relevant

feature, although the mechanism may differ from that of 40 Hz stimulation. Indeed, the relationship is hypothetical and would require experiments that directly manipulate musical rhythm while measuring gamma activity, A β pathology, and microglial responses.

A similar idea of temporal structure has been proposed outside the AD literature. In the context of epileptic seizures, Štillová et al. [22] proposed that the particularly high repetition rate and long-term periodicity of K. 448 may resonate with brain activity. Although this study concerns a different disorder and makes a different mechanistic claim, it provides an example of how temporal organization of musical stimulus may be considered biologically relevant. Together with findings of Li et al. [29], these studies support the broader hypothesis that temporal structure may be an important property to investigate.

B. Rhythm-BDNF-AD

This framework connecting rhythm, BDNF, and AD is more indirect. Here, we attempt to bridge the two distinct links of studies: rhythm and BDNF with BDNF and AD.

Previous studies have shown that exposure to slow rhythm music (6 hours per day for 21 days) significantly enhanced BDNF levels in the hypothalamus of mice models [46]. Similarly, listening to Mozart's K. 448 enhanced BDNF levels in the dorsal hippocampus CA3 and dentate gyrus, while the BDNF levels in dorsal hippocampus CA1 were not affected [47]. Music seems to affect selective regions, and a change in BDNF levels seems to be correlated with enhanced spatial cognition ability, as measured with the Morris water maze task [47]. BDNF may have affected hypothalamus activity by regulating glucose and energy metabolism of hypothalamus [46].

The systematic review by Kühlmann et al. [48] suggests that higher BDNF levels and an enhanced propensity for neurogenesis and neuroplasticity in music-exposed rodents are patterns repetitively observed in multiple rodent studies. Although not specifically AD patients, an increase in serum BDNF levels after listening to Mozart's music for patients with mild cognitive impairment [49] and young adults [50] suggests that similar patterns are observed in both rodent models and humans.

Another strand of literature suggests that depletion of BDNF may be linked with A β accumulation, tau phosphorylation, neuroinflammation and neuronal apoptosis [1]. Connecting these two strands, it may be possible that listening to specific rhythm, such as slow rhythm music, can enhance BDNF levels, which may in turn slow neurodegeneration in AD by either increasing neuroplasticity or preventing the accumulation of A β plaques and NFT.

However, it is important to note that whether rhythm, or broadly music, directly leads to changes in BDNF levels is not entirely clear, as many studies tested the combined effect of music and exercise. For instance, although this was in a study related to depression, BDNF levels in human populations increased after participating in an activity combining

music and exercise [20]. Physical exercise has also been shown to enhance BDNF levels and seems to have a similar effect on the brain as music (promoting synaptic protein expression and neurogenesis) [19]. It may be that music and exercise may be operating synergistically, with the interaction between music and exercise amplifying the overall impact [12].

C. Timbre-Gamma Oscillations-AD

This framework connecting timbre, gamma oscillations, and AD is inferred. As established in the section “Differential Biological Modulation in Non-AD Context,” timbral features and other features (tonal and rhythmic) seem to each engage different areas of the brain [16]. Auditory roughness, an aspect of timbre, engages a cascade of neural activity: initial high-gamma synchronization in the auditory cortex, limbic activation in the insula and amygdala, and finally the recruitment of parietal and prefrontal cortices [51]. Again, although this study was conducted to investigate the effect of music against anxiety, Luo et al.’s (2025) study is consistent with this pathway. Major-key violin timbre produced significant cortical activation, especially in the Brodmann areas 9 and 32 in the frontal lobe [18]. This suggests that timbre’s roughness may recruit prefrontal circuits as part of its anxiety reducing effect.

Importantly, this effect seems to be specific to the gamma band rather than the general property of neural oscillations. In the study by Luo et al. [18], both beta and gamma bands were measured, but gamma activity showed more robust changes among the anxiety group. Granger causality analysis further suggested that the anxiety reduction previously linked with the prefrontal circuits is strongly associated with gamma-band connectivity [18]. Luo et al. [18] interpreted that gamma oscillations reflect emotion-cognition interactions and rapid information processing.

While musical timbre, specifically auditory roughness of violin, appears to influence gamma bands, the disruption of gamma oscillations is a prominent feature in many neurodegenerative diseases and may be related to cognitive deficits [36]. Indeed, several studies reported alterations in gamma oscillations, such as loss of gamma band synchronization, in AD [36].

However, because the effect of timbre on gamma activity was observed in non-AD context (anxiety), the therapeutic potential of gamma modulation in AD relies on separate 40 Hz sensory stimulation research. These studies demonstrated that 40 Hz stimuli may be able to reduce A β plaques and increase related microglial activity [43,44,45].

Although there seems to be no studies that explicitly studied the effect of musical timbre on AD-related gamma alterations, we can infer from these separate lines of evidence that if specific timbral features can restore gamma oscillations, it may be possible that neurodegeneration in AD may be alleviated via pathways, such as A β pathology. We emphasize once more that this framework remains hypothetical and needs empirical validation.

Adjacent Mechanisms: Whole Music Exposure, miR-132, and AD

Figure 4. Proposed adjacent mechanism linking whole music exposure to AD via miR-132 regulation. Unlike the feature-isolated frameworks in Figure 3, this model considers music exposure as an undifferentiated whole. Gray boxes below the pathway indicate the underlying evidence sources, connecting human studies (demonstrating upregulated miR-132 expression following music exposure) with animal and human models (establishing miR-132's regulatory role in A β production and tau protein expression). The inset note emphasizes therapeutic considerations: optimal outcomes depend on precise control of music duration and intensity (avoiding cognitive deficits associated with overexpression of miR-132) and may be contingent upon individual musical aptitude.

Unlike the three feature-specific frameworks above, this section (Figure 4) considers evidence connecting whole music exposure with miR-132, a microRNA implicated in AD pathology. Although this section does not isolate a specific feature, it is included in the review as miR-132 seems to be one of the most mechanistically detailed and is relevant to the broader field of music medicine and sensogenomics. It is therefore presented as an adjacent mechanism rather than as a feature-pathway framework.

Nair et al. [52] studied the effect of music listening on gene regulation and identified an upregulation of six microRNAs, including miR-132. Nair and colleagues' study in 2019 [54] found a similar result in not only passive listening but also active musical performance, as observed by sequencing peripheral blood microRNA expressions in professional musicians after 2 hours of classical music performance.

miR-132 gained particular attention as it seems to play a critical role in regulating tau protein and A β production, important pathological pathways in AD [52]. Hernandez-Rapp et al. [30] found that miR-132 or its target Sirt1 can regulate A β production in humans, with miR-132 leading to downregulation of human A β -40 and A β -42 levels, while loss of miR-132 led to A β production, aggregation, and deposition in mice models. Smith et al. [33] showed that miR-132 deficiency may also lead to increased tau expression, phosphorylation, and aggregation.

Furthermore, downregulation of miR-132 has been observed in the early and mid-stages of AD [35]. The difference in miR-132 expression in AD was also stronger than other neuronal miRNAs, suggesting that the downregulation of miR-132 may not be due to a simple cellular alteration in a diseased brain, but rather closer to being a pathological cause [35].

Considering this, modulating miR-132 levels through music exposure seems to show potential for AD treatment. However, there are two factors that must be taken into consideration.

First of all, while restoring miR-132 levels was shown to rescue hippocampus-dependent functions in AD mouse models, overexpression of the same microRNA seemed to be associated with worsening in cognitive tasks [34]. This suggests that for music to be used therapeutically, the duration and intensity must be carefully controlled, as there seems to be a "goldilocks zone" for miR-132 levels.

Another factor is that this change in miR-132 was only observed in individuals shown to have high musical aptitude [52]. This suggests that there could be genetic or epigenetic differences due to prior musical experience among musically apt individuals that may differentially interact with the miR-132 pathway. This is an important consideration as each individual has different levels of musical aptitude, and the effect of this aptitude on miR-132 regulation cannot be clearly outlined yet.

Discussion

Constructing these feature-pathway frameworks demonstrates a clear asymmetry in the strength of supporting evidence. Framework A is the only one that directly tested isolated acoustic features (rhythm) against AD pathology outcomes in real animal models. Framework B, on the other hand, bridges two well-supported links, music's effect on BDNF and BDNF's effect on AD pathology. However, this gap is complicated by the frequent confounding of music and exercise in existing literature. Framework C is the most inferential, with the link between timbre, gamma oscillations, and AD not clearly defined. Timbre's effect on gamma oscillations is established in non-AD context, while gamma stimulation's effect on AD pathology is established in non-musical context. While all three frameworks partially depend on studies based on entire music (not isolated features), the adjacent mechanism is solely based on studies that treat music as an undifferentiated stimulus. This asymmetry itself indicates where feature-isolated AD research should prioritize moving forward.

Limitations and Future Directions

There are several limitations and confounds in this review that should be further studied.

Musical Aptitude Confound

A recurring confound across this review is musical aptitude. Several changes by music were only observed in individuals that reported high musical aptitude [52,17], and many studies, taking account of this confound, designed their population to only have individuals with musical experience or only have individuals with no prior musical training experience [18,16]. Furthermore, although musical aptitude seems to greatly influence the therapeutic effects of music, the concept of musical aptitude itself is not clearly defined and is often self-reported [11]. This collectively suggests that many of the pathway's effects discussed in this review may not uniformly generalize across all music listeners. A clearer definition and measurement method of musical aptitude must be first established in order for future research to effectively study the effect of musical aptitude on music listening and AD.

Music-Exercise Confound

Similarly, Framework B's rhythm-BDNF link is complicated by studies that combine music listening with exercise, making it unclear whether rhythm or other musical features are sufficient alone to elevate BDNF. Studies should investigate the effect of musical feature alone (rhythm) on BDNF levels, while removing exercise components or keeping it as a control.

Animal to Human Translation

Many studies related to music, brain, and AD, often use rodent models. This is likely because rodent models enable the usage of more invasive experiments, such as directly stimulating the brain with electrical stimulus [45], analyzing gut-microbiota [25], and directly analyzing the BDNF levels in the hippocampus [47]. However, rodents and humans are indeed different species, and results obtained in rodent models may not directly translate to humans. In addition, music may not be perceived the same way as humans in animal models, and many studies suggest that music may lack ethological relevance for animals [12]. All three frameworks involve studies based on rodent models, and future research should study whether the same patterns also appear in humans.

Dose-Response Relationship

The “goldilocks zone” observed for miR-132, where restoration and overexpression led to adverse effects [34] underscores a broader limitation: no study in this review systematically varied the duration or intensity of musical exposure to establish a dose-response relationship. There were attempts to quantify acoustic features using mathematical ratios in rhythm [17] and melody [15]. Further work should quantify and parametrize these acoustic features and outline the effects on AD-related pathways. One important element that should also be quantified and tested is duration of music exposure. Many studies discussed in this review had varying exposure durations, ranging from minutes to months. However, exposure time seems to greatly affect the outcome, as in a study by Petekkaya et al. [50], notable changes in serum BDNF only appeared after 15 days.

Furthermore, continuing with the musical aptitude confound, each individual may have different outcomes after listening to the same musical stimulus as individuals have different musical backgrounds. The influence of musical aptitude levels on this dose-response relationship should also be further studied.

Further Acoustic Feature-Specific Relationships

Again, a limitation is that many studies simply treat or generalize all classical music together, while each music and composer may have different acoustic compositions. Simply comparing music of different genres or composers isn't sufficient to reveal the mechanism behind music and AD-related pathways.

Another major gap is the feature-pathway link for tonality. Although tonality was shown to differentially affect anxiety-related symptoms [18], it lacks evidence that can be linked to AD-related pathways. Future research should thus test the effect of tonality on AD context, perhaps by using AD mice models.

Depression and AD

Another interesting line of future research is exploring how depression and AD may be related to each other. Depression and AD were discussed separately in this review, but the two seem to engage in similar pathways, such as BDNF [19,1]. Depression also seems to exacerbate AD pathology through lactate-dependent activation of potassium channel Kv1.3, promoting A β -containing exosome spreading [53]. The further

mechanistic connection between depression and AD should be studied. The feature-specific effects of music could be able to simultaneously affect both conditions.

Implications

Although it is not directly related to AD, the sex-specific responses observed by Štillová et al. [22] as well as the differential responses by anxiety groups and control groups in Luo et al. [18] suggest that a single intervention is unlikely to suit all individuals. Even for pharmacological treatments, each individual responds to each drug differently [21]. Music should move away from the general idea that all music can impact individuals in the same way; each acoustic component that constitutes a musical stimuli seems to have the potential to differentially help alleviate neurological disorders, such as AD. Further research finding the optimal features on an individual level may be able to support the movement toward prescribed, standardized music medicine [19,22]. We hope that the feature-pathway frameworks proposed in this review could serve as a starting point for future research aiming towards these individualized, symptom-targeted prescriptions.

Conclusion

This review suggests that music's individual acoustic features engage distinct biological pathways that may be relevant to AD. By connecting feature-isolation research and AD neuroscience, we constructed three feature-pathway frameworks (A-C) connecting rhythm and timbre to A β and tau pathology, BDNF, and gamma oscillations. Alongside these feature-specific pathways, we also highlighted an adjacent mechanism involving whole music exposure and miR-132 regulation. These pathways each have different levels of evidence support, and this asymmetry suggests where future feature-specific research should prioritize moving forward. While several confounds, including musical aptitude and a heavy reliance on rodent models, limit how far these frameworks can be generalized, the convergence of evidence across neuroimaging, clinical studies, cellular and animal models suggests that this topic is worth pursuing further. Indeed, the therapeutic potential of music depends on understanding the exact mechanisms behind it: which acoustic feature actually did the work. As the field moves toward more personalized, prescribed music medicine, the feature-pathway framework proposed in this review serves as a conceptual starting point for future research by clarifying what can be inferred from current evidence and highlighting empirical gaps.

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References

- Gao, L., Y. Zhang, K. Sterling, and W. Song. "Brain-derived neurotrophic factor in Alzheimer's disease and its pharmaceutical potential." *Translational Neurodegeneration* 11, no. 1 (2022): 4.
- Rossetti, A. "Towards prescribed music in clinical contexts: More than words." *Music and Medicine* 6, no. 2 (2014): 70.
- Huynh, A., K. Noll, W. J. Ray, F. F. Lang, and M. Rui. "Toward precision music medicine in oncology care: Reproducible, scalable and biomarker-driven interventions." *EClinicalMedicine* 96 (2026): 104001.

- Chen, Y., J. Sun, J. Tao, and T. Sun. "Treatments and regulatory mechanisms of acoustic stimuli on mood disorders and neurological diseases." *Frontiers in Neuroscience* 17 (2024): 1322486.
- Navarro, L., A. Gómez-Carballa, S. Pischedda, J. Montoto-Louzao, S. Viz-Lasheras, A. Camino-Mera, T. Hinault et al. "Sensogenomics of music and Alzheimer's disease: An interdisciplinary view from neuroscience, transcriptomics, and epigenomics." *Frontiers in Aging Neuroscience* 15 (2023): 1063536.
- Cuddy, L. L., and J. Duffin. "Music, memory, and Alzheimer's disease: Is music recognition spared in dementia, and how can it be assessed?" *Medical Hypotheses* 64, no. 2 (2004): 229–235.
- Peck, K. J., T. A. Girard, F. A. Russo, and A. J. Fiocco. "Music and memory in Alzheimer's disease and the potential underlying mechanisms." *Journal of Alzheimer's Disease* 51, no. 4 (2016): 949–959.
- Shankar, N. "Music therapy: A necessary addition to the treatment of neurodegenerative disorders?" *Georgetown Medical Review* 6, no. 1 (2022).
- Irish, M., C. J. Cunningham, J. B. Walsh, D. Coakley, B. A. Lawlor, I. H. Robertson, and R. F. Coen. "Investigating the enhancing effect of music on autobiographical memory in mild Alzheimer's disease." *Dementia and Geriatric Cognitive Disorders* 22, no. 1 (2006): 108–120.
- Matziorinis, A. M., and S. Koelsch. "The promise of music therapy for Alzheimer's disease: A review." *Annals of the New York Academy of Sciences* 1516, no. 1 (2022): 11–17.
- Navarro, L., F. Martínón-Torres, and A. Salas. "Sensogenomics and the biological background underlying musical stimuli: Perspectives for a new era of musical research." *Genes* 12, no. 9 (2021): 1454.
- U, K. K., M. Pranjic, A. Rigby, I. Pallás-Ferrer, H. Anand, R. Kunnavil, and A. C. Jaschke. "The molecular basis of music-induced neuroplasticity in humans: A systematic review." *Neuroscience & Biobehavioral Reviews* 175 (2025): 106219.
- Gómez-Carballa, A., L. Navarro, J. Pardo-Seco, X. Bello, S. Pischedda, S. Viz-Lasheras, A. Camino-Mera et al. "Music compensates for altered gene expression in age-related cognitive disorders." *Scientific Reports* 13, no. 1 (2023): 21259.
- Vuust, P., O. A. Heggli, K. J. Friston, and M. L. Kringelbach. "Music in the brain." *Nature Reviews Neuroscience* 23, no. 5 (2022): 287–305.
- Harding, E. E., J. C. Kim, A. P. Demos, I. R. Roman, P. Tichko, C. Palmer, and E. W. Large. "Musical neurodynamics." *Nature Reviews Neuroscience* 26, no. 5 (2025): 293–307.
- Alluri, V., P. Toivainen, I. P. Jääskeläinen, E. Glerean, M. Sams, and E. Brattico. "Large-scale brain networks emerge from dynamic processing of musical timbre, key and rhythm." *NeuroImage* 59, no. 4 (2011): 3677–3689.
- Grahn, J. A., and M. Brett. "Rhythm and beat perception in motor areas of the brain." *Journal of Cognitive Neuroscience* 19, no. 5 (2007): 893–906.
- Luo, Q., Y. Wang, K. Yang, A. Qian, P. Nie, M. Xi, W. Zhang et al. "Acoustic features of music differentially modulate anxiety through EEG gamma oscillations and prefrontal connectivity." *Scientific Reports* 16, no. 1 (2025): 1455.
- Cheng, H., H. Xie, Q. Tang, L. Yi, and J. Zhu. "Light and classical music therapies attenuate chronic unpredictable mild stress-induced depression via BDNF signaling pathway in mice." *Heliyon* 10, no. 13 (2024): e34196.

Yeh, S., L. Lin, Y. K. Chuang, C. Liu, L. Tsai, F. Tsuei, M. Lee et al. "Effects of music aerobic exercise on depression and brain-derived neurotrophic factor levels in community dwelling women." *BioMed Research International* 2015 (2015): 1–10.

Fitzgerald, P. J., and B. O. Watson. "Gamma oscillations as a biomarker for major depression: An emerging topic." *Translational Psychiatry* 8, no. 1 (2018): 177.

Štillová, K., T. Kiska, E. Koritáková, O. Strýček, J. Mekyska, J. Chrastina, and I. Rektor. "Mozart effect in epilepsy: Why is Mozart better than Haydn?" *Acoustic qualities-based analysis of stereoelectroencephalography. European Journal of Neurology* 28, no. 5 (2021): 1463–1469.

Ramírez-Rivera, S., and G. Bernal. "Music is capable of inducing changes in gene expression in gastric cancer cells." *Journal of Gastrointestinal Cancer* 50, no. 1 (2019): 175–180.

Brun, C., and J. Exbrayat. "The effects of sounds and music on cells and organisms: A promising and developing area of research." *Athens Journal of Sciences* 9, no. 3 (2022): 157–176.

Zhang, Z., Y. Wu, S. Zhou, P. Fu, and H. Yan. "Effects of music and white noise exposure on the gut microbiota, oxidative stress, and immune-related gene expression of mice." *Microorganisms* 11, no. 9 (2023): 2272.

Masters, C. L., R. Bateman, K. Blennow, C. C. Rowe, R. A. Sperling, and J. L. Cummings. "Alzheimer's disease." *Nature Reviews Disease Primers* 1, no. 1 (2015): 15056.

Walker, L. C. "A β plaques." *Free Neuropathology* 1 (2020): 31.

Wang, Y., and E. Mandelkow. "Tau in physiology and pathology." *Nature Reviews Neuroscience* 17, no. 1 (2015): 22–35.

Li, J., C. Wu, Q. Liu, M. Liu, T. Liu, A. Li, G. Fu et al. "Mozart's rhythm influence on Alzheimer's disease progression via modulation of pathological damage and cognition." *iScience* 28, no. 8 (2025): 113168.

Hernandez-Rapp, J., S. Rainone, C. Goupil, V. Dorval, P. Y. Smith, M. Saint-Pierre, M. Vallée et al. "MicroRNA-132/212 deficiency enhances A β production and senile plaque deposition in Alzheimer's disease triple transgenic mice." *Scientific Reports* 6, no. 1 (2016): 30953.

Bathina, S., and U. N. Das. "Brain-derived neurotrophic factor and its clinical implications." *Archives of Medical Science* 6, no. 6 (2015): 1164–1178.

Zhang, M., and Z. Bian. "Alzheimer's disease and microRNA-132: A widespread pathological factor and potential therapeutic target." *Frontiers in Neuroscience* 15 (2021): 687973.

Smith, P. Y., J. Hernandez-Rapp, F. Jolivet, C. Lecours, K. Bisht, C. Goupil, V. Dorval et al. "miR-132/212 deficiency impairs tau metabolism and promotes pathological aggregation in vivo." *Human Molecular Genetics* 24, no. 23 (2015): 6721–6735.

Walgrave, H., S. Balusu, S. Snoeck, E. Vanden Eynden, K. Craessaerts, N. Thrupp, L. Wolfs et al. "Restoring miR-132 expression rescues adult hippocampal neurogenesis and memory deficits in Alzheimer's disease." *Cell Stem Cell* 28, no. 10 (2021): 1805–1821.e8.

Lau, P., K. Bossers, R. Janky, E. Salta, C. S. Frigerio, S. Barbash, R. Rothman et al. "Alteration of the microRNA network during the progression of Alzheimer's disease." *EMBO Molecular Medicine* 5, no. 10 (2013): 1613–1634.

- Nimmrich, V., A. Draguhn, and N. Axmacher. "Neuronal network oscillations in neurodegenerative diseases." *NeuroMolecular Medicine* 17, no. 3 (2015): 270–284.
- Fell, J., P. Klaver, C. E. Elger, and G. Fernández. "The interaction of rhinal cortex and hippocampus in human declarative memory formation." *Reviews in the Neurosciences* 13, no. 4 (2002): 299–312.
- Gruber, T. "Selective visual-spatial attention alters induced gamma band responses in the human EEG." *Clinical Neurophysiology* 110, no. 12 (1999): 2074–2085.
- Gruber, T., M. M. Müller, and A. Keil. "Modulation of induced gamma band responses in a perceptual learning task in the human EEG." *Journal of Cognitive Neuroscience* 14, no. 5 (2002): 732–744.
- Kaiser, J., B. Ripper, N. Birbaumer, and W. Lutzenberger. "Dynamics of gamma-band activity in human magnetoencephalogram during auditory pattern working memory." *NeuroImage* 20, no. 2 (2003): 816–827.
- Jensen, O., J. Kaiser, and J. Lachaux. "Human gamma-frequency oscillations associated with attention and memory." *Trends in Neurosciences* 30, no. 7 (2007): 317–324.
- Stam, C. J., A. M. Van Cappellen Van Walsum, Y. A. L. Pijnenburg, H. W. Berendse, J. C. De Munck, P. Scheltens, and B. W. Van Dijk. "Generalized synchronization of MEG recordings in Alzheimer's disease: Evidence for involvement of the gamma band." *Journal of Clinical Neurophysiology* 19, no. 6 (2002): 562–574.
- Iaccarino, H. F., A. C. Singer, A. J. Martorell, A. Rudenko, F. Gao, T. Z. Gillingham, H. Mathys et al. "Gamma frequency entrainment attenuates amyloid load and modifies microglia." *Nature* 540, no. 7632 (2016): 230–235.
- Yi, S., J. Zou, X. He, H. Chen, Z. Lin, L. Zhang, Y. Zhu et al. "Transcranial ultrasound stimulation pulsed at 40 Hz improves cognition and neuroinflammation in female mice with Alzheimer's disease." *Research* 9 (2026): 1244.
- Lv, S., F. Mo, Z. Xu, Y. Wang, Y. Liu, M. Han, Y. Duan et al. "Integrated dopamine sensing and 40 Hz hippocampal stimulation improves cognitive performance in Alzheimer's mouse models." *Nature Communications* 16, no. 1 (2025): 5948.
- Angelucci, F., E. Ricci, L. Padua, A. Sabino, and P. A. Tonali. "Music exposure differentially alters the levels of brain-derived neurotrophic factor and nerve growth factor in the mouse hypothalamus." *Neuroscience Letters* 429, no. 2–3 (2007): 152–155.
- Xing, Y., W. Chen, Y. Wang, W. Jing, S. Gao, D. Guo, Y. Xia et al. "Music exposure improves spatial cognition by enhancing the BDNF level of dorsal hippocampal subregions in the developing rats." *Brain Research Bulletin* 121 (2016): 131–137.
- Kühlmann, A. Y. R., A. De Rooij, M. G. M. Hunink, C. I. De Zeeuw, and J. Jeekel. "Music affects rodents: A systematic review of experimental research." *Frontiers in Behavioral Neuroscience* 12 (2018): 301.
- Pecci, M. T., W. Verrusio, A. F. Radicioni, A. Anzuini, A. Renzi, V. Martinelli, E. Ettorre et al. "Music, spatial task performance, and brain plasticity in elderly adults." *Journal of the American Geriatrics Society* 64, no. 10 (2016): e78–e80.
- Petekaya, E., D. Ünalmiş Aykar, and Z. Kaptan. "An analysis of the relationship of "the Mozart effect" with BDNF levels in anatomy education." *Anatomical Sciences Education* 17, no. 4 (2024): 770–778.

Arnal, L. H., A. Kleinschmidt, L. Spinelli, A. Giraud, and P. Mégevand. "The rough sound of salience enhances aversion through neural synchronisation." *Nature Communications* 10, no. 1 (2019): 3671.

Nair, P. S., P. Raijas, M. Ahvenainen, A. K. Philips, L. Ukkola-Vuoti, and I. Järvelä. "Music-listening regulates human microRNA expression." *Epigenetics* 16, no. 5 (2020): 554–566.

Liu, X., H. Wang, X. Tian, Y. Luo, M. Ma, Z. Zheng, Y. Wang et al. "Depression exacerbates AD pathology through lactate-dependent activation of microglial Kv1.3 to promote A β -containing exosome spreading." *Journal of Neuroinflammation* 22, no. 1 (2025): 166.

Nair, P. S., T. Kuusi, M. Ahvenainen, A. K. Philips, and I. Järvelä. "Music-performance regulates microRNAs in professional musicians." *PeerJ* 7 (2019): e6660.

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Gender Differences in Startup Investment Efficiency and Business Survival

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Abstract

Women are becoming more active in entrepreneurship, but businesses linked with women tend to get a smaller share of startup investment. This study compared women-founded, women-owned, or women-led businesses with businesses associated with men. A structured comparative review of ten quantitative studies was completed. Five studies focused mostly on investment efficiency or broader financial performance, and five focused on business survival. The findings did not show a clear performance advantage for either gender. Women-associated businesses tended to receive less funding and started with fewer assets or smaller teams. Only one study directly measured revenue per dollar invested and found higher revenue efficiency among women-linked startups. The other financial results were mixed, while survival findings also changed according to industry, location, business size, and statistical controls. When a gender difference became smaller after funding or experience was controlled, this did not necessarily mean gender had no influence, because those factors may themselves be linked with unequal opportunities. Overall, resources, experience, and business context appear important, while gender may indirectly influence access to these advantages.

Keywords

Women entrepreneurs; startup performance; investment efficiency; business survival; gender differences; venture funding.

Introduction

Startups have an influence on economic development because they give new products to consumers and make competition for existing companies. To define it, “a start-up is a young, innovative company that develops new products, services, or business models and is typically in an early growth phase” (Otto Beisheim School of Management, 2026). Startups give a means for new ideas and research to become a practical reality in an industry, and they have added benefits as well, such as offering employment. The OECD, for example, points out that young firms “account for about 20% of total employment but create almost half of all new jobs across OECD countries” (OECD, 2020, p. 1). Not all startups succeed though, so researchers look at their performance to work out what makes growth and survival or vice-versa. The findings help all those involved in them from the entrepreneurs to investors, so funding decisions and strategies for success can be more effective.

Women are more active in entrepreneurship than before, but they remain underrepresented among founders of high-growth and venture-funded businesses. Data from 30 countries document this increase, from an average of 6.1% (2001–2005) to 10.4% (2021–2023), but still in 2023, only approximately one in ten women started a business, compared with one in eight men (Elam et al., 2024, p. 10). Venture capital has a gender gap that is even bigger; for instance, startups in the U.S. with all-female founding teams added up to only 6.5% of venture-capital deals and 1.9% of total deal value in 2024 (Donegan, 2026). Startups by their nature need capital for various tasks, such as developing their ideas or recruiting skilled employees, so investment matters to help them survive and then succeed.

Labeling a startup a success or a failure is subjective, because the relevant measures are multidimensional and cannot be reduced to one indicator (Ben Saad, 2024). This variety is shown in Mayer-Haug et al.’s (2013) study as it lists a number of potential measures, including the amount of investment a company receives, the revenue or profit it generates, its employment growth, or its ability to remain operational over time (p. 1252). That list is not exhaustive; other studies listing factors like acquisition or initial public offering as a successful outcome (Gangwani et al., 2023). The measures can lead to different conclusions about the same startup; for example, a startup could receive substantial funding without becoming profitable, but then another one could survive for many years without achieving rapid growth. It motivates researchers to think about using more than one indicator when trying to test a startup’s performance. This study does that because it defines startup success through



investment efficiency and business survival, which means it can assess financial performance and long-term continuity together.

Investment efficiency is the amount of business revenue generated relative to the amount of investment received. Some research (e.g., Ang et al., 2022) views success by the amount of investment a startup gets, but this study considers efficiency of investment usage as more important. It gives weight to startups that receive less investment but use those resources more effectively and generate more revenue for each dollar received. As an example, Abouzahr et al. (2018) found that startups founded or co-founded by women generated \$0.78 per dollar invested, which was better than those made entirely by men at \$0.31. Revenue, though, should not be confused with profit, as revenue is income generated through business activities, but profit is the amount remaining after costs and expenses have been deducted. That means the measure here is looking at capital efficiency as opposed to overall profitability. Only Abouzahr et al. (2018) directly measures revenue for each dollar invested in the studies used here; the other financial studies look at broader measures such as sales, profit, employment growth, or risk-adjusted performance.

Business survival focuses on a company's ability to keep its operations going for a certain amount of time from when it started. What it means to be alive in business is explained by Eurostat, as it says the definition means remaining active through employment, turnover, or investment during the years following the company's creation (Eurostat, 2024). The length of time depends on a researcher's prerogative, so it could be three years or ten years, for example. There also might be a consideration to measure the percentage of an original group of businesses that remains active at each point. There are other studies that look at related factors like average operational lifespan or the risk of failure during a given period. An example showing this is the U.S. Bureau of Labor Statistics, as it follows groups of newly established businesses from year to year to measure their survival and longevity (U.S. Bureau of Labor Statistics, n.d.). However, results based on different observation periods cannot be compared directly because survival normally decreases as the follow-up period is getting longer.

The research completed in this area already gives a mixed picture about the performance of startups linked with women compared to the ones started by men. Abouzahr et al. (2018) has received substantial media attention. That study found that startups founded or co-founded by women received considerably less investment, but that they used it with greater revenue efficiency. It gave evidence of lower funding not meaning weaker financial efficiency. Survival studies are less consistent. One of the recent studies by Millán et al. (2026) found that women-led startups had a much lower risk of failure than men-led startups. This does not continue a clear pattern, however, because Couture and Houle (2020) reported that women-owned Canadian startups had a lower overall survival rate than men-owned and equally owned startups. There is other research in the area that seems to show evidence of the differences reducing when the businesses being compared have characteristics that are alike. An example of this is Farhat and Mijid (2018) who found no gender difference in survival, profit, sales, employment, or asset growth after matching firms according to industry, owner experience, education, age, and working conditions. There is certainly research in the literature, but there is a struggle to find consistency. This underscores the multidimensional nature of business performance: startup performance seems to depend on the sample, country, industry, business size, and definition of female involvement. Looking at this existing data also gives more credibility to the need to use more than one measure of success when trying to find conclusions in this area.

A tendency of the previous research is for it to look at just one of the many dimensions of startup performance. An example of this is research that looks at venture funding by comparing investment and revenue, but then it does not consider if the businesses survive in the long term (e.g., Abouzahr et al., 2018). Then, other studies focus on closure rates, but they do not measure how efficiently startups convert investment into revenue (e.g., Millán et al., 2026). The comparisons of studies can be complicated too, because there can be inconsistencies with classifications, such as researchers varying between women-founded, majority women-owned, or women-led businesses. This study tries to close that gap by considering investment efficiency and survival together, and by recording each study's gender definition.

This study's purpose is to compare existing quantitative evidence on the performance of startups associated with women and men. The research question asked is: How does the performance of women-founded, women-owned, or women-led startups compare with that of businesses associated with men in terms of investment efficiency, broader financial performance, and business survival? Considering the previous research, it is hypothesized that businesses associated with women will generally receive less investment. Their broader financial performance may be similar, stronger, or weaker depending on factors such as funding, experience, industry, and business size. Revenue generated per dollar invested is treated as one specific measure from one study as opposed to being something all five financial studies can test. Differences in survival are expected to be smaller and less



consistent, as they may depend on factors such as industry, country, company size, funding level, and the way female ownership or leadership is defined.

Methods

The study design is a structured comparative review of quantitative research. Data is taken from published studies that compared businesses connected with women and men. The selected studies were organized into two main categories of startup success. The first category was investment efficiency and financial performance, which included measures such as revenue, profit, sales growth, and return on investment. The second category was business survival, including survival rates, closure rates, and risk of failure. This method made it possible to compare findings from different countries, industries, samples, and research designs.

Studies were identified through searches of several databases, including Google Scholar, ScienceDirect, and SAGE Journals. The searches were conducted in July 2026 using key search terms, such as “women-founded startup performance,” “female-owned business survival,” “gender differences startup success,” “women-led startup revenue,” “female founder investment efficiency,” and “male and female business survival rates.” At stage one of the process, titles and abstracts were screened to see if they appeared relevant to the research question. Those passing this stage had the full article examined. The reference lists of relevant studies were also checked to identify other research that had not appeared in the original searches. After the title and abstract screening, 43 potentially relevant studies went forward to full-text review.

Selected studies met the criteria of quantitative data that directly compared businesses associated with women and men. A second requirement was for them to examine startups or relevant business-survival samples as well as having at least one measure of financial performance or survival. To be selected, the study needed to report the sample and the way gender involvement was defined. Sources had to be peer-reviewed journals or reports issued by recognized research organizations. Studies were excluded if they were based on opinions or lacked comparison of the two genders. Studies that had the same general dataset were retained only if they had different methods that made a meaningful difference in the outcomes. The 43 full-text studies were then checked against these requirements. Sources were removed when they lacked a direct gender comparison, usable financial or survival data, or enough information about the sample and research method. Ten studies provided the clearest evidence for the research question. Five mainly examined investment efficiency or broader financial performance, while five mainly examined business survival. This division was used to give similar attention to both parts of the research question, not because the studies were equal in quality. When a study covered both areas, it was placed in the category connected most closely to its main analysis. Some of the included studies used broader business samples and not just strict startups, including proprietorships and manufacturing establishments with at least ten employees. They were kept because they still gave relevant gender comparisons, but this makes the studies less directly comparable.

A standardized research table was used as the main tool for collecting information from each study. The same categories were recorded for every source, including the author and publication year, country and setting, sample size, gender definition, measure of success, women-linked result, men-linked result, main conclusion, and an important limitation. Numerical findings were checked against the original article or an official publisher, university, government, or research-organization source when possible. The wording used by each study was also retained, because women-founded, women-owned, women-led, and woman-controlled businesses do not mean exactly the same thing. Recording each definition separately helped prevent the results from different studies being compared in an inaccurate way.

The first outcome category covered investment efficiency and financial performance. Measures in this group included revenue generated per dollar invested, the amount of financial capital received, sales and total revenue, net profit, return on sales, employment growth, and risk-adjusted performance. The second category focused on business survival and included survival after a fixed period, closure or exit rates, operational duration, estimated risk of failure, and hazard ratios. These indicators were grouped under two broad categories, but they were not treated as mathematically identical measurements. This was important because only Abouzahr et al. (2018) directly measured revenue generated for each dollar invested.

Examination of the extracted findings used narrative comparative analysis. Studies were compared according to whether they showed stronger performance among women-associated businesses, stronger performance among men-associated businesses, no statistically significant gender difference, or results that changed depending on factors such as industry, country, location, or statistical controls. Percentage-point differences and ratios were calculated only when the original studies provided directly comparable numerical results. The findings were not combined into one numerical average because the



studies used different samples, gender definitions, time periods, and statistical measures. For example, a hazard ratio cannot be averaged with a ten-year survival percentage, while logged turnover cannot be directly compared with revenue per dollar invested. Both raw and adjusted findings were considered, especially when controls for experience, funding, industry, or company size changed the results.

The studies were not treated as equally strong evidence. The research studies that had larger or more representative samples, clear outcome definitions, appropriate comparison groups, and statistical controls were weighted more heavily. However, sample size was not the only consideration because a smaller study could measure a specific outcome more directly, but then a very large study could still use a broad sample or a different definition of gender involvement.

The study does have limitations. It only used English-language sources. The definitions of women's involvement had big variation from women-founded, women-owned, women-led, and woman-controlled firms. Publicly available studies may be more likely to report striking findings, and some full datasets could not be checked because they were not publicly available. Despite these limitations, a consistent extraction process made it possible to identify patterns and disagreements across the ten studies. The studies also covered very different countries and time periods, with most of the evidence coming from North America and Europe and from adult owners or founders. None of the included studies focused on East Asia or young or student founders, so the results may not apply directly to those groups.

Results and Discussion

1. Results

Ten studies met the selection criteria for this comparative review. To make the findings easier to compare, the studies were separated into two groups according to their main measure of startup success. Group 1, as presented in Table 1, has five studies that examined investment efficiency or broader financial performance. Only Abouzahr et al. (2018) directly measured revenue per dollar invested. The other four studies looked at related financial outcomes such as capital, sales, profitability, employment growth, and risk-adjusted performance.

Table 1. Investment efficiency and broader financial performance findings.

Study & Setting	Gender Definition & Sample	Success Measure	Women-linked Result	Men-linked Result	Main Finding	Notable Limitation
Abouzahr et al. (2018) 350 MassChallenge accelerator alumni (multiple locations).	At least one woman founder/co-founder versus all-male founding team 92 women-linked and 258 male-founded startups.	Average external funding raised / five-year cumulative revenue / revenue per \$1 of funding.	\$935,000 funding / \$730,000 revenue / \$0.78 revenue per \$1 funded.	\$2.12 million funding / \$662,000 revenue / \$0.31 revenue per \$1 funded.	Women-founded or co-founded startups received less than half the funding but generated 10% more revenue and about 2.5 times more revenue per funding dollar.	Accelerator alumni only / mixed-gender teams grouped with women-founded firms / survey-based data; revenue is not profit or investor return.
Alsos et al. (2006) newly registered Norwegian firms followed for 19 months.	Founder gender descriptive results: 318 firms (61 women-founded, 257 men-founded) Capital analysis: 360; turnover analysis: 327.	Financial capital (debt + equity) and sales turnover, reported as ln(NOK + 10,000).	Capital: 10.57 at registration, 11.00 after 19 months / turnover: 11.81.	Capital: 11.32 at registration, 11.84 after 19 months / turnover: 12.61.	Women-founded firms obtained significantly less capital and had lower unadjusted turnover; the turnover gap disappeared after controlling for capital.	Short follow-up; surviving firms only / self-reported data; logged values are not actual NOK amounts.
Gottschalk & Niefert (2013) Founded German firms (2005–2008) / followed for up to four years.	Female-only versus male-only founding teams / mixed teams separate. 4,654 firms: 503 female-founded, 3,766 male-founded, 385 mixed.	Relative and absolute employment growth; annual sales; return on sales.	Relative growth: 0.203; absolute growth: 1.24 full-time equivalent (FTE); sales: €237,000; return on sales: 10.0%.	Relative growth: 0.265; absolute growth: 1.66 FTE; sales: €360,000; return on sales: 14.4%.	Women-founded firms performed worse unadjusted. After controls, growth gaps disappeared, but sales and profitability remained significantly lower.	Different sample sizes by measure; short observation period; no data on working hours, family responsibilities, risk attitudes, or self-efficacy.



Study & Setting	Gender Definition & Sample	Success Measure	Women-linked Result	Men-linked Result	Main Finding	Notable Limitation
Driga & Prior (2010) Spanish manufacturing small and medium-sized enterprises (SMEs) founded in 2000–2004 and observed through 2005.	Woman-controlled if the CEO was a woman 4,450 firms: 533 woman-controlled and 3,917 man-controlled.	Average annual sales and employment growth; Sharpe ratio based on net profit and profit variability.	Sales growth: 39.70%; employment growth: 19.25%; Sharpe ratio: 0.0349.	Sales growth: 45.20% / employment growth: 21.24% / Sharpe ratio: 0.0838.	Woman-controlled firms had significantly lower sales growth and risk-adjusted performance / employment growth was not significantly different. Lower startup resources partly explained the gap.	Manufacturing firms only / CEO gender rather than founder gender / surviving firms only, creating possible survivorship bias.
Jaiswal (2020) US ventures founded in 2004 and followed through 2011.	Female-majority versus male-majority owner teams 4,928-firm cohort, with 2,756 majority-owned firms used in the analysis.	Annual survival, total revenue, and net profit.	No significant disadvantage in survival, revenue, or profit; average same-industry experience: 9.44 years.	No significant overall advantage; average same-industry experience: 12.85 years.	No overall gender performance gap. Men's 3.4 additional years of industry experience explained 47% of the explained net-profit gap.	One US founding cohort; equal-gender teams excluded / revenue and profit analyses may have survivorship bias.

The second group has five studies that are linked with business survival. These studies measure success through outcomes such as long-term survival rates, closure rates, business exit, and the estimated risk of failure. Their findings are summarized in Table 2.

Table 2. Business survival findings.

Study & Setting	Gender Definition & Sample	Success Measure	Women-linked Result	Men-linked Result	Main Finding	Notable Limitation
Millán et al. (2026) Chilean high-growth startups founded in 2010–2014, all receiving CORFO support and followed for eight years.	Gender of startup team leader 888 firms: 107 women-led and 781 men-led.	Time to business cessation using Cox proportional-hazards models.	Eight-year survival: 49.2%; Model 2 hazard ratio: 0.5743 (42.57% lower failure risk).	Eight-year survival: 31.4% / reference group in the Cox model.	Women-led startups had higher survival. However, gender was not significant in the full model including funding and the gender–funding interaction.	Publicly funded Chilean startups only / few women-led firms; binary gender measure; possible selection effects.
Couture & Houle (2020) Canadian startup corporations entering from 2005–2013.	Majority women-owned (51%+), majority men-owned, or equally owned 534,494 firms: 99,328 women-owned, 333,385 men-owned, 101,781 equally owned.	Ten-year Kaplan–Meier survival for the 2005 cohort; Cox proportional-hazards exit models.	57.1% survived ten years; 14.9% higher exit risk than men-owned firms.	61.3% survived ten years; Cox-model reference group.	Women-owned firms had lower overall survival; equally owned firms had the highest survival at 67.0%. Results varied substantially by industry.	Canadian-controlled private corporations with fewer than 100 employees only; ownership gender was unavailable for some firms.
Kalnins & Williams (2014) Texas sales-tax-collecting proprietorships founded in 1990–2003 and followed through 2006.	Owner gender inferred from first names 1,004,636 proprietorship establishments.	Survival duration using Weibull hazard models across 402 industries and 1,664 ZIP codes.	Longer survival in 24 industries and 76 ZIP codes; strongest geographic advantage in large cities.	Longer survival in 95 industries and 177 ZIP codes; aggregate and broad-sector models generally favored men.	No universal gender advantage: survival differences depended strongly on industry and location.	Texas proprietorships only; gender inferred from names; survival only; no data on firm size, education, hours worked, or profitability.



Study & Setting	Gender Definition & Sample	Success Measure	Women-linked Result	Men-linked Result	Main Finding	Notable Limitation
Farhat & Mijid (2018) US firms from the 2004 Kauffman Firm Survey cohort, followed through 2011.	430 women-owned firms matched with 430 men-owned firms on owner and business characteristics.	Survival, assets, employment, profit, sales growth, and capital injections.	Same survival and performance-growth rates; firms started and remained smaller.	Same survival and performance-growth rates; firms were larger in size and sales.	After matching comparable firms, no gender gap appeared in survival or business-performance growth.	One US founding cohort; matched sample may exclude unmatched firms; women-owned firms remained smaller despite similar growth.
Shiferaw (2009) Ethiopian private manufacturing establishments observed annually from 1996–2002.	Female-owned if women represented at least one-third of owners establishments with 10+ employees, increasing from 471 to 686 annually.	Observed exit rate and discrete-time proportional-hazards risk of exit.	12% observed exit rate; adjusted exit risk about 0.75 times that of male-owned establishments.	18% observed exit rate; hazard-model reference group.	Female-owned establishments had significantly better survival after controlling for size, productivity, ownership structure, and industry factors.	Not limited to startups; firms below 10 employees excluded; “exit” could mean closure, falling below the cutoff, or changing industry; possible selection bias.

2. Discussion

3. Investment Efficiency and Broader Financial Performance

Table 1’s five studies do not show a consistent financial advantage for either the women-associated or the men-associated startups. The most direct evidence of investment efficiency was Abouzahr et al. (2018). As shown in Table 1, women-linked startups received less funding but generated approximately 2.5 times more revenue per funding dollar than the all-male-founded group. This gives one direct example of women-associated startups using investment efficiently even when they received less funding, but it is only one study. This result must be interpreted carefully, because the study examined only companies linked to the MassChallenge accelerator, so the businesses had already passed a competitive selection process. Another point is that companies with one woman and several men on the founding team were grouped as businesses founded by women. The study measured revenue rather than profit. High revenue can coincide with high costs, so the result does not show that women-linked companies were more profitable.

Alsos et al. (2006) show why access to financial resources matters. The women-founded businesses in Norway received less capital at the registration stage and over the 19 months that followed. Unadjusted sales turnover was lower for the women-founded businesses as well; however, the gender difference in turnover disappeared after the researchers controlled for the amount of capital the businesses had received. This shows that capital was important to the original difference in turnover. However, it does not prove that gender had no influence, because access to capital may itself be connected with gender. This supports the argument that unequal access to capital can make differences in performance at a later time.

Research from Germany by Gottschalk and Niefert (2013) reported less favorable results for women-founded startups. Before controls were added, women-founded businesses had lower annual sales and return on sales. Once founder and business characteristics were considered, the employment-growth differences disappeared, but the gap in sales and profitability stayed large. Explaining these results, the authors note issues, such as women having less education and experience in their industries; moreover, they tended to form small founding teams (Gottschalk & Niefert, 2013).

The findings from Gottschalk and Niefert (2013) connect in some ways with those by Driga and Prior (2010) who looked at Spanish manufacturing firms. Women-controlled businesses had lower sales growth and risk-adjusted performance, but the difference in employment growth was not statistically significant. Continuing the investment pattern, women-controlled firms started out with fewer assets and employees, so it points to them coming into the market in a weaker position. It brings attention to the point that performance differences cannot be looked at without thinking about the conditions businesses started out from.

Jaiswal (2020) found no overall disadvantage for female-majority-owned ventures in survival or net profit. The difference that did appear was related to the amount of related industry experience each group had. Male-majority owners had more industry experience, and this explained 47% of the part of



the net-profit gap accounted for by the model. This result points to experience being important, but it does not prove that gender had no influence. Opportunities to gain industry experience may themselves be related to gender.

Taken together, the financial studies only partly support the hypothesis. Repeatedly, the data showed women-associated businesses starting out with fewer financial resources. Abouzahr et al. (2018) also provide direct evidence of higher revenue efficiency in their particular sample. The other studies do not consistently show women-associated firms as generating stronger financial results. Some found lower raw sales or profitability, and then others found that the gaps disappeared or became smaller after funding, experience, industry, and business characteristics were considered. Therefore, it would be inaccurate to conclude that startups associated with either women or men are always more financially successful.

4. Business Survival

The business-survival studies in Table 2 also produced mixed results. The number of studies favoring each outcome, however, was not treated as a measure of evidentiary strength because the samples and research designs differed substantially. The results still support the expectation that survival differences would be less consistent than differences in access to investment.

Millán et al. (2026) reported stronger survival among women-led Chilean startups in its earlier analysis, as summarized in Table 2. However, it should also be noted that the full model pointed to no gender advantage when funding and the interaction between gender and funding was considered. The result should not be overlooked because it suggests that any survival advantage may be connected to the relationship between leadership and access to financial support, more so than gender operating independently. The study was also limited to startups that had received support through Chile's CORFO program, so the findings seem to be excluding the companies without government assistance.

Shiferaw (2009) also reported a lower adjusted risk of exit among female-owned establishments after business size, productivity, ownership structure, and industry were considered. This result gives support to the idea that women-owned firms can be at least as sustainable as those owned by men. It should also be noted that these were manufacturing establishments with at least ten employees and that some were not completely new startups. An exit could also mean that a company had fallen below the employment requirement or moved to another industry, so it was not just about complete closure.

Couture and Houle (2020), however, found lower overall survival among majority women-owned Canadian startups, and equally owned firms had the strongest survival. This suggests that mixed ownership may provide benefits that are not available to businesses controlled mainly by one gender. It was found as well that the results had large differences in outcomes across industries, so the types of businesses that women and men entered appear relevant.

Farhat and Mijid (2018) add support to the final interpretation from Couture and Houle (2020). Their study matched 430 women-owned firms with 430 men-owned firms that had similar owner and business characteristics. After this matching process, there was no gender difference in survival, profit, or growth rates. Women-owned firms started smaller and continued to have lower total sales, but their rate of development was similar to that of the matched male-owned companies. It points to simple comparisons of all women-owned and men-owned businesses can exaggerate gender differences when the groups differ in industry, experience, starting size, or working conditions. At the same time, the matched sample only compares firms that already looked alike on these characteristics. It does not show whether gender played a role in why firms had different sizes, industries, or levels of experience before the matching happened.

The idea that business context alters results continues in the Kalnins and Williams (2014) study. A very large sample of Texas proprietorships showed men-owned businesses to have stronger survival in broad aggregate comparisons. However, women-owned businesses performed better in some industries and locations, particularly in large cities, showing that overall statistics can hide important patterns within particular markets. A location or industry that provides strong networks, customers, or support for women may produce a different outcome from the overall national or regional result.

The survival studies as a collective do not show a universal advantage for either gender. Women-associated firms performed better in some samples, men-associated firms performed better in another, and several findings changed when controls or narrower industry and location categories were used. The evidence therefore supports the second part of the hypothesis. Survival differences appear to be smaller and more dependent on context than a basic comparison of women and men would suggest.

It would be unwise to treat each study equally; for example, Couture and Houle (2020) and Kalnins and Williams (2014) used several hundred thousand or more than one million businesses, so their findings



provide stronger evidence about broad survival patterns than smaller specialized samples. Farhat and Mijid (2018) used a much smaller sample, but its matched design made the comparison between women-owned and men-owned firms more controlled. Abouzahr et al. (2018) directly measured revenue per dollar invested, but its accelerator sample of 350 businesses limits how widely the result can be applied. Therefore, the conclusions were based on study quality and relevance as opposed to counting how many studies supported each outcome.

5. Factors Explaining the Different Findings

The recurring pattern across the two tests in this study is that additional factors beyond gender need to be looked at. One of these that is critical is access to resources. The financial studies repeatedly show that women-associated firms are usually starting with issues like less investment and a smaller number of employees. Lower starting resources equates to less assets, and it can affect all parts of the business from product development to factors like marketing and expansion. It makes it harder for companies to grow through sales even when the business uses its available capital effectively. Alsos et al.'s (2006) findings support this because the turnover gap disappeared once financial capital was controlled.

Experience seems to be of great importance as well. Jaiswal (2020), for example, showed that male-majority owners had more related industry experience, so this had an influence on the net-profit difference between the genders. Previous experience stretches wide as it can give knowledge of customers, suppliers, regulations, and management. It may also help founders build networks that support financing and growth. The importance here is that what might seem like a gender difference may partly be connected to unequal previous opportunities to gain business experience.

Industry and location are further explanations. Some industries require substantial capital and are more likely to attract venture investors, while others operate at a smaller scale. Couture and Houle (2020) supported this point with the survival results changing depending on the industries; moreover, Kalnins and Williams (2014) showed big differences in the industries and geographical areas. Comparing all startups together can be misleading if women and men are concentrated in different parts of the economy.

However, funding, networks, and industry experience should not be treated as completely separate from gender. Gender inequality can affect access to important things like investors and mentoring as well as earlier opportunities for leadership and business experience. It means that when a performance difference becomes smaller after funding or experience is controlled, this does not mean that gender had no influence. These resources may be pathways through which gender indirectly affects startup outcomes. This interpretation still recognizes the importance of business resources without overlooking the unequal opportunities that may shape how those resources are obtained.

The definitions used by the studies had an impact on what the comparisons showed. Some research examined the gender of the founder, but then there were other studies using terms like majority ownership or the main startup leader. A company with one woman and several male founders may have been treated as women-linked in one study but as mixed-gender in another. These categories describe different types of involvement and should not be treated as identical.

6. Context and Limitations

There are some important limits to how widely these results can be applied. The ten studies cover different countries and time periods, and most of the evidence comes from North America and Europe and from adult business owners or founders. None of the included studies examines East Asia or student or young founders. Venture funding, gender norms, and economic conditions vary across countries and over time, so the studies should not be treated as if they came from one setting.

Some of the samples go beyond a strict definition of startups. Kalnins and Williams (2014) studied Texas proprietorships and inferred owner gender from first names, and the Shiferaw (2009) study looked at manufacturing establishments with at least ten employees. The review only used English-language sources, the studies used different definitions of women's involvement, and no formal statistical meta-analysis was completed. These issues do not make the studies unusable, but they do limit how confidently one result can be applied to all startups.

7. Practical Implications and Future Research

The mixed findings can have some practical meaning. Investors and accelerators should be careful about assuming that founder gender by itself predicts whether a startup will perform well. Several studies showed women-associated businesses starting with less capital, fewer assets, or less industry experience, so support programs may need to think about access to funding, mentoring, networks, and earlier experience. At the same time, the evidence does not show that women-founded businesses will



always perform better once they receive funding. Future research could follow the same businesses over time and measure both revenue efficiency and survival, instead of studying these outcomes in separate samples. It would also help to use clearer definitions of women-founded, women-owned, and women-led businesses and to include more research from East Asia and from young or first-time founders.

8. Comparison of the Two Success Measures

The results show why startup success should not be judged through one measure alone. Investment efficiency explains how effectively a business turns financial resources into revenue, but it does not show if a company is going to stay active over the long term. Similarly, survival does not guarantee that financial performance is strong. A business can keep operating for a number of years, while showing little growth or profit. The evidence gives partial support to the hypothesis. Women-associated businesses usually received fewer resources, and one study showed much greater revenue per dollar invested. The broader financial performance across all five studies was mixed though. The survival evidence was also inconsistent and depended strongly on the sample and statistical controls. The most reasonable conclusion from the results is not that women or men are naturally better at creating successful startups. Instead, gender is connected with differences in funding, experience, industry, starting size, location, and ownership structure. These conditions appear to play an important role in influencing financial performance and long-term survival, and some may also be pathways through which gender has an indirect effect.

Conclusion

This study asked how women-led startups compare with businesses associated with men in terms of investment efficiency, broader financial performance, and business survival. As opposed to one gender outperforming the other, the findings are mixed across the measures in the studies included in this research paper. The clearest pattern was that women-associated businesses tended to receive less investment and therefore started with fewer assets and smaller teams. That weaker starting position can affect later outcomes, including financial results and survival.

The most direct evidence on claims of greater investment efficiency among women-linked startups is Abouzahr et al. (2018). It found that women-linked firms generated more revenue for every dollar of funding in that particular accelerator sample. The other four financial studies did not directly test revenue per dollar invested; they looked at broader measures such as capital, sales, profitability, employment growth, or risk-adjusted performance. Some showed lower sales or profitability among women-associated businesses, while others found that the differences disappeared or becoming smaller when controls were considered. The mixed outcome carried over to the survival results as well.

Women-associated businesses survived longer in some studies, men-associated businesses had stronger survival in another, and other research found no clear difference between the groups.

Rather than treating the two groups as competitors, the results point to funding, previous industry experience, business size, industry, and location as important parts of explaining startup performance. These factors should not be treated as completely separate from gender, because access to funding, networks, and experience may itself be influenced by unequal opportunities. It was clear too that there is a lot of variation between studies when it comes to defining a women-associated startup. Some studies use women-founded or women-owned, while others use the broader category of women-led. These are not identical categories, which limits how far the studies can be combined into one claim.

This study has several limitations. First, it included only English-language sources. There was also the fact that some studies examined established small businesses, proprietorships, or manufacturing establishments, so they were not actually strict startups. The samples came from different countries and time periods, most were based on adult founders, and none focused specifically on East Asia or young founders. The samples and success measures varied considerably, and there was also no formal statistical meta-analysis completed. Despite these limitations, the evidence suggests that startup success is shaped by resources, experience, and business context, while gender may indirectly influence access to those resources and opportunities.

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References

- Abouzahr, K., Krentz, M., Harthorne, J., & Brooks Taplett, F. (2018, June 6). Why women-owned startups are a better bet. Boston Consulting Group. <https://www.bcg.com/publications/2018/why-women-owned-startups-are-better-bet>
- Alsos, G. A., Isaksen, E. J., & Ljunggren, E. (2006). New venture financing and subsequent business growth in men- and women-led businesses. *Entrepreneurship Theory and Practice*, 30(5), 667–686. <https://doi.org/10.1111/j.1540-6520.2006.00141.x>
- Ang, Y. Q., Chia, A., & Saghafian, S. (2022). Using machine learning to demystify startups' funding, post-money valuation, and success. In V. Babich, J. R. Birge, & G. Hilary (Eds.), *Innovative technology at the interface of finance and operations* (pp. 271–296). https://doi.org/10.1007/978-3-030-75729-8_10
- Ben Saad, F. (2024). How to measure the success of technology-based start-ups—A comprehensive overview of the perspectives of academics & practitioners. *Junior Management Science*, 9(1), 1306–1340. <https://doi.org/10.5282/jums/v9i1pp1306-1340>
- Couture, L., & Houle, S. (2020). Survival and performance of start-ups by gender of ownership: A Canadian cohort analysis (Analytical Studies Branch Research Paper Series No. 450). Statistics Canada. <https://publications.gc.ca/site/eng/9.891234/publication.html>
- Donegan, A. (2026, March 4). 2025 US All In: Female founders in the VC ecosystem. PitchBook. <https://pitchbook.com/news/reports/2025-us-all-in-female-founders-in-the-vc-ecosystem>
- Driga, O., & Prior, D. (2010). Start-up conditions and the performance of women- and men-controlled businesses in manufacturing industries. *Revista de Contabilidad—Spanish Accounting Review*, 13(1), 89–124. [https://doi.org/10.1016/S1138-4891\(10\)70013-3](https://doi.org/10.1016/S1138-4891(10)70013-3)
- Elam, A., Hughes, K. D., & Samsami, M. (2024). GEM 2023/24 women's entrepreneurship report: Reshaping economies and communities. Global Entrepreneurship Research Association. <https://gemconsortium.org/report/202324-womens-entrepreneurship-report-reshaping-economies-and-communities-2>
- Eurostat. (2024, October 23). Business demography (bd): Reference metadata in Single Integrated Metadata Structure (SIMS). European Commission. https://ec.europa.eu/eurostat/cache/metadata/en/bd_sims.htm
- Farhat, J., & Mijid, N. (2018). Do women lag behind men? A matched-sample analysis of the dynamics of gender gaps. *Journal of Economics and Finance*, 42(4), 682–709. <https://doi.org/10.1007/s12197-017-9416-8>
- Gangwani, D., Zhu, X., & Furht, B. (2023). Exploring investor-business-market interplay for business success prediction. *Journal of Big Data*, 10, Article 48. <https://doi.org/10.1186/s40537-023-00723-6>
- Gottschalk, S., & Niefert, M. (2013). Gender differences in business success of German start-up firms. *International Journal of Entrepreneurship and Small Business*, 18(1), 15–46. <https://doi.org/10.1504/IJESB.2013.050750>
- Jaiswal, M. (2020). Gender differences and new venture performance. *New England Journal of Entrepreneurship*, 23(1), 41–61. <https://doi.org/10.1108/NEJE-08-2019-0038>
- Kalnins, A., & Williams, M. (2014). When do female-owned businesses out-survive male-owned businesses? A disaggregated approach by industry and geography. *Journal of Business Venturing*, 29(6), 822–835. <https://doi.org/10.1016/j.jbusvent.2013.12.001>
- Mayer-Haug, K., Read, S., Brinckmann, J., Dew, N., & Grichnik, D. (2013). Entrepreneurial talent and venture performance: A meta-analytic investigation of SMEs. *Research Policy*, 42(6–7), 1251–1273. <https://doi.org/10.1016/j.respol.2013.03.001>
- Millán, B., Kuschel, K., Bustamante, C., Carrasco, J. A., & Catalán, P. (2026). Female leadership in startups: Analyzing survival rates and challenges in emerging economies. *Management Research: Journal of the Iberoamerican Academy of Management*. Advance online publication. <https://doi.org/10.1108/MRJIAM-06-2025-1744>
- Organisation for Economic Co-operation and Development. (2020, May 13). Start-ups in the time of COVID-19: Facing the challenges, seizing the opportunities. https://www.oecd.org/content/dam/oecd/en/publications/reports/2020/05/start-ups-in-the-time-of-covid-19-facing-the-challenges-seizing-the-opportunities_e5297e09/87219267-en.pdf
- Otto Beisheim School of Management. (2026). Start-up: Embracing innovation and entrepreneurship. <https://www.whu.edu/en/news-insights/glossary/start-up/>



Shiferaw, A. (2009). Survival of private sector manufacturing establishments in Africa: The role of productivity and ownership. *World Development*, 37(3), 572–584.
<https://doi.org/10.1016/j.worlddev.2008.08.004>

U.S. Bureau of Labor Statistics. (n.d.). Establishment age and survival data. U.S. Department of Labor.
<https://www.bls.gov/bdm/bdmage.htm>

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Sustainability in the Sportswear Sector: Problems, Progress, and Potential Improvements

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Abstract

As one of the biggest consumers of the world's water and producers of emissions, the textiles industry has come under fire for sustainability issues in recent years. Sportswear firms stand out from their peers as big users of synthetic fibers like polyester and nylon produced from crude oil which can shed harmful microfibers into local waterways. They also have found themselves under fire for poor working conditions at supplying factories and their use of chemicals to achieve various desirable characteristics of sporting clothes and footwear has also been found to have negative consequences for wider society.

While firms have sought to address their issues and many have committed to lowering emissions and improving practices in the coming years, much remains to be done to achieve their goals. Clearly, economic factors affect what firms can do to improve sustainability in a competitive market when consumers are sensitive to price differences between the likes of Nike and Adidas.

Nevertheless, this essay argues that more could be done even in the face of cost constraints. Given that young shoppers tend to be more mindful of sustainability issues and sportswear will be marketed to these shoppers in the years to come, firms would do well to listen to them.

Keywords

Sustainability in the sportswear sector; Sustainability issues; Sportswear manufacturer; Textile industry

Introduction

Despite associating themselves with healthy lifestyles and elite performance, sportswear brands have been criticized over the years for manufacturing in ways that are harmful to the health of the environment and the well-being of their own workers. While such criticisms are not unique in the wider clothing and fashion sector, Nike, Adidas and Puma and their peers find themselves subject to some of the strictest judgements. This is because their products must typically deliver some level of technical performance, comfort and suitability for specific sports and activities. At the same time, the wide range of sportswear manufacturers active around the world means firms are competing not just on quality but also on price. Firms must therefore find ways of competing on several fronts simultaneously. This often means using a range of materials and chemical treatments in addition to the usual dyeing and weaving of everyday or even luxury clothing. The final product is often produced at least partly from synthetic materials like polyester or nylon, which are made through processes involving the burning of hydrocarbons like oil, and which can shed microplastic pollution when washed.

Sustainability issues do not start and end in the field of environmental science, however. Firms often outsource production of running shoes and sports clothing to factories in countries where labor laws and worker rights vary. Big brands have been scrutinized in recent years over links to forced labor and unsafe practices in some of these factories. This has led to many opening themselves up to external audits as well as taking internal action. Despite such efforts, accusations from the likes of labor and human rights groups continue to suggest there is work to be done.

In this essay, I examine sustainability issues amongst sportswear manufacturers in 5 sections. The next section outlines the big issues with sustainability as they relate to fossil fuel use, water consumption and pollution, waste, and social responsibility issues. The third section then covers what firms in the sportswear industry are already doing. Section 4 discusses the economics of the industry as it relates to sustainability issues. Section 5 then offers thoughts on what more could be done by producers and consumers to up their own game on sustainability. The final section concludes.



Why this matters

Although sustainability is a topic with which all industries must contend, sportswear has particularly visible issues that are not easily remedied. Not only is it a large consumer of hydrocarbons and water, but also the sportswear industry is a large producer of waste chemicals.

What elevates the environmental impact of sportswear relative to other forms of textiles is the particularly strong use of synthetic fibers – the production of which tends to require hydrocarbons – and use of blended fabrics and materials. Blends are hard to separate and can therefore be difficult to recycle. Consequently, sportswear manufacturers are less able to re-use existing materials to meet demand and must rely on producing goods from raw materials. This ultimately inhibits improvement in the sustainability practices of sportswear firms.

The industry also employs an estimated 60 to 70 million people worldwide, whose labor is responsible for 2% of the world's total economic output (*Garments and Apparel*, 2024). Sportswear firms have a duty of care to ensure these workers have safe and clean working environments and are paid fairly.

Sustainability in sportswear: what are the issues?

Fossil Fuels

One of the big issues facing the sportswear industry is its link to fossil fuels. According to the UN, the broader fashion industry accounts for as much as 8% of global greenhouse gas emissions (Mishra, 2025). A significant driver of this is the use of synthetic fibers like polyester in the manufacture of textiles.

Polyester is essentially a plastic made from polyethylene terephthalate (PET), which is derived from crude oil. According to Textile Exchange, polyester accounts for the majority of the world's manufactured fibers each year. In 2024, it accounted for almost 6 in every 10 tons of all fiber produced worldwide. Total production of polyester per person is projected to rise significantly by 2030 (*Materials Market Report*, 2025).

Mass production of polyester – alongside other synthetic materials, for which production is energy intensive – has negative spillover effects on the environment and wider society. A recent study by Han et al. (2026) estimated that global emissions from plastics increased 170% in the decade to 2022 and textiles were one of the biggest drivers of this growth.

This is a sore point for sportswear in particular. More than many other strands of the fashion and textiles industry, sportswear manufacturers use synthetic materials including polyester, spandex, and rubber in producing clothing and footwear. This is of course by design, as such materials allow manufacturers to offer consumers more breathable clothing, water proofing, and other desirable properties of sportswear.

For example, running shoes are typically comprised of synthetic materials like rubber soles for grip and polyester upper components to support airflow (Fashion for Good, 2026). Adidas makes the latest Real Madrid soccer jerseys out of polyester, just as they and their competitor Nike do for other sports teams' jerseys they sell at large scale around the world.

Not only are sportswear manufacturers liable to have outsized carbon footprints from manufacturing processes, but also they rely on global shipping networks to deliver goods from production sites to consumer markets. Nike's biggest market in terms of revenue is North America, followed by Europe, the Middle East and Africa (*Nike's Revenue by Region 2026*, 2026). However, the vast majority of Nike's goods are produced in China and Southeast Asia (Williams, 2019). Transporting goods between regions typically requires the burning of hydrocarbons to power ships and trucks.

Despite this, shipping is considered relatively more energy efficient than the production process. This is at least the case when it comes to Nike's main source of global revenues, footwear. Researchers at MIT found that a typical pair of running shoes requires more than 360 processing steps to assemble, many of which are carbon-intensive. Furthermore, with more than a third of production based in China, where coal is still widely used in electricity production, powering factories may be more carbon intensive than it would be in countries where cleaner energy is more prevalent. Consequently, more than two-thirds of the carbon associated with running shoes is estimated to originate from their manufacturing processes (Chu, 2013).



It is not just the producers that contribute to carbon emissions. The washing, tumble drying and ironing of a cotton t-shirt account for 48% of its carbon footprint. This suggests consumers make a significant contribution to the total emissions associated with washable sportswear goods. Cutting the tumble drying and ironing would reduce the footprint by an estimated 37% (*The True Cost of Sportswear*, n.d.).

Water

The production of materials depends in part on water. For natural materials like leather and cotton, water is used in farming or crop growing. For the former, not only is water consumption a factor in raising animals, but also the tanning process is water-intensive. For the latter, irrigation may be needed, particularly when rainfall is insufficient. There are also potential concerns with run-off water carrying chemicals like pesticides contaminating local water systems.

Further along the supply chain, industrial processes required to make sportswear goods often need water which is sourced from lakes or rivers near to production sites. Industrial water consumption can reduce the quantity and flow of the local water source, potentially affecting local populations and wildlife dependent on it. This tends to be more of an issue with the production of natural fibers like wool and cotton, rather than synthetic fibers. For instance, in order to make one cotton shirt, 2,500 liters of water are needed but to make a single polyester dress requires less than half this quantity (*Fashion Business Water Usage*, n.d.).

There are other processes required in the manufacture of sportswear which can also be problematic for firms and the environment. Dyeing and bleaching garments can see wastewater returned to local water sources carrying harmful chemicals. Indeed, in the past, some of the biggest concerns over the environmental effects of sportswear manufacturing have come from wastewater pollution created through chemicals bleeding in to local water systems (Hubbard, n.d.).

Although industry makes an effort to improve water efficiency and reduce negative spillover effects to local water systems caused by the production of goods, the consumption of them can also cause negative externalities.

When washing sportswear made from synthetic fibers, garments can shed small fibers. These microplastics that may escape from the likes of polyester and nylon sportswear in the washing machine can then end up in waterways. Typical domestic washing machines lack filters capable of trapping these tiny fibers and they can escape wastewater treatment, potentially ending up in drinking water and affecting ecosystems. Research has found that up to 40% of microfibers can escape from water treatment facilities into lakes, rivers and oceans (Hartline et al., 2016). Even when microfibers are removed during water treatment, they can end up in 'sewage sludge'. After processing it to remove pathogens, this mixture of solid materials can end up as fertilizer which may then contaminate crops when added to them.

Dyes, flame retardants, anti-wrinkle agents and other chemical treatments applied to sportswear have been found to be toxic (Weis, 2024). Some chemicals found in clothing are linked to cancer (Wicker, 2023). Microfibers may even combine with other harmful contaminants in water like pesticides and metals, creating even more harmful compounds. Consequently, when passed into local water systems, these harmful substances contaminate the food chain. Fish and other aquatic animals consuming microfibers end up as food for other animals and even humans.

The Center for Environmental Health (CEH) in California has sent legal notices to numerous sportswear brands after tests in recent years indicated high levels of Bisphenol A (BPA). According to the Mayo Clinic, BPA exposure may be linked to high blood pressure, type 2 diabetes and cardiovascular disease. Studies also suggest BPA exposure can affect children's behavior and affect the brain (Mayo Clinic Staff, 2023). CEH has issued notices to the likes of Under Armour, New Balance and Skechers to name just a few, citing concerns with BPA in products including sports bras, athletic shirts and shorts, and leggings (Difrisco, 2022).

Despite its potentially harmful effects, the human body can at least break down BPA relatively quickly. Other chemicals often found in sportswear take far longer to break down. Per- and polyfluoroalkyl substances – known as PFAS – have been dubbed 'forever chemicals' due to their resistance to disintegration. Although they have only been in existence since the 1940s, it is believed that they can last for thousands of years. According to Johns Hopkins University, PFAS can affect reproductive systems, affect development, and increase cancer risk among other harmful effects (Coulson, 2024).



Sportswear companies like Nike, Adidas, and others have used PFAS in their goods to make fabrics resistant to sweat, water, and stains (Tan & Islam, 2026). However, these companies found themselves the target of Greenpeace protests in the 2010s over the use of PFAS in sports and leisure apparel. Famously, the environmental charity staged what looked like a soccer match near the Adidas head office in Germany in 2014, with ‘players’ wearing red paint on their feet and displaying the words ‘detox our feet’.

Although sportswear companies, including Adidas, publicly stated their intentions to eliminate PFAS and other hazardous chemicals, recent tests suggest they are still present in a range of sportswear goods, including sports bras made by the likes of Nike, Adidas, and Under Armour (Gribkoff, 2022).

Even more recently, Lululemon found itself in trouble in Texas. The state’s Attorney General launched an investigation into whether the company misled buyers of its activewear products. The investigation will focus on whether PFAS are present in their materials and if so, whether this contradicts the company’s branding messages around wellness and sustainability (Texas Office of the Attorney General, 2026). Lululemon denies these claims, saying it eliminated PFAS from its clothing in 2023.

There is much that scientists still have to learn about PFAS, which are common not just in sportswear but also a wide range of consumer goods. However, it is estimated that 98% of Americans have traces of PFAS in their blood, and 200 million Americans are served by water systems in which PFAS are known to be present (Amarello, 2020). This is not a problem exclusive to the USA of course, and the prevalence of PFAS worldwide suggests the vast majority of us likely have this in our blood. A study even found that babies were exposed to a significant amount of PFAS before birth (Liu et al., 2026).

Waste

Around the world, almost two-thirds of clothing goes to landfills, and a quarter of fashion waste is incinerated, according to recent estimates. An estimated 60% of new clothing will be in landfills within a year of its purchase (Hall, 2024). In the USA alone, more than 9 million tons of clothing and footwear were delivered to landfills in 2018 (the most recent year for which data is available). In the same period, less than 20% of that amount was recycled (United States Environmental Protection Agency, n.d.).

Recycling rates remain low for many materials used to make sportswear. Although polyester does relatively better than other materials like elastane (3%), nylon (2%), and cotton (1%), the percentage of new polyester production from recycling actually fell steadily from almost 15% in 2021 to just 12% in 2024 (the latest year for which data is available). Despite a rise in the total quantity of polyester made from recycled material, total production has grown by almost 30% over this period, outpacing the rise in recycled production.

Given the challenges and relatively low rates of recycling sportswear, significant amounts of sportswear goods – much of it made from plastic-based materials – goes to landfills. It can sit there for up to 200 years as it does not decompose like natural materials (Plummer, 2026). Even when it does break down, it can end up as microplastics that contaminate soil and water, to the detriment of ecosystems. PFAS may also be present in these materials, which could leach into soil and affect ecosystems for generations to come.

Nevertheless, as sustainability has increasingly affected consumption and production decisions in sportswear and textile markets more broadly, producers have sought to meet demand for their products with more sustainable production. Recycling materials is not straightforward though. It can be a labor-intensive process which may require the use of chemicals, which itself poses problems for workers and the local environment (*Materials Market Report*, 2025).

Another challenge in making more use of recycled material is sportswear producers’ use of blended fibers. Separating individual fibers from blends can be technically challenging and costly. Chemical finishes may also be applied to clothing which can create further complications in encouraging more of a circular economy for sportswear goods.

Social sustainability

Sportswear firms have faced criticism in the past for outsourcing production to factories with poor working conditions and sometimes using child labor. After facing huge public pressure to address labor conditions, in 1999 Nike founded the non-profit Fair Labor Association to monitor and train companies



in safe working practices (The World, 2016). Today, Nike is joined by the likes of New Balance, Adidas, New Era and Arena as accredited members.

However, sportswear firms such as these continue to be accused of being complicit in labor issues amongst suppliers. In 2020, the Australian Strategic Policy Institute (ASPI) published findings from its investigation into the use of forced labor of Uyghur Muslims forcibly relocated outside of their native Xinjiang to other parts of China. ASPI identified 82 companies that either directly or indirectly benefit from the use of such workers. Amongst them were Nike, Adidas, Fila, Puma and Skechers. ASPI's report claimed that Uyghur workers in a Qingdao factory made Nike shoes during the day before attending a night school with a curriculum matching that of 're-education camps' in Xinjiang (Xu et al., 2020). In 2022, researchers found traces of cotton in Adidas and Puma t-shirts directly from Xinjiang. Both companies denied they had links to the region.

In the last few years, Adidas and Nike have continued to face criticism on labor issues ranging from lack of access to filtered drinking water to allegedly failing to pay wages. In a recent report, Amnesty International USA accused suppliers of major firms including Adidas of suppressing labor rights and aggressively discouraging workers from joining trade unions (2025). Puma has also come under fire for similar problems relating to its own suppliers (Brook et al., 2023).

What sportswear firms are doing to boost sustainability efforts

Amidst rising awareness of sustainability and the role firms can play, and facing pressure from the likes of Greenpeace and politicians, major sportswear firms have been making an effort to address sustainability issues.

In its most recent assessment of major firms' performance on sustainability matters around the world, S&P – a financial and analytics company – named Asics, Puma, and Anta Sports (a major Chinese sportswear producer) as standout players in the sportswear sector. The S&P Sustainability Yearbook names companies S&P consider to be strong performers on sustainability issues relative to their peers (S&P Global, 2026).

In 2018, major brands including Nike, Adidas, Puma, Decathlon and Lululemon signed up to the United Nations' Fashion Industry Charter for Climate Action, alongside other major clothing and footwear brands ranging from H&M to LVMH. Signatories commit to reducing their emissions by 30% between 2015 and 2030, and to achieving net zero emissions by the year 2050.

However, in a recent progress report, the UN stated that although climate action is progressing amongst the signatories, it is not at the required pace to hit 2030 targets. The UN notes progress does vary but different levels of disclosure make it challenging to fully assess each firm's progress (UNFCCC Authors, 2025).

Consumers may well perceive such differences. In its latest annual rankings of the world's top brands by reputation, RepTrak placed Adidas in 2nd place, while Nike has fallen to number 50. Only 2 years ago both were similarly placed (2026 *Global RepTrak*, 2026). Adidas' rise in the standings is a result of improved perceptions over sustainability issues including employee well-being.

Firms across the sector have launched various initiatives to try and improve their environmental impact. For example, Puma announced it is working with RE&UP Recycling Technologies to improve its use of polyester recycled from apparel. By 2030 the company is targeting a rate of 100% for recycled fibers used in its polyester fabric (*PUMA and RE&UP Announce a Multi-Year Collaboration to Scale Circular Textile Solution*, 2025).

More important than perceptions are actions and firms are starting to build up a track record of delivering change. Puma announced it reduced its greenhouse gas (GHG) emissions by 24% between 2022 and 2023 and it achieved its goal of producing 90% of its products from recycled or certified materials in 2024 (*PUMA Reaches Goal of Making 9 out of 10 Products with Recycled or Certified Materials*, 2025). Adidas announced a reduction of 22% in Scope 1 & 2 GHG emissions (these are emissions the company has direct control over) between 2022 and 2025 and says 99% of polyester used comes from recycling (Adidas, n.d.). Meanwhile Nike announced an even more impressive 69% of GHG emissions between 2020 and 2024, and a 40% reduction in freshwater consumption by material suppliers over the last decade (Nike, n.d.).



While firms work on reducing their carbon footprints, efforts to promote more circular use of materials and products have increased. Some firms have launched their own programs to recycle old goods. Such programs include New Balance' Reconsidered and Nike Refurbished amongst others. Firms are also partnering with companies that can help improve material recycling rates. One example of this is Lululemon's partnership with the Australian company Samsara Eco, which is helping the firm improve its use of textile-to-textile recycling (lululemon, 2024).

As regards labor issues, firms like Nike and Adidas publicly disclose the companies to which they outsource production. This allows human rights and labor organizations to better monitor and assess compliance with ethical standards and local laws.

Sportswear firms now publish codes of conduct and policies relating to working conditions and human rights on their website. Many also state they conduct internal audits. Firms who are members of the Fair Labor Association are required to allow independent and unannounced audits from external examiners. Both Adidas and Puma signed up to the Pakistan Accord, which commits them to certain standards on safety at suppliers in the country (International Accord for Health and Safety in the Textile and Garment Industry, n.d.).

Despite their intentions, firms still face criticism over working conditions. This is similarly true for their environmental efforts. The industry has been accused of 'greenwashing', which refers to the practice of making something appear clean and environmentally friendly when it is not. These accusations have cast doubt over the credibility of firms' sustainability goals and even over achievements firms have reportedly made. One recent example of this is Nike, which got in to trouble in the United Kingdom when it was ruled to have made misleading sustainability claims in advertising its tennis shirts (Mitchell, 2025).

Meanwhile, Adidas was taken to court in Germany by an environmental and consumer protection agency after being accused of deception over failing to disclose how it would meet its sustainability goals (Wenzel, 2025). This court case highlights one risk firms may face in overpromising and underdelivering on sustainability issues. As Greenpeace alleged of Adidas, it did not take enough action to effect change despite being one of the first global companies to commit to ending the use of hazardous chemicals in its goods production back in 2011. Greenpeace says the company failed to set clear targets for this goal and consequently made little progress (Brodde, 2014).

The economics of sustainability in the sportswear market

As the previous section suggests, firms are being held accountable on sustainability issues. However, not all sportswear consumers equally prioritize sustainability issues when they make spending decisions.

According to consultancy Bain & Company's analysis of its own global consumer survey, the most important factors when purchasing clothes and accessories are quality, price, fit, durability, and style. Environmental considerations and social impact ranked 6th and 10th respectively (D'Arpizio et al., 2022). Clearly, price and value for money continue to be the dominant factors in determining sportswear spending decisions.

Furthermore, Bain & Company identifies five groups of consumers within its sample which broadly give similar responses to questions relating to sustainability issues. Looking at this breakdown suggests a positive relationship between consumers' willingness to take sustainable action and consumer incomes. In other words, those who place more emphasis on these issues are those who can most afford to purchase sustainably sourced products at higher prices.

Relatedly, a recent survey conducted for a study in India – a country where the typical consumer income, as measured by GDP per person, is lower than major sportswear consuming countries like North America, Europe and China (International Monetary Fund, 2026) – also found price, design and fit to be the most important considerations when shopping for Nike and Adidas products (Bhatnagar, 2026).

Even in larger, high income consumer markets, at times of economic uncertainty and relatively high price inflation consumers may be more sensitive to prices and reduce their spending plans for sportswear (Becker et al., 2022). When consumers are more constrained by finances, they may be less likely to buy sporting goods made with (for example) organic materials sourced from producers with safe working practices if the price is above alternatives available to them. As suggested by the Indian



study, this may be especially true in lower income countries where consumers may be most sensitive to price.

While it may not be the number one factor determining sportswear spending decisions, issues relating to sustainability are clearly a consideration. Bain & Company report that around 15% of global fashion consumers are 'already highly concerned about sustainability' and these shoppers make spending decisions which try to reduce harm. A problem for not just these consumers but also the remaining 85% is the lack of transparency – and in some cases credibility – around firms' sustainability practices.

Bain & Company's research notes there is a gap between consumers' attitudes (what they say in surveys) and their behavior (what they actually do). For example, consumers report buying secondhand clothes and responsibly disposing of unwanted clothing more than they actually do. Of all the factors considered in the report, the largest discrepancies between consumers' reported behavior and actions occur when people must do their own homework before shopping. These are actions like buying from brands 'with ethical labor policies' and with 'sustainability certification', the information for which does not appear on packaging. Without it, consumers need to do their own research to know whether they are buying sportswear which can accurately be described in these ways.

More positively, Rausch et al. (2021) conducted experiments with online shoppers to better understand consumers' attitudes and behavior towards sustainability. Their work suggests consumers actually prefer to purchase products from firms paying their workers fair wages, offering good working conditions, and with environmentally friendly production practices, compared to a 20% price discount.

However, even for consumers who are willing and able to investigate the sustainability practices of sportswear firms, finding the information and forming a confident view can be challenging. Sustainability certifications available to sportswear producers can be difficult to understand. The OECD notes that many certificates are 'black boxes' awarded on a pass/fail basis (OECD, 2025). While some certificates offer more detail than others, this means trade unions and companies outsourcing their production (as major sportswear companies frequently do) may be unable to assess the extent to which a supplier passes or fails. An outstanding firm and one which just barely passes both receive the same passing score, but the pass/fail criteria treat them equally.

Sustainability standards can also vary from one country to another. For sportswear producers where materials may be sourced in one country, dyed in a second, and woven in a third country, differing standards in each country can make it hard to assess sustainability practices across the global supply chain. Australia, for example, runs a voluntary scheme for the waste management practices of clothing producers, though few companies were quick to sign up to it (Woods, 2024). This contrasts with the European Union (EU), where mandatory measures are more strictly enforced. The EU introduced a law in 2024 which bans sportswear firms from making generic claims about the environmental effects of their production and practices without proof to support the claims. This represents part of a wider push in the EU to increase the life cycle of sportswear and textiles more broadly as part of its plans to realize a circular economy by 2050 (European Parliament, 2020).

For consumers, although sustainability certifications are intended to provide them with transparency and give confidence that firms and products comply with certain standards, the numerous and diverse range of certificates may in fact complicate things. In trying to reduce the information asymmetry faced by consumers, the various and voluntary nature of standards may simply confuse consumers.

Producers themselves face costs in complying with sustainability practices. Clearly, it is more costly to provide workers with good working conditions and higher wages. If environmentally friendly practices were the cheapest available to firms which are motivated to maximize profits, they would surely produce more cleanly. However, in many regions where sportswear production occurs like China and South East Asia, coal and other hydrocarbons continue to be burned to make electricity that powers factories because it is relatively cheap (*Record Coal Generation Share in Indonesia and the Philippines Surpasses Poland and China*, 2024). Sportswear firms purposefully outsource manufacturing of their goods to countries where labor costs are cheaper. While Nike's biggest consumer market is in North America and it would save money on transportation of its goods if it produced there, it does not make commercial sense for them to do this. Nike's cost savings on transportation would likely be much smaller than the higher labor costs it would pay if production moved to (e.g.) Michigan.



Results and Discussion

What can be done to materially improve sustainability?

Producers

As the previous section suggests, consumers are sensitive to price and firms' production decisions are clearly motivated to a large extent by costs. While consumers are sensitive to sustainability and social responsibility issues, the reality for the sportswear industry is that it will have to find ways of improving sustainability whilst managing costs. Faced with financial constraints, firms may have to find innovative ways of improving sustainability if they are to meet their goals, whether set by a UN Charter or simply in catching up to competitors who are ahead of the game.

In dealing with their carbon footprints, firms must identify methods of addressing emissions across their supply chains. Signatories to the UN's Fashion Industry Charter for Climate Action commit to phasing out coal by 2030 (United Nations, 2023). However, their major production sites are still in regions where coal is a major source of electricity.

Moving away from coal can be challenging given its low cost and prevalence in certain regions. The likes of Puma and Nike do not control energy policies in China for instance but they can choose to locate production in regions where cleaner energy forms are more prevalent. Increasingly, renewable forms of energy are cheaper than the likes of coal and gas (Gulledge, 2025). While the infrastructure in many regions is yet to scale up to the size needed to support industry, cost-effective renewable energy is increasingly attainable for sportswear firms.

Increasing transparency over manufacturing processes and allowing stakeholders like the UN to better understand and assess progress on climate initiatives could help improve trust in firms' production practices. Of course, disclosing a lot of detail may be costly to a firm both in terms of process and if it shows the firm has done little to reduce its carbon footprint.

However, firms being more transparent and opening themselves up to scrutiny allow for honest assessments, which can bode well in the longer term. Such transparency can ultimately start to foster more trust and allow consumers to make more informed consumption decisions over sportswear. If firms are unwilling or unable to provide transparency, regulators and governments may even consider mandating disclosures. If reducing information asymmetry ultimately benefits wider society, albeit at a possible cost to individual firms, then there is a case to be made for more oversight.

Reducing waste from the sector is complicated by the limits of industry's recycling ability. Industry may benefit in the long term from investing in research to improve our ability to recycle textiles. While it is a cost to the firms who may contribute to it, it should be considered investment. More efficient recycling could actually help reduce the need to source materials from around the world and reduce emissions associated with new production.

More circular usage of old sportswear may threaten firms' ability to make new sales. However, the growing secondhand market could present firms with a chance to earn new sources of revenue. Nike, Adidas and others already run programs of taking in unwanted products and renewing them for sale in the secondhand market. These firms could consider letting their design teams make changes to the goods they take in. That way, secondhand products could be reworked into something new which firms could sell.

As for water consumption issues, using organic materials can help reduce the water usage for fiber production. For example, organic cotton is estimated to require over 90% less water than non-organic cotton (*Is Organic Cotton Sustainable? Here's What You Need to Know*, 2020). This is because organic cotton relies on rainwater rather than irrigation.

However, this is not straightforward. Organic crop yields are typically low relative to non-organic alternatives. Furthermore, there may be a more limited choice of materials available to firms relying on organic crops (Safaya et al., 2016). This means organic materials may be more scarce and therefore more costly to source than non-organic alternatives. Costs will ultimately then be passed on to end consumers of sportswear goods produced with organic materials. Consequently, at least in the short term, consumers wanting to support the role of organic materials in their sportswear goods will likely pay a higher price for their goods. Not all consumers will be willing and able to make this choice.



Adherence to international, commonly understood sustainability standards can help firms and consumers' perceptions of them. Such standards and certifications can be a sign of good governance and adhere to good practices when it comes to conditions for workers and the environment. Having a smaller number of certificates which can be easily scrutinized and internationally accepted would reduce information asymmetry, allowing consumers to make more informed decisions about their sportswear spending.

Consumers

While more could be done to help consumers better understand and more easily verify just how sustainable sportswear products are at the point of purchase, consumers still need to consider what more they can do after purchase. The burden of change does not fall solely on sportswear producers.

One such change could be a reduction in consumption of apparel and footwear. McKinsey, a consultancy, notes that the number of clothes purchased per person grew by 60% from 2000 to 2014 and consumers keep clothing items for roughly half as long as they used to (Remy et al., 2016). The rise of fast fashion and entry in to the sportswear market of lower priced firms like Uniqlo have coincided with rising consumer incomes. This has led to a rise in consumers viewing particularly cheaper sportswear as increasingly disposable.

By extending the life of the sporting garments consumers buy in their own wardrobes, consumers can help to reduce the carbon footprint of production and shipping. Re-selling clothes is another way in which consumers can extend the life of garments. Indeed, the rise of second-hand marketplaces like Poshmark and eBay has elevated these resale platforms into mainstream consciousness. According to Thredup, another resale marketplace for clothing, the global used apparel market is expected to double in size between 2021 and 2026. The company projects the secondhand resale market to grow more than twice as much as the wider market for apparel by 2030 (ThredUp, 2026).

This suggests consumers are willing to change their consumption habits and 49% of younger generations surveyed by Thredup say they have reduced their consumption of low-quality clothing due to the fact that it cannot be resold. This trend is arguably driven more by economic factors than sustainability issues. Thredup's survey suggests two-thirds of buyers now consider the resale value of garments before purchasing them, and the share of sellers who do so to generate income more than doubled to 57% in the last year. Nevertheless, the ultimate effect can be to reduce environmental problems.

For sportswear, there may be less appetite amongst thrift store shoppers for well used sporting apparel. The thought of wearing running shoes, gym shirts or leggings that have been well worn by someone else may be too much of a deterrent for lower prices to overcome. However, Thredup reports that Athleta and Lululemon are amongst the top 10 brands by total orders on its website. A look at similar websites suggests retro Adidas and Nike clothing and shoes do quite well, as do more recent unwanted purchases sold as 'new' or 'like new'.

This trend has not gone unnoticed by sportswear manufacturers. It is typically younger shoppers (Gen Z and Millennials) who are more likely to re-sell clothing and much of the projected growth in the resale market is expected to come from new shoppers who look to resale sites. Recent trends have already contributed to programs such as Nike Refurbished and Adidas' take back and resale scheme.

With regards to washing synthetic fibers and limiting the spread of microplastics in the water, we could all try to be more economical and wash clothes less. This is difficult when many items sold by sportswear manufacturers are used for exercising but washing in cold water. Of course, choosing products with more sustainable materials and natural fabrics which are biodegradable would help reduce problems with microplastics in waste. There are also special filters that can be used in washing machines which capture microfibers.

In the absence of clearly understood certifications for good working practices making it easier for consumers to know whether firms are adhering to certain labor standards, we could all be more vigilant online. An online search can tell you much about a brand and can allow us to make more informed decisions about whether we want to wear that company's branding on our sports clothing and footwear.



Conclusion

When it comes to sustainability issues, the sportswear industry stands out from the wider fashion and apparel sector due to its significant use of synthetic fibers and chemical treatments, which can be significantly harmful to the environment. It has also faced severe scrutiny over labor conditions at its suppliers.

As these issues have come to light and are better understood, companies have taken action to improve their working practices but much remains to be done if they are to meet public commitments. With many of the biggest sportswear firms headquartered in the biggest consumer markets – like the USA (e.g. Nike), Germany (Adidas), and Japan (Asics) – but production largely occurring in lower income regions far from these places, where labor laws less familiar to the head office, it suggests costs continue to be a bigger concern than sustainability.

While that is understandable in a competitive worldwide market where consumers report price and quality as the biggest considerations when purchasing new sportswear, there is long term incentive for firms to improve their sustainability practices. Even for firms constrained by finances, there are commercial reasons to improve working and environmental practices. Crucially, it is the younger generations that factor sustainability issues into their spending decisions most and they are the consumers to whom Nike and others must appeal to in the years to come. Firms would do well to play by their rules.

References

- 2026 *Global RepTrak*. (2026). Reptrak. <https://www.reprtrak.com/globalreprtrak/>
- Adidas. (n.d.). *Impact | Planet*. Adidas. <https://www.adidas.com/us/go/campaign/impact/planet>
- Amarelo, M. (2020, October 14). *Study: More Than 200 Million Americans Could Have Toxic PFAS in Their Drinking Water*. Environmental Working Group. <https://www.ewg.org/news-insights/news-release/study-more-200-million-americans-could-have-toxic-pfas-their-drinking>
- Amnesty International USA. (2025, November 26). *Stitched Up: Denial of Freedom of Association for Garment Workers in Bangladesh, India, Pakistan and Sri Lanka*. <https://www.amnestyusa.org/reports/stitched-up-denial-of-freedom-of-association-for-garment-workers-in-bangladesh-india-pakistan-and-sri-lanka/>
- Becker, S., Bright, K., Genta, J., & Thiel, A. (2022, July 5). *Tackling inflation and margin pressure in the sporting goods industry*. McKinsey & Company. <https://www.mckinsey.com/industries/retail/our-insights/tackling-inflation-and-margin-pressure-in-the-sporting-goods-industry>
- Bhatnagar, T. (2026). ANALYSIS OF CONSUMER BEHAVIOUR : A COMPARATIVE RESEARCH STUDY OF NIKE AND ADIDAS. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.6371178>
- Brodde, K. (2014, June 11). *Adidas is back onside!* Greenpeace International. <https://wayback.archive-it.org/9650/20200402053507/http://p3-raw.greenpeace.org/international/en/news/Blogs/makingwaves/adidas-is-back-onside/blog/49596/>
- Brook, J., Sreypich, S., & Rathana, P. (2023, February 8). *Authorities Aided Alleged Union-Busting at Puma-Supplying Factory*. CamboJA News. <https://cambojanews.com/authorities-aid-alleged-union-busting-at-puma-supplying-factory/>
- Chu, J. (2013, May 22). *Footwear's (carbon) footprint*. MIT News | Massachusetts Institute of Technology. <https://news.mit.edu/2013/footwear-carbon-footprint-0522>
- Coulson, M. (2024, March 28). *The Omnipresence of PFAS—and What We Can Do About Them*. Johns Hopkins Bloomberg School of Public Health. <https://publichealth.jhu.edu/2024/what-to-know-about-pfas>



D'Arpizio, C., Levato, F., Capellini, M., Flammini, B., Luthra, P., & Improta, G. (2022, October 21). *How Brands Can Embrace the Sustainable Fashion Opportunity*. Bain & Company; Bain & Company. <https://www.bain.com/insights/how-brands-can-embrace-the-sustainable-fashion-opportunity/>

Difrisco, E. (2022, October 12). *New Testing Shows High Levels of BPA in Sports Bras and Athletic Shirts*. Center for Environmental Health. <https://ceh.org/latest/press-releases/new-testing-shows-high-levels-of-bpa-in-sports-bras-and-athletic-shirts/>

European Parliament. (2020, December 29). *Fast fashion: EU laws for sustainable textile consumption*. <https://www.europarl.europa.eu/topics/en/article/20201208STO93327/fast-fashion-eu-laws-for-sustainable-textile-consumption>

Fashion Business Water Usage. (n.d.). ImpactBuying. <https://impactbuying.com/fashion-business-water-usage/>

Fashion for Good. (2026, February 10). *What's Really Inside Your Running Shoe? Unpacking Footwear Material Innovation*. Fashion for Good. https://www.fashionforgood.com/our_news/footwear-material-innovation/

Garments and Apparel. (2024, May 8). United Nations University. <https://unu.edu/cpr/article/garments-and-apparel>

Gribkoff, E. (2022, February 15). *IN DEPTH: First-of-its kind testing points to dangers and unknowns of PFAS in clothing*. EHN. <https://www.ehn.org/pfas-clothing-2656587709/pfas-in-athletic-wear>

Gulledge, J. (2025). Renewable energy is cheaper and healthier – so why isn't it replacing fossil fuels faster? *The Conversation*. <https://doi.org/10.64628/aai.raae4hdjt>

Hall, M. (2024, December 19). *Textile Waste Facts*. Business Waste. <https://businesswaste.com/waste-types/textile-waste/textile-waste-facts/>

Han, Y., Zhang, Y., Liu, X., Bai, J., Xue, Y., Ma, W., & Wen, Z. (2026). A full-process global inventory of plastic emissions for treaty implementation. *Environmental Impact Assessment Review*, 120, 108410. <https://doi.org/10.1016/j.eiar.2026.108410>

Hartline, N. L., Bruce, N. J., Karba, S. N., Ruff, E. O., Sonar, S. U., & Holden, P. A. (2016). Microfiber Masses Recovered from Conventional Machine Washing of New or Aged Garments. *Environmental Science & Technology*, 50(21), 11532–11538. <https://doi.org/10.1021/acs.est.6b03045>

Hubbard, J. (n.d.). *Water consumption and footwear*. World Trade Organization. https://www.wto.org/english/res_e/publications_e/wtr10_forum_e/wtr10_6july10_e.htm

International Accord for Health and Safety in the Textile and Garment Industry. (n.d.). *Pakistan Accord on Health and Safety in the Textile and Garment Industry*. International Accord. <https://internationalaccord.org/countries/pakistan/>

International Monetary Fund. (2026). *World Economic Outlook (April 2026) - GDP per capita, current prices*. <https://www.imf.org/external/datamapper/NGDPDPC@WEO/OEMDC/ADVEC/WEOWORLD/EU/CHN/USA>

Is Organic Cotton Sustainable? Here's What You Need to Know. (2020, June 23). Sustainme.In. <https://www.sustainme.in/blogs/news/is-organic-cotton-sustainable-here-s-what-you-need-to-know>

Liu, S. H., Chen, Y., Feuerstahler, L., Koelmel, J. P., Godri Pollitt, K. J., Xu, Y., Lanphear, B., Yolton, K., Chen, A., Pennell, K. D., Braun, J. M., & Manz, K. E. (2026). Quantifying PFAS-Omics Burden Scores for Nontargeted Analysis Using Multidimensional Item Response Theory: An Exploratory



Analysis of Novel and Legacy PFAS in Cord Blood. *Environmental Science & Technology*, 60(8), 6322–6340. <https://doi.org/10.1021/acs.est.5c06490>

lululemon. (2024, April 3). *lululemon Introduces First Enzymatically Recycled Polyester Product*. Lululemon. <https://corporate.lululemon.com/newsroom/our-stories/2024/lululemon-introduces-first-enzymatically-recycled-polyester-product>

Materials Market Report. (2025). <https://textileexchange.org/app/uploads/2025/09/Materials-Market-Report-2025.pdf>

Mayo Clinic Staff. (2023, March 24). *What is BPA? Should I be worried about it?* Mayo Clinic. <https://www.mayoclinic.org/healthy-lifestyle/nutrition-and-healthy-eating/expert-answers/bpa/faq-20058331>

Mishra, V. (2025, March 27). *Fast fashion fuelling global waste crisis, UN chief warns*. UN News. <https://news.un.org/en/story/2025/03/1161636>

Mitchell, A. (2025, December 3). *Nike, Superdry and Lacoste ads banned over green claims*. BBC; BBC News. <https://www.bbc.com/news/articles/ckgm79djr9yo>

Nike. (n.d.). *Sustainability*. About Nike. <https://about.nike.com/en/mission/focus-areas/sustainability>

Nike's revenue by region 2026. (2026, July 9). Statista. https://www.statista.com/statistics/241692/nikes-sales-by-region-since-2007/?srsltid=AfmBOoqx98-hxc__DV1CVrSXw0s-_LsZAM5V4VPPV5J-PdTmjtlI2Jt

OECD. (2025). *The role of sustainability certifications in due diligence in the garment and footwear sector*. <https://doi.org/10.1787/ac8179f2-en>

Plummer, D. (2026, February 26). *How Long Does Everyday Waste Take To Break Down After Disposal?* Forbes. <https://www.forbes.com/sites/dianneplummer/2026/02/26/how-long-does-everyday-waste-take-to-break-down-after-disposal/>

PUMA and RE&UP Announce a Multi-Year Collaboration to Scale Circular Textile Solution. (2025, March 26). PUMA. <https://about.puma.com/en/newsroom/corporate-news/2025/26-03-2025-puma-and-reup-announce-multi-year-collaboration-scale>

PUMA reaches goal of making 9 out of 10 products with recycled or certified materials. (2025, April 22). PUMA. <https://about.puma.com/en/newsroom/corporate-news/2025/22-04-2025-puma-reaches-goal-making-9-out-10-products-recycled-or>

Rausch, T. M., Baier, D., & Wening, S. (2021). Does sustainability really matter to consumers? Assessing the importance of online shop and apparel product attributes. *Journal of Retailing and Consumer Services*, 63, 102681. <https://doi.org/10.1016/j.jretconser.2021.102681>

Record coal generation share in Indonesia and the Philippines surpasses Poland and China. (2024, July 1). Ember. <https://ember-energy.org/latest-updates/record-coal-generation-share-in-indonesia-and-the-philippines-surpasses-poland-and-china/>

Remy, N., Speelman, E., & Swartz, S. (2016, October 20). *Style that's sustainable: A new fast-fashion formula*. McKinsey & Company. <https://www.mckinsey.com/capabilities/sustainability/our-insights/style-thats-sustainable-a-new-fast-fashion-formula>

Safaya, S., Zhang, G., & Mathews, R. (2016). Toward sustainable water use in the cotton supply chain. In *Water Footprint Network*. https://waterfootprint.org/resources/Assessm_water_footprint_cotton_India.pdf



- S&P Global. (2026). *2026 Sustainability Rankings Industry Overview*.
<https://www.spglobal.com/sustainable1/en/csa/yearbook/2026/industry#year=2026&industryName=Textiles%2C%20Apparel%20%26%20Luxury%20Goods>
- Tan, C., & Islam, S. (2026). A probe into 'forever chemicals' in activewear lays bare fashion's greenwashing problem. *The Conversation*. <https://doi.org/10.64628/aa.xmtum7cp6>
- Texas Office of the Attorney General. (2026, April 13). *Attorney General Ken Paxton Launches Investigation into Lululemon Over Potential Presence of Toxic "Forever Chemicals" in Activewear*. Texas Attorney General. <https://www.texasattorneygeneral.gov/news/releases/attorney-general-ken-paxton-launches-investigation-lululemon-over-potential-presence-toxic-forever>
- The True Cost of Sportswear*. (n.d.). Decathlon. https://www.decathlon.co.uk/c/htc/the-true-cost-of-sportswear_4cd0cb2d-9053-4633-87bb-260f9579a9c9
- The World. (2016, July 30). *How Nike solved its sweatshop problem*. The World from PRX. <https://theworld.org/stories/2016/07/30/how-nike-solved-its-sweatshop-problem>
- ThredUp. (2026). *2026 Resale Report*. https://cf-assets-tup.thredup.com/resale_report/2026/ThredUp_Resale_Report_2026.pdf
- UNFCCC Authors. (2025). From Commitments to Clarity: Tracking Progress Toward Fashion's Climate Commitments. In *United Nations Climate Change*.
https://unfccc.int/sites/default/files/resource/Fashion%20Charter_Tracking%20Progress%20Report%202025.pdf
- United Nations. (2023, July 31). *New Analysis Shows How Fashion Industry Can Lighten its Carbon Footprint*. United Nations Climate Change. <https://unfccc.int/news/new-analysis-shows-how-fashion-industry-can-lighten-its-carbon-footprint>
- United States Environmental Protection Agency. (n.d.). *Nondurable Goods: Product-Specific Data*. EPA. <https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/nondurable-goods-product-specific-data>
- Weis, J. (2024, January 13). *Laundry is a top source of microplastic pollution. Here's how to clean your clothes more sustainably*. PBS News. <https://www.pbs.org/newshour/science/laundry-is-a-top-source-of-microplastic-pollution-heres-how-to-clean-your-clothes-more-sustainably>
- Wenzel, E. (2025, April 9). *Adidas greenwashing judgment offers warnings about climate claims*. Trellis. <https://trellis.net/article/adidas-greenwashing-lawsuit-warning-climate-claims/>
- Wicker, A. (2023, July 3). *Are your clothes making you sick? The opaque world of chemicals in fashion*. The Guardian. <https://www.theguardian.com/fashion/2023/jul/02/fashion-chemicals-pfas-bpa-toxic>
- Williams, I. (2019, October 18). *Running Shoes*. ArcGIS StoryMaps; Esri.
https://storymaps.arcgis.com/stories/bf9e96fd8eae4b398ce2310e0034fc42?utm_source=copilot.com
- Woods, C. (2024, April 5). *Can fashion waste be outlawed? - Law Society Journal*. Law Society Journal. <https://lsj.com.au/articles/can-fashion-waste-be-outlawed/>
- Xu, V., Cave, D., Leibold, J., Munro, K., & Ruser, N. (2020, March 1). *Uyghurs for sale*. Australian Strategic Policy Institute. <https://www.aspi.org.au/report/uyghurs-sale/>



Comparing Working Memory Deficits Across ADHD and Anxiety in Youth: A Preliminary Meta-Analysis

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Abstract

Although attention-deficit/hyperactivity disorder (ADHD) and anxiety disorders are conventionally treated as distinct diagnostic categories, both have been linked to working memory (WM) impairment in children and adolescents, prompting an inquiry into whether the magnitude of WM impairment may be comparable across the two conditions. This preliminary meta-analysis pooled the Hedges' g effect sizes across six studies (four ADHD studies, two anxiety studies), comparing WM performance in youth with ADHD, clinically diagnosed anxiety, or elevated trait anxiety against comparison groups. A random effects model calculated effect for ADHD ($g = 1.12$, 95% CI [0.46, 1.78], $p < .001$) and for anxiety ($g = 0.69$, 95% CI [0.34, 1.05], $p < .001$); heterogeneity was high for ADHD ($I^2 = 91.0\%$) and low for anxiety ($I^2 = 26.5\%$). A leave-one-out sensitivity analysis identified one ADHD study (Cockcroft, 2011) as the leading factor, as its exclusion lowered the ADHD estimate to $g = 0.80$ (95% CI [0.30, 1.29]), a value that converges closer with the anxiety estimate. The results provide support that WM impairment across ADHD and anxiety may reach a comparable magnitude; however, because the anxiety estimate rests on only two studies and the ADHD subgroup shows heterogeneity, the present analysis cannot determine whether these deficits arise from a shared processing mechanism. Future research should prioritize additional pediatric WM-anxiety studies and longitudinal designs.

Keywords

working memory; ADHD; anxiety; meta-analysis

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder marked by persistent inattention and/or hyperactivity–impulsivity (American Psychiatric Association [APA], 2013). It affects an estimated 3.4% of children and adolescents worldwide (Polanczyk et al., 2015), and the symptoms and impairments often persist into adulthood (Sibley et al., 2017). Alongside ADHD, anxiety disorders represent another major source of impairment among adolescents. These disorders involve excessive fear or anxiety that disrupts daily functioning (APA, 2013). They affect 6.5% of children and adolescents worldwide (95% CI [4.7, 9.1]), making them the most common youth mental disorder (Polanczyk et al., 2015). They often impair school attendance and academic performance (Finning et al., 2019; Mazzone et al., 2007).

Both disorders implicate working memory (WM), a limited-capacity system that temporarily stores and manipulates information during complex activities (Baddeley, 2000). Baddeley's working memory model represents short-term memory as consisting of four interacting systems: the phonological loop (PL) which retains verbal-acoustic information; the visuospatial sketchpad, which processes visual and spatial material; the episodic buffer, which integrates information across modalities into a unified representation; and the central executive (CE), which controls attention and coordinates the subordinate systems (Baddeley, 2011). Because WM supports reading comprehension, mathematical problem-solving, following instructions, and learning, deficits can produce substantial academic and everyday impairment (Alloway & Alloway, 2010; Gathercole et al., 2003).

Evidence links WM impairment to both conditions, although potentially through different processes. Children with ADHD show large deficits in tasks requiring storage and manipulation, particularly when



CE demands increase (Kasper et al., 2012); simple PL storage appears relatively spared, since forward digit span does not reliably distinguish children with ADHD, while backward digit span, which additionally recruits the CE, does (Cockcroft, 2011). On the other hand, anxiety may consume attentional resources through worry and threat monitoring, weakening goal-directed processing and reducing WM efficiency (Eysenck et al., 2007; Owens et al., 2008). Attentional Control Theory further predicts that anxiety's effect on WM should concentrate on verbal processing specifically, because ruminative worry itself relies on inner verbal activity, therefore interfering with PL function (Eysenck et al., 2007). These deficits raise the possibility that ADHD and anxiety produce overlapping patterns of impaired information processing.

Although WM impairment does not uniquely distinguish ADHD and anxiety from other forms of psychopathology, these two conditions provide a particularly informative comparison because they frequently co-occur and can produce overlapping cognitive difficulties, making it difficult to determine how strongly observed WM deficits track diagnostic category rather than broader vulnerability (Manassis et al., 2007; Maric et al., 2018). Direct comparisons that separate ADHD-only, anxiety-only, and comorbid groups remain relatively limited, yet existing studies demonstrate that these groups can differ in WM (Manassis et al., 2007; Kofler et al., 2024). Taken together, these features render ADHD and anxiety a particularly useful comparison.

Although prior research links WM impairment to both conditions, whether there is a substantial difference in the magnitude of that between ADHD and anxiety in youth remains inconclusive. The present meta-analysis therefore compares WM deficits across the two literatures; comparable effect sizes would indicate similarity in the observed level of impairment and may motivate further investigation of overlapping processing constraints.

Methods

We searched PubMed on 14 July 2026 using two parallel search terms, both combining terms with ("working memory" OR "central executive" OR "verbal working memory" OR "visuospatial working memory") AND ("child" OR "adolescent" OR "youth" OR "pediatric"). The ADHD subgroup terms were ("ADHD" OR "attention deficit hyperactivity disorder" OR "attentiondeficit/hyperactivity disorder"); the anxiety subgroup terms were ("anxiety" OR "anxiety disorder" OR "generalized anxiety" OR "social anxiety" OR "separation anxiety"). The search was restricted to studies published after 2000 and to peer-reviewed journal articles. Because this study was designed as a preliminary review, the search was limited to PubMed; this restriction may have reduced retrieval breadth and is considered in the Limitations section.

Figure 1 summarizes the study selection process. The two PubMed searches identified 280 records in total, with 270 and 10 results for ADHD and anxiety, respectively. The disparity between the two yields previews the imbalance in pediatric anxiety-WM literature documented later on. Records were then screened by title and abstract, leaving ten articles for review. These were accessed and assessed against three criteria: (1) a sample of children or adolescents, age range 4-16 years; (2) a control group permitting estimation of WM differences between youth with ADHD or anxiety and typically developing peers; and (3) sufficiently reported statistics, namely averages and standard deviations to compute a standardized effect size. For the anxiety subgroup, eligible studies could define anxiety either through clinical diagnosis or elevated trait-anxiety grouping. These criteria excluded four further articles: one utilized a sample without a clinical ADHD diagnosis; one exclusively restricted its ADHD sample to the predominantly inattentive subtype and was therefore excluded in favor of samples representing a broader range of ADHD presentations; one did not report extractable means or standard deviations; and one was excluded due to concerns about measure comparability with the remaining pool. The remaining six met all the inclusion criteria and carried forward into the analysis. Ferrin and Vance (2014) was retained despite its primary focus on anxiety and depressive symptoms within ADHD because it reported an



extractable ADHD-control WM comparison satisfying the same inclusion criteria as the other ADHD studies. All screening and data extraction were conducted by the author, and because there was no independent duplication through researcher triangulation, the possibility of selection error cannot be excluded.

With most of the studies reporting multiple WM outcomes, verbal WM was selected as the pooled measure for five of the six studies because it was the only construct reported comparably across them, and because attentional control theory predicts anxiety-related impairment concentrates in verbal rather than visuospatial function (Eysenck et al., 2007), consistent with Visu-Petra et al. (2011), who found a significant deficit on verbal WM tasks but not on visuospatial WM tasks within the same sample. Karaca Cengiz et al. (2025) contributed a CE composite (CNSVS) rather than a verbal measure, since no alternative WM-anxiety study meeting inclusion criteria was identified.

Figure 1. Study selection flow chart.

Hedges' g was calculated using Cambridge Insight Effect Size Calculator as the standardized mean difference in WM performance between clinical and comparison groups, divided by the standard deviation, with the bias-correction factor applied (Hedges & Olkin, 1985). Positive g values indicated poorer WM performance in the clinical group relative to controls. Pooled estimates were calculated using an inverse-variance random-effects model, with between-study variance estimated using the DerSimonian-Laird method. A leave-one-out analysis recomputed the ADHD pooled estimate with each study removed in turn, to check whether any single outlier was heavily affecting the result. A chi-square test comparing the two subgroups' pooled estimates was used to determine how the ADHD and anxiety effects differed.

Results and Discussion

Study and Sample Characteristics

The synthesis retained six studies, four contributing to the ADHD subgroup (total $N = 768$) and two to the anxiety subgroup (total $N = 177$). ADHD subgroup sample sizes ranged from 55 (Elosúa et al., 2017) to 508 (Ferrin & Vance, 2014); anxiety subgroup sample sizes ranged from 80 (Karaca Cengiz et al., 2025) to 97 (Visu-Petra et al., 2011). Participant ages spanned approximately 4 to 16 years across the studies. Grouping procedures also varied substantially across studies. ADHD samples generally relied on diagnostic of clinical classifications. For the anxiety subgroup, Karaca Cengiz et al. (2025) used a clinical social anxiety disorder diagnosis, whereas Visu-Petra et al. (2011) classified preschool children dimensionally according to trait-anxiety level without diagnosis.

The four ADHD studies handled potential IQ differences between groups differently: Elosúa et al. (2017) matched groups on IQ directly, Ferrin & Vance (2014) instead entered IQ as a covariate, and Holmes et al. (2014) did not report controlling for a significant IQ gap between groups in comparison. Recruitment settings also varied: Cockcroft (2011) drew ADHD participants from special-education schools and controls from separate mainstream schools, and Karaca Cengiz et al. (2025) recruited controls from an outpatient counseling clinic instead of a general population. This difference may also alter estimated effect sizes if comparison groups differ in cognitive or clinical characteristics unrelated to the two conditions. External validity was narrowed by control of comorbidities, ranging from tolerant (Cockcroft, 2011), which retained children with oppositional defiant disorder, conduct disorder, and learning disorders, to strict (Ferrin & Vance, 2014), which excluded conduct disorder, autism spectrum disorder, and eight further conditions, yielding a purer but perhaps less representative ADHD sample. A further complication concerns anxiety within the ADHD evidence base: Ferrin & Vance (2014) reported elevated anxiety within their ADHD sample, rendering comorbidity an alternative explanation for any apparent similarity.

Synthesis

The four ADHD subgroup studies produced a pooled Hedges' g of 1.12 (95% CI [0.47, 1.78], $z = 3.31$, $p < .001$), indicating a very large WM deficit in children and adolescents with ADHD relative to typically developing controls. Heterogeneity was high ($Q(3) = 33.42$, $p < .001$, $I^2 = 91.0\%$), reflecting a wide



spread across the four estimates: Cockcroft (2011) produced by far the largest effect ($g = 2.19$, $N = 72$); and Ferrin & Vance (2014), by far the largest sample, produced the smallest effect ($g = 0.47$, $N = 508$).

The two anxiety-subgroup studies produced a pooled Hedges' g of 0.69 (95% CI [0.34, 1.04], $z = 3.85$, $p < .001$). Both contributing estimates were in the expected deficit direction: Visu-Petra et al. (2011; $g = 0.53$, 95% CI [0.13, 0.93], $N = 97$) and Karaca Cengiz et al. (2025; $g = 0.89$, 95% CI [0.44, 1.35], $N = 80$). With only two studies ($k = 2$), a heterogeneity statistic carries little information here ($Q(1) = 1.36$, $p = .243$, $I^2 = 26.5\%$) unlike the ADHD subgroup. The difference between the pooled ADHD and anxiety effects was not statistically significant, $Q(1) = 1.24$, $p = .265$.

Table 1. Study characteristics, methodological considerations, and effect sizes.

Author	Sub.	Age (years)	Recruitment (& Groups)	Subtype / Comorbidity	WM measure	IQ handling	Nclinical / Ncontrol	Sex Distribution	Hedges' g	95% CI
Cockcroft (2011)	ADHD	6.6-11.25	ADHD from 4 special education schools; controls from 3 schools (DSM-IV-TR + Conners ratings)	ADHD-I (n=27) and ADHD-HI (n=25); Anxiety/mood disorders excluded; ODD, CD, LD and DCD present	AWMA verbal WM composite	RCPM; IQ as covariate	52 / 20	ADHD 33M/19F, control 10M/10F	2.19	[1.56, 2.82]
Holmes et al. (2014)	ADHD	8-11	ADHD through pediatric psychiatrists; controls from 10 state primary schools	Combined-type ADHD; ASD excluded	AWMA verbal WM composite	WASI measured; groups not IQ-matched	83 / 50	ADHD 71M/12F, control 27M/23F	1.20	[0.82, 1.58]
Elosúa et al. (2017)	ADHD	9.24 (ADHD mean), 9.18 (control mean)	ADHD from psychiatry outpatient unit; controls from public school (DSM-IV-TR)	20 combined, 6 inattentive	Backward Digit Span	K-BIT; IQ ≥ 85	26 / 29	ADHD 17M/9F, control 13M/16F	0.76	[0.21, 1.30]
Ferrin & Vance (2014)	ADHD	6-16	Both ADHD and controls from 50 schools and assessed at 5 university clinics (DSM-IV & K-SADS-PL)	ADHD-CT (n=303) and ADHD-IA (n=77); anxiety/depression assessed; learning disorders, conduct disorder, psychosis and major medical/neurological conditions excluded	Digit Span verbal WM	WISC-III; controls had higher IQ; IQ as covariate	380 / 128	ADHD 314M/66F, control 98M/30F	0.47	[0.27, 0.67]
Visu-Petra et al. (2011)	ANX	4.6-7.4	Both from preschool (median split of Spence Preschool Anxiety Scale)	Dimensional trait anxiety; N/A	Backward Digit Recall	RCPM; IQ as covariate	48 / 49	53M/45F (total in full sample, task-specific not recorded)	0.53	[0.12, 0.93]
Karaca Cengiz et al. (2025)	ANX	12-16	SAD group from university child psychiatry service; controls from outpatient counseling clinic (K-SADS-PL-DSM-5)	Social anxiety disorder; N/A	CNSVS WM domain	WISC-IV FSIQ; IQ ≥ 80	40 / 40	anxiety 10M/30F, control 10M/30F	0.89	[0.43, 1.35]

Figure 2. Forest plot of Hedges' g for ADHD (blue) and anxiety (orange) studies



Sensitivity Analysis

A leave-one-out analysis of the ADHD subgroup showed the pooled estimate was clearly sensitive to Cockcroft (2011): excluding it, the largest single effect, lowered the pooled estimate to $g = 0.80$ (95% CI [0.30, 1.29], $p = .002$), hereafter the adjusted ADHD estimate, and reduced heterogeneity to $I^2 = 82.5\%$. Excluding Holmes et al. (2014) yielded $g = 1.11$ (95% CI [0.17, 2.05], $p = .021$, $I^2 = 92.5\%$); excluding Elosúa et al. (2017) yielded $g = 1.25$ (95% CI [0.37, 2.12], $p = .005$, $I^2 = 94.0\%$); and excluding Ferrin & Vance (2014) yielded $g = 1.36$ (95% CI [0.65, 2.08], $p < .001$, $I^2 = 83.3\%$).

Findings

Although the full ADHD effect exceeded the anxiety effect, substantially greater heterogeneity within the ADHD subgroup complicates that apparent difference; excluding Cockcroft (2011), the two subgroup effects converged more closely. Furthermore, Ferrin & Vance (2014)'s 508 participant comparison produced an effect ($g = 0.47$) closest to the anxiety estimates. Across the studies examined, this pattern provides preliminary support that ADHD and anxiety can accompany WM impairment of comparable magnitude; however, it does not establish that the deficits originate from the same cognitive process, especially since unmeasured or incompletely controlled comorbidity could partly account for the pattern.

Limitations

This review is limited in several respects. The anxiety subgroup rests on only two studies ($k = 2$), which limits how confidently its heterogeneity and precision can be determined. With only six studies overall, formal tests of publication bias would have limited power; small-study effects therefore cannot be ruled out, particularly because Cockcroft (2011) reported the largest ADHD effect size despite a relatively smaller sample. Two of the four ADHD studies (Holmes et al., 2014; Ferrin & Vance, 2014) did not match groups on IQ, leaving IQ as a possible confound in the reported WM deficits. Excluding an ADHD-I-only study also limits generalizability across ADHD subtypes and could affect the pooled estimate if WM impairment systematically differs across presentation.

Comorbidity remains a limitation because the included studies did not consistently measure both ADHD and anxiety symptoms within the same participants; the observed convergence may therefore partly reflect unmeasured cross-diagnostic symptoms. The six studies also used different WM tasks: for example, digit span versus a computerized composite score, which may explain some of the high heterogeneity ($I^2 = 91.0\%$). A longitudinal design would help clarify the specific mechanics between WM deficits and either condition, which the cross-sectional studies synthesized here cannot address. Given that anxiety disorders constitute the most prevalent youth mental health condition (Polanczyk et al., 2015), the shortage of comparable pediatric WM-anxiety studies represents a pressing gap for future research to close.

Conclusion

The present analysis provides preliminary evidence that WM impairment may reach a comparable magnitude across ADHD and anxiety in youth. Both pooled estimates share a direction, and the adjusted ADHD estimate ($g = 0.80$) and the anxiety estimate ($g = 0.69$) are of similar magnitude.

The anxiety finding, by contrast, is derived from only two studies; a subgroup built on two comparisons cannot be cross-checked as readily as a larger subgroup permits. In addition, the ADHD subgroup shows substantial heterogeneity; comparable effect sizes therefore provide preliminary evidence for similarity in observed level of impairment. Future research should enlarge the pediatric anxiety evidence base, apply comparable WM measures across diagnoses, and assess both symptom dimensions within the same participants to determine whether a common pathway actually accounts for this pattern.

This synthesis accordingly addresses the acquisition, rather than the treatment, of WM impairment alongside each diagnosis; because the included studies were cross-sectional, however, the findings cannot establish when, through what process, or whether any intervention could reduce the deficit.



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References

- Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of experimental child psychology*, 106(1), 20–29. <https://doi.org/10.1016/j.jecp.2009.11.003>
- American Psychiatric Association (APA) (2013). *Diagnostic and Statistical Manual of Mental Disorders*. 5th Edn. Washington, DC: APA.
- Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences*, 4(11), 417–423. [https://doi.org/10.1016/s1364-6613\(00\)01538-2](https://doi.org/10.1016/s1364-6613(00)01538-2)
- Baddeley, A. (2011). Working Memory: theories, models, and controversies. *Annual Review of Psychology*, 63(1), 1–29. <https://doi.org/10.1146/annurev-psych-120710-100422>
- Karaca Cengiz, S. N., Guney, E., Ozaslan, A., & Saripinar, E. G. (2025). Theory of mind, metacognition, and executive functions in adolescents with social anxiety disorder: a comparative study. *Child and Adolescent Psychiatry and Mental Health*, 19(1), 108. <https://doi.org/10.1186/s13034-025-00968-4>
- Cockcroft, K. (2011). Working memory functioning in children with attention-deficit/hyperactivity disorder (ADHD): A comparison between subtypes and normal controls. *Journal of Child and Adolescent Mental Health*, 23(2), 107–118. <https://doi.org/10.2989/17280583.2011.634545>
- Elosúa, M. R., Del Olmo, S., & Contreras, M. J. (2017). Differences in Executive Functioning in Children with Attention Deficit and Hyperactivity Disorder (ADHD). *Frontiers in Psychology*, 8, 976. <https://doi.org/10.3389/fpsyg.2017.00976>
- Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion (Washington, D.C.)*, 7(2), 336–353. <https://doi.org/10.1037/1528-3542.7.2.336>
- Finning, K., Ukoumunne, O. C., Ford, T., Danielson-Waters, E., Shaw, L., Romero De Jager, I., Stentiford, L., & Moore, D. A. (2019). Review: The association between anxiety and poor attendance at school - a systematic review. *Child and adolescent mental health*, 24(3), 205–216. <https://doi.org/10.1111/camh.12322>
- Ferrin, M., & Vance, A. (2014). Differential effects of anxiety and depressive symptoms on working memory components in children and adolescents with ADHD combined type and ADHD inattentive type. *European Child & Adolescent Psychiatry*, 23(12), 1161–1173. <https://doi.org/10.1007/s00787-013-0509-4>
- Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2003). Working memory skills and educational attainment: evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology*, 18(1), 1–16. <https://doi.org/10.1002/acp.934>
- Hedges, L. V., & Olkin, I. (1985). *Statistical methods for meta-analysis*. Academic Press.
- Holmes, J., Hilton, K. A., Place, M., Alloway, T. P., Elliott, J. G., & Gathercole, S. E. (2014). Children with low working memory and children with ADHD: same or different? *Frontiers in Human Neuroscience*, 8, 976. <https://doi.org/10.3389/fnhum.2014.00976>



Kasper, L. J., Alderson, R. M., & Hudec, K. L. (2012). Moderators of working memory deficits in children with attention-deficit/hyperactivity disorder (ADHD): a meta-analytic review. *Clinical psychology review*, 32(7), 605–617. <https://doi.org/10.1016/j.cpr.2012.07.001>

Kofler, M. J., Groves, N. B., Chan, E. S. M., Marsh, C. L., Cole, A. M., Gaye, F., Cibrian, E., Tatsuki, M. O., & Singh, L. J. (2024). Working memory and inhibitory control deficits in children with ADHD: an experimental evaluation of competing model predictions. *Frontiers in Psychiatry*, 15, 1277583. <https://doi.org/10.3389/fpsyt.2024.1277583>

Manassis, K., Tannock, R., Young, A., & Francis-John, S. (2007). Cognition in anxious children with attention deficit hyperactivity disorder: a comparison with clinical and normal children. *Behavioral and Brain Functions*, 3(1), 4. <https://doi.org/10.1186/1744-9081-3-4>

Maric, M., Bexkens, A., & Bögels, S. M. (2018). Is Clinical Anxiety a Risk or a Protective Factor for Executive Functioning in Youth with ADHD? A Meta-regression Analysis. *Clinical Child and Family Psychology Review*, 21(3), 340–353. <https://doi.org/10.1007/s10567-018-0255-8>

Mazzone, L., Ducci, F., Scoto, M. C., Passaniti, E., D'Arrigo, V. G., & Vitiello, B. (2007). The role of anxiety symptoms in school performance in a community sample of children and adolescents. *BMC Public Health*, 7(1), 347. <https://doi.org/10.1186/1471-2458-7-347>

Owens, M., Stevenson, J., Norgate, R., & Hadwin, J. A. (2008). Processing efficiency theory in children: Working memory as a mediator between trait anxiety and academic performance. *Anxiety Stress & Coping*, 21(4), 417–430. <https://doi.org/10.1080/10615800701847823>

Polanczyk, G. V., Salum, G. A., Sugaya, L. S., Caye, A., and Rohde, L. A. (2015). Annual research review: a meta-analysis of the worldwide prevalence of mental disorders in children and adolescents. *Journal of Child Psychology and Psychiatry*, 56 (3), 345–365. <https://doi.org/10.1111/jcpp.12381>

Sibley, M. H., Swanson, J. M., Arnold, L. E., Hechtman, L. T., Owens, E. B., Stehli, A., Abikoff, H., Hinshaw, S. P., Molina, B. S. G., Mitchell, J. T., Jensen, P. S., Howard, A. L., Lakes, K. D., Pelham, W. E., & MTA Cooperative Group (2017). Defining ADHD symptom persistence in adulthood: optimizing sensitivity and specificity. *Journal of child psychology and psychiatry, and allied disciplines*, 58(6), 655–662. <https://doi.org/10.1111/jcpp.12620>

Visu-Petra, L., Cheie, L., Benga, O., & Alloway, T. P. (2011). Effects of anxiety on memory storage and updating in young children. *International Journal of Behavioral Development*, 35(1), 38–47. <https://doi.org/10.1177/0165025410368945>

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Analysis of State Compliance Regarding International Human Rights Legal Frameworks

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Abstract

Despite the existence of ICCPR and ICESCR, Civil and Political Rights and Economic, Social and Cultural Rights violations persist across states that have signed or ratified the covenants. This paper answers the question 'Why do these violations persist despite existing legal protections and what might improve state compliance?' The paper combines legal analysis of key treaty provisions with six case studies, three case studies for each covenant, tested against five hypotheses and a null hypothesis centred on state sovereignty. The main findings of the research are, first, Civil and Political Rights violations stem primarily from the weak enforcement mechanisms of the state and the vague treaty language supported by Korea, Iran and Latvia case studies, second, Economic, Social and Cultural Rights violations follow various combinations of reasons such as resource scarcity in Burundi, insufficient political will in the United States, and structural non-justiciability in India. The persistence of noncompliance is best explained not by a single failure of international law but by the distinct nature of the rights each covenant protects. To eliminate the compliance gap in each treaty requires targeted cause-specific reforms, such as clearer treaty definitions, conditional resource assistance, and compulsory human rights educational systems, rather than a single institutional fix. These findings suggest that improving compliance depends less on states relinquishing sovereignty and more on narrowing the specific legal, political, and institutional gaps that currently allow state sovereignty to be invoked as a justification for noncompliance.

Keywords

Human Rights; Human Rights Violations; International Covenant on Civil and Political Rights (ICCPR); International Covenant on Economic, Social and Cultural Rights (ICESCR); State compliance

Introduction

Any second, state authorities can arrest a journalist on false allegations, sentence a religious minority to death over a social media post or deny a dying child emergency healthcare simply because her father lacks a voter registration receipt.



To prevent such atrocities from happening, the United Nations established multilateral treaties like the International Covenant on Civil and Political Rights (ICCPR) and the International Covenant on Economic, Social and Cultural Rights (ICESCR) to guarantee that freedom of expression remains the foundation stone of every free society. Under the ICCPR, freedom of opinion and expression are recognized as “indispensable conditions for the full development of the person” (United Nations, 2011), while ICESCR Article 11-1 obligates states to ensure the right to an adequate standard of living.

Despite these multilateral treaties existing, human rights violations and global economic hardships persist. As a 2024 statistics report by the World Bank indicates, almost 700 million people are suffering from extreme poverty (World Bank 2024). In terms of the ICCPR, governments often justify restrictions “under the guise of national security, public order, public health, and public morals, also known as ‘proportionality tests’” (Gunatilleke 2020), which are exacerbated by systemic flaws where treaty monitoring and enforcement structures are “woefully inadequate” (Hafner-Burton 2012). Regarding the ICESCR, scholars like Sengupta (2010) and Salomon (2011) demonstrate that poverty persists not simply from shortages, but from a “lack of political motivation” and structural inequality, while Verner’s (2007) examination of “Social resilience and Social Fragility in Haiti” and Ventura (2026) emphasize institutional weaknesses and conflicting international economic constraints.

Examining this topic is critically relevant and significant because human rights protections remain tenuous when international agreements lose their practical power against state self-interest and structural barriers. While existing literature criticizes weak enforcement and identifies root causes of non-compliance, it consistently fails to provide practical solutions to overcome these barriers. This research addresses that gap by comparing the ICCPR and ICESCR, illustrating the critical gap between reality and the covenants, and analyzing past enforcement successes alongside causes of non-compliance to propose a clear, realistic framework for strengthening treaty compliance.

The current international legal system lacks sufficient enforcement. People are not adequately educated about the necessary rights they deserve and which should be respected by their government. Lastly, the accessibility of courts is insufficient as people with no wealth cannot complain or protest against their government’s violations.

Even though the ICCPR and the ICESCR both exist to protect each state’s citizens’ human rights, violations of both civil and political rights and economic and social rights persist. Scholars have discussed various explanations, such as enforcement and resources, but rarely examine how these dynamics operate in relation to covenants simultaneously. This condition raises a central question: “Why do violations of both Civil and Political Rights and Economic and Social Rights persist, despite the existence of legal protections in the ICCPR and the ICESCR, and what might be done to improve state compliance?” Understanding the distinction matters because any effort to improve state compliance must first identify whether the underlying obstacle engenders a systematic violation of Human Rights, or is a practical limitation such as political unwillingness or institutional capacity.

Although both the ICCPR and ICESCR aim at the full realization of human rights, the gap between their legal guarantees and actual state compliance persists. The compliance gap in human rights law can be best explained by the distinct nature of political rights as opposed to economic and social rights. While the civil and political rights gap is largely due to the lack of enforcement mechanisms, the economic and social rights gap can be attributed to a lack of political will, enforcement, and resources. Comprehending these as distinct failures rather than a single predicament is essential in terms of designing effective remedies and closing the compliance gap persisting within the International Human Rights legal frameworks.

The paper proceeds in six parts. Part I reviews the existing literature on the violations of the ICCPR and the ICESCR, identifying the explanatory gaps. Part II addresses the methodology used to test these explanations, including the selection of the hypothesis. Part III assesses the essence of the covenants



and the articles and examines the similarities and differences between the ICCPR and the ICESCR. Part IV presents different case examples of human rights violations in terms of freedom of speech and poverty. Part V conducts a cross-cutting analysis on each hypothesis, measuring which case studies carry the best explanatory weight and how they interact with each other. Part VI presents the policy recommendations for improving state compliance before the paper concludes by synthesising these findings into a broader context.

Methods

To examine these factors, this research adopts both legal analysis and the case study methodologies to compare and contrast the different causes of ICCPR and ICESCR violations and to propose practical solutions. The legal analysis methodology is appropriate for examining how violations relate to national sovereignty and the weak enforcement mechanisms of international legal systems. Meanwhile, the case study approach provides direct empirical evidence of specific violations of human rights.

Results and Discussion

Statement of Hypothesis

Countries do not follow international human rights law because it lacks binding authority, as domestic laws can invalidate the enforcement of international legal frameworks. Countries often ignore international human rights law because they value state sovereignty over international legal systems. Since there is no ultimate mechanism of enforceability for these treaties, a nation's domestic laws will almost always take priority. Consequently, if a sovereign country decides its own laws come first, international agreements lose their power.

Hypothesis 1

Firstly, legal protections in both ICCPR and ICESCR are inadequate or underspecified. The vagueness embedded in both the ICCPR and ICESCR significantly contributes to noncompliance. For instance, Article 2, paragraph 1 of the ICESCR states that the rights should be realized to the “maximum of its available resources”; however, it does not specify what actually constitutes a state's maximum resource capacity (ICESCR, 1966). This ambiguity leaves the standard open to broad interpretation, which varies by state. Similarly, Article 19, paragraph 3 of the ICCPR states that rights are “subject to certain restrictions, but these shall only be such as are provided by law and are necessary” (ICCPR, 1966). Yet it fails to specify what qualifies as “necessary,” allowing states to justify limitations on rights that may far exceed the treaty's original intention.

Hypothesis 2

Second, countries justify the violation of human rights with the disguise of protecting their national security and public order. Under Article 18 of the ICCPR, everyone has the freedom to choose, change, and practice their religion or belief, either individually or with others, in both public and private spaces (ICCPR, 1966). However, a review of scholars' reports on freedom of expression and opinion violations reveals that governments often merge their responsibility for national security with religious norms, especially in traditionally religious nations, in order to suppress minority voices and preserve absolute power within the state.

Hypothesis 3

Third, there is a lack of enforcement mechanisms. Article 2, paragraph 3 of the ICCPR notes that individuals whose “rights or freedoms as herein recognised are violated shall have an effective remedy”



directly addressing justiciability and enforcement actions; however, its practical effectiveness varies depending on each country's domestic legal system (ICCPR, 1966). Furthermore, Article 2, paragraph 1 of the ICESCR emphasizes "achieving progressively the full realization of the rights" (ICESCR, 1966). This reliance on progressive development undermines immediate enforceability, ultimately leaving human rights violations without immediate judicial remedy.

Hypothesis 4

Fourth, compliance is hampered by a lack of resources, particularly in developing regions such as African nations. Article 2, paragraph 1 of the ICESCR states that the effective implementation of human rights relies heavily on the amount of resources available within a state (ICESCR, 1966). However, many African countries face severe resource constraints, making them far less likely to achieve the full realization of human rights without financial support from other nations.

Hypothesis 5

Fifth, a lack of political commitment severely weakens international human rights treaties, regardless of scarce resources. Even though some scholars argue that the major predicament of the ICESCR is due to the limited amount of resources available within the states, political commitment inside a country ultimately dictates the effectiveness of the treaty. For instance, Arjun Sengupta's case study on poverty in the United States demonstrates that resource availability does not correspond with poverty reduction (Sengupta, 2010). Instead, the case study reveals another limitation of the ICESCR, showing how the lack of political commitment can obstruct the realization of human rights, even when a state has sufficient resources.

Part III: Legal Analysis

ICCPR

The International Covenant on Civil and Political Rights, specifically Article 19, Article 2, and Article 4 are the legal frameworks that are the legal provisions central to this analysis. The ICCPR matters most to the research question because it is often neglected and mentioned the most in regard to freedom of speech. The ICCPR is designed to protect freedom of expression adequately. However, the ICCPR currently has weak points which provide legal loopholes and heavily depend on domestic legal systems that states exploit to suppress freedom of speech. It matters to the research question because the purpose of this research is to evaluate how state non-compliance is allowed by the international treaty itself and ultimately recommend a solution.

The primary authority of the ICCPR is the UN Human Rights Committee in General Comment No.34. Article 19 of the ICCPR broadly protects the right to "seek, receive, and impart information of all kinds across borders" (ICCPR, 1966). Additionally, in Article 19 paragraph 3, it mentions that "there could be restrictions to respect the rights of others or for the protection of national security, public order, public health or morals" (ICCPR, 1966).

Evidently, the rules regarding possible "restrictions" are too broad and can be interpreted however the state wants it to be interpreted as. Specifically, the terms "public order" and "public morals" in Article 19 paragraph 3 lack clear definition in international law, granting states a wide exception of suppressing freedom of opinion and expression. Moreover, the ICCPR lacks centralized enforcement mechanisms. There are multiple cases where the Human Rights Committee have identified violation of human rights, but it seems to lack the power to punish states for violating the ICCPR, leaving enforcement totally dependent on the state's government's willingness to comply.



Article 2 of the International Covenant on Civil and Political Rights requires states to respect and ensure all covenant rights for its citizens disregarding race, color, sex, language, religion, political beliefs, or other status. To achieve this, Article 2(3)(a)-(c) outlines that in order to fulfill the treaty, a state must provide domestic remedies to the violated. First, states should provide an “effective remedy” to anyone whose rights were violated. Second, states must ensure that everyone seeking justice has an opportunity to get a hearing by an official court. Lastly, states must ensure that the person actually receives the help or remedies they were promised. However, simply writing these rules into law is not enough to ensure state compliance with the ICCPR. According to General Comment No. 3, “the implementation does not depend solely on constitutional or legislative enactments, which in themselves are often not per se sufficient”(General Comment, 1981) . Moreover, for these treaties to actually work, the committee emphasizes that education is essential, noting that “all administrative and judicial authorities should be aware of the obligations which the State party has assumed”(General Comment, 1981).

Article 4 of the ICCPR allows governments to “derogate” from certain human rights obligations during an officially proclaimed emergency, which is when a nation is threatened(General Comment, 2001). However, this power is strictly limited. First, emergency measures should be limited: “measures are limited to the extent strictly required by the exigencies of the situation”(General Comment, 2001). This prevents governments overreacting and disregarding the proportionality test. Second, the government must immediately tell other states through the United Nations Secretary-General about the exact rights that will be suspended and an explanation why(ICCPR Article 4, paragraph 3). Lastly and most importantly, Article 4 of the ICCPR and the general comment of its state core human rights which cannot be taken away under any circumstances. The core human rights includes: “right to life, prohibition of torture, and freedom of thought, conscience, and religion”(ICCPR). According to General comment No.29, the ultimate goal during a national security crisis must always be the “restoration of a state normalcy where full respect for the Covenant can again be secured”(General Comment No.29 paragraph 1). Therefore, Article 4 plays a key role of being a safeguard. Even when a crisis challenges a nation’s ability to protect its people, governments cannot use national security as an excuse or justification to ignore international law and abuse their citizens to maintain their power.

ICESCR

The legal framework most central to this paper’s research question is Article 2-1 of the ICESCR. It establishes the mechanism through which all substantive rights in the Covenant, including the right to an adequate standard of living under Article 11, are meant to be realised. This provision matters because it does not impose an immediate obligation of result, as ICCPR does, but rather a duty of conduct; states must “take steps to the maximum of its available resources with a view to achieving progressively the full realisation” of the rights recognised.

The essence of the Article 2-1 lies in its conditional progressive nature. Unlike a rule that specifies a fixed standard of compliance, it ties the pace of realization to a state’s resource capacity and permits fulfillment “by all appropriate means”, a phrase that is left entirely undefined within the treaty text. This vagueness is not incidental but reflects a deliberate compromise intended to accommodate states with different economic capacities. However, it also means that terms central to state accountability (maximum, available resources, appropriate means) function more as an open standard than as enforceable rules. As Robertson stated, without objective criteria for measuring what constitutes a state’s maximum available resources, it becomes difficult to distinguish between states that are genuinely resource constrained and those that are simply unwilling to prioritise ESCR compliance. This ambiguity creates space for states to invoke Article 2-1 defensively, framing the noncompliance as a resource limitation even where the underlying cause is political rather than due to the limited resources.

Article 11-1 is the substantive provision through which poverty is most directly framed as a human rights violation rather than a purely economic condition. The article recognizes “the right of everyone to an



adequate standard of living... including adequate food, clothing and housing, and to the continuous improvement of living conditions," while requiring states to "take appropriate steps to ensure the realization of the right" This provision establishes the legal baseline against which state conduct – such as the persistence of extreme poverty in Burundi, the United States, or elsewhere – can be evaluated as the violation of human rights rather than dismissed as an unfortunate but legally neutral social outcome.

The essence of Article 11-1 mirrors the interpretive looseness of Article 2-1, which carries no measurable threshold, giving states wide discretion over what level of provision satisfies the right. The policies link to "international co-operation based on free consent" and further allow states to attribute continued deprivation to insufficient external assistance rather than domestic policy failures. This ambiguity directly informs the case studies depicted below.

Part IV: Case Study

Case Study 1

This case study examines the United Nation Human Rights Committee's response to South Korea's violation of Kim's right to freedom of expression to test three hypotheses: International agreements lose their power because sovereign countries prioritize their own domestic laws and lack an external system to enforce them; Governments often restrict freedom of expression under the guise of national security just to maintain their absolute power; and, while the multilateral treaties regarding international human rights mandate effective remedies for rights violations, its enforcement remains inconsistent because it ultimately depends on the strength and compliance of each country with its domestic laws.

This case is selected because it is a clear example of a nation violating a human rights treaty despite signing it. In addition, this case happened during a crucial period of political transition in South Korea, which reveals how freedom of expression is essential for a democratic state. During the 1990s, South Korea was in an era of transition, moving away from an authoritarian military dictatorship and moving towards a democratic state.

The 1998 case *Kim v. The Republic of Korea* was brought by Keun-Tae Kim, a South Korean citizen who was arrested and imprisoned for distributing political documents. These documents criticized his own government's policies and advocated for national reunification. The government falsely accused Kim of advocating for North Korea under its National Security law, using confessions obtained through physical and mental torture to claim his writings promoted communist ideologies associated with North Korea. However, the United Nations Human Rights Committee concluded that the South Korean government committed a major human rights violation by going against Article 19 of the ICCPR. The Committee ruled that the state had stripped Kim from his fundamental right to hold and peacefully express political opinions without harming national security (United Nations, 1998).

The case proves the hypothesis. Despite the appeals from international human rights groups, Amnesty International designated Kim as a "Prisoner of Conscience," and Kim received the Robert F. Kennedy Memorial Award for Human Rights. Nevertheless, Mr. Kim remained isolated in jail (Chira, 1988). The South Korean government's neglect of the appeals demonstrates that states frequently disregard international human rights treaties when domestic political interests or regime stability are at stake. The United Nations Human Rights Committee only intervening after the violation occurred highlights the lack of an immediate, external enforcement system which will prevent nations from prioritizing their own values instead of international legal systems.



The case also supports this hypothesis. The South Korean government actively weaponized its ongoing conflict with North Korea as an excuse to protect its authoritarian power. By framing pro-democracy advocates as communists and North Korean spies; the government effectively undermined efforts to bring democracy to the country with the excuse of maintaining national security and public order. The South Korean government's complete disregard for human rights is also proved as they used severe physical and mental torture to get false confessions, which was needed to prove their narrative. Because the United Nations Human Rights Committee ruled that Kim's political beliefs and activities did not actually harm South Korea's national security, it is clear that national security was just an excuse instead of a legitimate reason.

The case also supports this hypothesis. The case reveals that the South Korean government completely ignored Article 19 of the ICCPR while claiming to "protect" its national security. Instead of respecting international human rights treaties, the government prioritized absolute control over its citizens, directly violating the ICCPR. This case demonstrates how without a country's willingness to comply with the international legal systems with its domestic legal system, the enforcement of the treaties like ICCPR are inconsistent and weak.

Case Study 2

This case study examines the United Nations Human Right Council's reaction regarding Iran's violation of Kasra Nouri's right to freedom of expression. This case was selected because it clearly shows how and why nations violate human rights despite signing international treaties like the ICCPR. Using this case clearly reveals how international legal frameworks are constantly challenged by global politics and historical context. Furthermore, researching this case allows for a deeper examination of how countries balance national security against freedom of expression and opinion, especially since states seem to prioritize their immediate security over international treaties.

The 2018 case of Kasra Nouri v. Iran clearly reveals how a government violates the right to freedom of expression. Kasra Nouri, a journalist and a Gonabadi Dervish religious minority, was arrested for reporting on peaceful protests(USCIRF, n.d.). The Iranian government accused Kasra Nouri for threatening national security. The government emphasized Nouri's religious identity and his journals to claim he was trying to cause chaos and insult Islamic values. However, the International Human Rights organizations and the United Nations experts sent letters raising serious concerns regarding Iran violating Article 19 of the ICCPR as Kasra Nouri did not threaten nor harm Iran's national security. They stated that the government wrongfully punished Nouri for practicing his religion and peacefully sharing information with the public.

This case proves hypothesis 3, proving that International agreements lose their power because sovereign countries prioritise their own domestic laws and lack an external system to enforce them. This is better understood with the context that starting from late 2017, Iran had its largest protest which was ignited by high unemployment rate, inflation, and government corruption(BBC, 2018). Additionally, on June 7, 2017, "ISIS committed shooting and bombing attacks towards the Iran Parliament building and the Mausoleum of Ruhollah Khomeini in Tehran, leaving 12 civilians dead and 42 wounded"(Winsor, 2017). For a few months before Nouri was arrested, the Iranian government struggled with the constant threat of terror from ISIS and continuous protests from its citizens.

This case proves hypothesis 2. In other words, the case proves that governments often restrict freedom of expression and religion under the guise of national security just to maintain their absolute power. "In July 2018, Nouri was reportedly sentenced to 12 years in prison, 74 lashes, two years in exile, two years of deprived social rights, and a two-year travel ban"; he received such punishment due to "Illegal Assembly, Public Disorder Spreading Propaganda & False or Misleading Ideas, Information, or Materials Unlawful Disobedience"(USCIRF, n.d.).



By utilizing the chaotic state of the nation, the Iranian government suppressed Kasra Nouri as he was writing articles that criticized the government. This case demonstrates how, especially authoritarian, states conflate religious identity and journalism with existential threats to national security, using harsh rulings to silence dissent for their domestic power.

Case Study 3

This case study examines the European Convention on Human Rights' response to Latvia violating a journalist's right to freedom of opinion and expression. The case of Nagla v. Latvia is chosen because it is a rare, concrete example of a state complying with international human rights remedies rather than neglecting them. Unlike most of human rights rulings that fail to enforce remedies, this case illustrates how a state compensated the journalist. Utilizing this case will provide a vital insight for the enforcement mechanisms of international human rights treaties.

The Nagla v. Latvia case, placed at the European Court of Human Rights, addressed the Latvian police's sudden search and investigation of journalist Ilze Nagla's house and the seizure of her digital storage devices after she claimed a massive security leak in the State Revenue database. The search happened three months after Nagla mentioned the nickname "Neo" in her broadcast; the Latvian government searched and seized Nagla's digital storage without any approval from its judicial authorities (Human Rights Guide, n.d.). The ECHR ruled that the Latvian government's action violated Article 10 of the European Convention on Human Rights, which clearly established that a journalist's right to protect their sources is part of freedom of expression (Voorhoof, 2013).

The case proves hypothesis 3, demonstrating that states prioritize domestic issues over international human rights treaties, but it also uniquely illustrates the opposite: states could prioritize international human rights treaties over domestic interests. Despite Latvia prioritizing the investigation of the hacker "Neo" and therefore violating Nagla's rights, Latvia ultimately complies with the international framework due to its enforcements. This is proven by the fact that the Latvian government fully complied with the court's ruling and ultimately paid remedies to the Latvian journalist Ilze Nagla: "EUR 10,000 in respect of non-pecuniary damage" (Voorhoof, Dirk, 2013). And since then, this case makes it self-explanatory why Latvia and other European countries follow the ECHR-consistent and legal enforcement.

This case proves hypothesis 2 by illustrating how governments often restrict freedom of expression under the guise of national security. At first, Latvia's primary motivation was to identify and punish "Neo", the hacker responsible for leaking sensitive information from the State Revenue Service database. However, as they were investigating the incident and securing evidence, the Latvian police and government bypassed judicial approval which was there to serve as legal safeguards. Instead of getting approval, they executed a sudden search and seized Nagla's digital storage devices. Eventually, the ECHR recognized that the investigation itself to catch "Neo" wasn't illegal or violating human rights. However, the government's aggressive methods totally violated Nagla's right to freedom of expression. During the case, the ECHR emphasized that the press wasn't an escape for criminals but a necessary check on state power in case of emergency. By prioritizing the prosecution of "Neo", this case, Latvia clearly demonstrates how easily "national security" can be weaponized to justify the suppression of free expression and journalism.

Case Study 4

The case of the United States, Burundi, and India demonstrates three different aspects of the reasons why poverty still exists and violates human rights, even though these countries have signed the ICESCR. Unlike Burundi and India, which are state parties to the ICESCR, the United States has signed but never ratified the Covenant. The United States presents a compelling case study for examining why economic and social



rights violations persist despite the existence of international legal protections. As one of the wealthiest nations in the world, the US does not fit the conventional reason for the causation of poverty which is primarily from a lack of resources. This makes it a useful case as a contrast, showing that resource abundance does not by itself produce the realization of economic, social, and cultural rights, allowing this paper to examine Hypotheses 1 (inadequate legal protections) and 5 (lack of political commitment) in a controlled setting where resources cannot serve as the primary explanation. Despite the US's status as a high-income country, the United States continues to exhibit significant levels of poverty and inequality. As of 2024, the official poverty rate stood at 10.6%, leaving 35.9 million people in poverty despite a slight decline from the previous year (United States Census Bureau, 2025). Sengupta's investigation into extreme poverty in the US demonstrates that severe deprivation exists even where the states possess more than sufficient resources to address it, framing this persistence as a human rights violation rather than merely an economic outcome. Turning to the United States' legal relationship with the ICESCR itself, while the US signed the Covenant in 1977, it has never ratified it (Sengupta, 2010). Thus, it cannot be treated as legally equivalent to a State party failing to comply with its treaty obligations; rather signature alone does not create binding treaty obligations under international law – it merely obligates the state not to act in ways that would defeat the treaty's object and purpose, falling well short of the "appropriate means" required under Article 2-1.

This gap between formal engagement and legal obligation is not merely technical. The US's continued refusal to ratify the ICESCR, despite decades of persistent poverty, reflects a broader pattern of domestic political resistance to treating economic and social rights as enforceable legal entitlements. Unlike civil and political rights (ICCPR), which are largely protected through the US Constitution and are therefore treated as justiciable, rights such as housing, healthcare, and an adequate standard of living have historically been addressed as a discretionary domestic policy and market mechanisms rather than binding legal commitments. This helps explain why the United States can simultaneously present itself as a global advocate for human rights while poverty remains a harsh societal predicament, and become an outlier among high-income democracies in its non-ratification of the ICESCR.

This background sets up two central observations that this case study will examine. First, that the persistence of poverty in the US cannot be attributed to a lack of resources and second, that its unratified status exemplifies how states can avoid entering into binding legal commitments. This distinction reflects a broader misconception that Cerqueira directly challenges in his analysis of ICESCR enforceability. He argues that ICESCR are frequently treated as merely aspirational, when in fact they carry a binding legal nature comparable to ICCPR once a state has ratified the relevant treaty (Cerqueira, 2016). Applied to the case of the US, this suggests that the absence of ratification is not a neutral or procedural gap, but a deliberate mechanism through which the United States avoids the binding obligations that ratification would otherwise impose. This reflects that the ICESCR's unratified status allows the US to avoid the binding legal accountability that Cerqueira argues.

As outlined above, two observations follow. First, the severity of poverty in the US does not correlate with the resources available to the state, supporting Sengupta's argument that political prioritisation, not material capacity and amount of resources, is the binding constraint on realising economic and social rights. Second, the United States' five-decade status as an unratified state functions as the deliberate political choice through which the state avoids binding accountability. Together, these observations suggest that poverty in the US persists not from insufficient resources, but from political unwillingness and the strategic avoidance of legal commitment.

The case of the United States demonstrates that the persistence of poverty as a human rights violation cannot be explained by resource scarcity alone. Rather, it confirms that political unwillingness (Hypothesis



5) and structural weaknesses in treaty enforcement (Hypothesis 1) together allow violations to persist even under otherwise favourable material conditions.

Case Study 5

The case of Burundi examines hypotheses 4 and 5. Burundi is one of the most impoverished nations in the world. They ranked 187th out of 193 countries on the 2024 Human Development Index; approximately 80% of its population lives in multidimensional poverty, with an additional 15% at risk of falling into it (Denning, 2026). Burundi's food insecurity affects roughly 15% of its population (Concern Worldwide, n.d.). These directly link to the violation of Economic, Social and Cultural Rights in the aspect of access to an adequate standard of living.

Burundi, as depicted above, is a country with various societal predicaments as an undeveloped country. The country has ratified both the ICCPR and ICESCR, and its constitution formally incorporates the rights enshrined in these treaties. Unlike the United States, Burundi's failure to realise the right to an adequate standard of living cannot be attributed to an absence of a binding legal commitment. Instead, the roots of the country's poverty lie in a combination of severe resource constraints and decades of political instability. Since gaining independence in 1962, Burundi has experienced recurring civil conflict and periods of violence that have repeatedly damaged infrastructure, disrupted agricultural production, and stalled national development of the country. The consequences of this instability are reflected in Burundi's human development outcomes, which is confirmed as the country ranks 187th out of 193 nations on the 2024 Human Development Index, and its maternal mortality rate, with nearly 500 deaths per 100,000 live births. Along with this, an ongoing food crisis sees 15% of the country facing acute food insecurity and the world's highest rate of childhood malnutrition. These conditions illustrate a distinct cause from the American case. (Concern Worldwide, n.d.) While the United States' case illustrates the importance of political commitment and how the ambiguity of the article provides a compromise to the government not to be critical of the crisis and lack enforcement, Burundi's case conveys the hypothesis of the lack of resources, political commitment, and also lack of enforcement.

The slow-growing pace of Burundi's GDP is largely due to the Burundian Civil War that persisted from 1993 to 2005. After the war ended, however, the new president of Burundi, Pierre Nkurunziza's rule from 2005 to 2020 took the shape of an authoritarian one-party system. The Human Rights Watch documented how this consolidation of power directly infringed on the Burundi citizens' Economic, Social, and Cultural Rights (HRW, 2019). In the 2020 elections, Nkurunziza's ruling party mobilised its youth league, the Imbonerakure, to forcibly collect voluntary contributions from citizens by restricting access to markets, water, and healthcare facilities for those who could not prove payment. One farmer from Kirundo province, interviewed in March 2019, described that the members of the Imbonerakure enforced the levy with intimidation regardless of the house's ability to pay: "They don't care if you're poor, they come with bats and clubs. We know we have to contribute, so even if we don't have money, we let our children go hungry to pay." (HRW, 2019). Along with it, access to the healthcare system was denied on the same basis. A man with a physical disability told researchers that his 12-year-old daughter was turned away from a hospital during an emergency because he could not produce an election receipt (HRW, 2019). Human Rights Watch thereby concluded that this practice violated Burundi's ICESCR obligations, as the daily necessities and healthcare systems, which are a cornerstone of the adequate standard of living, became contingent on political loyalty rather than a basic guaranteed right (HRW, 2019).

The Burundi case demonstrates that poverty is a human rights violation which cannot be reduced to resource scarcity alone, even though its status as a developing nation could lead to the assumption that resource scarcity is the only cause. While the severe underdevelopment in the country substantiates Hypothesis 4 (Lack of resources), the government's use of coercive contributions shows Hypothesis 5 (Lack



of political commitment). This distinguishes Burundi from the United States' case, whereas the United States illustrates how sufficient resources can still fail to produce compliance due to a lack of political will; Burundi illustrates how a state can subvert the binding treaty obligations through deliberate policy even with a lack of resources.

Case Study 6

The case of India examines Hypothesis 3 (Lack of enforcement), which examines how the persistence of poverty can stem from the structural inability of courts to directly enforce Economic, Social and Cultural Rights. Unlike the case of the United States and Burundi, India's constitution directly addresses ESCR, but does so in a way that denies them direct legal force, making it a useful case for isolating justiciability itself.

The Indian Constitution classifies Economic and Social rights, access to an adequate standard of living (ICESCR), under the Directive Principles of State Policy. However, its' Article 37 of the Indian Constitution, explicitly declares non-justiciable – meaning they cannot be directly enforced by the court. This structural gap left pavement and slum dwellers without a direct constitutional basis to contest the Bombay Municipal Corporation's 1981 decision to demolish their dwellings. The Supreme Court responded in *Olga Tellis v. Bombay Municipal Corporation* (1985) by reading the right to livelihood into Article 21's guarantee of the right to life reasoning that no person can live without the means of living (Constitution of India, 1950).

This case substantiates Hypothesis 3 in a distinctive way rather than lacking judicial engagement altogether; India's judiciary compensates for the non-justiciability of ESCR by the Government's constitution. While the Court recognised livelihood as part of the right to life, it simultaneously upheld the municipality's power to evict the very dwellers whose livelihood depended on their pavement dwellings, offering only humane treatment rather than a substantive remedy. This outcome illustrates that even when a right is judicially recognized, its enforcement remains constrained by the absence of a direct, justiciable ICESCR's framework.

Hence, the Indian case demonstrates that the persistence of poverty as a rights violation can result not from an absence of judicial will, but from a constitutional structure that denies enforceability. The United States illustrates an unwillingness to bind its politics to treaty obligations, and Burundi illustrates a state that has actively suffered due to the lack of resources as well as the government's oppression.

Part V: Cross-Cutting Analysis

An alternative explanation holds that states disregard international human rights law not because of resource constraints or a lack of political will specifically towards human rights law. They prioritise sovereignty as they view external legal obligations as constraints on their domestic policy-making autonomy rather than a framework. Yet this explanation struggles to account for what the case studies actually reveal.

Under Article 19 paragraph 3 of the ICCPR, it says the right to freedom of expression could be a subject of restriction under "the protection of national security or public order". However, the terms, "protection of national security and public order", lack clear definition in the ICCPR, ultimately causing states to evade its responsibilities to respect and ensure civil and political rights. For the case of *Kim v. Republic of Korea*, the government utilized the vagueness of the definition in order to frame peaceful, democratic documents as communist threats under its domestic national security law. Similarly, the Iranian government exploited the unclear broad terms in the case of *Kasra Nouri v. Iran*. Iran framed Nouri's journalism and religious minority identity with public disorder and spreading propaganda to maintain political control during an unstable domestic period. In both cases, the ICCPR's broad and vague wording allowed certain states to interpret "national security" whatever they wanted, transforming a legal safeguard into a tool of suppression. In both



cases, the ICCPR's vague wording did not simply go unenforced—it was actively repurposed as a tool of suppression, suggesting that the deeper problem lies in textual ambiguity rather than sovereignty alone.

This ambiguity is compounded, in both cases, by the state's use of identity and ideology to justify restriction. Especially in traditionally religious states, the government's political legitimacy is directly linked with its traditional religion. In the case of *Kasra Nouri v. Iran*, the Iranian government did not just arrest Nouri for his criticism against the government; they highlighted Nouri's religious identity as he was a religious minority in Iran. The Iranian government emphasized Nouri's religious identity in order to charge him of "spreading propaganda, public disorder, and unlawful disobedience". By doing this, the state framed Nouri's journalistic expression as a direct attack on Islamic values and second, utilized its national security as it was an unstable time period as the ISIS attacked Tehran in 2017(case was early 2018).

South Korea's democratic transition in the 1990s took place during a highly polarized, anti-communist paradigm. Kim's arrest under National Security Law was invoked by his political documents advocating for reunification of the peninsula. Instead of religion, the South Korean government utilized ideology to suppress freedom of expression even though the expression did not actually threaten national security. In both instances, the vagueness identified above was not merely exploited passively but actively weaponized through appeals to religious or ideological legitimacy.

This pattern points to a further, related failure: the absence of meaningful enforcement once such violations occur. For the *Kim vs. Republic of Korea* case, the United Nations Human Rights Committee formally declared that South Korea committed a major human rights violation against its own citizens. Similarly, for *Kasra Nouri*, demonstrating that without binding enforcement mechanisms, the ICCPR remains largely powerless against sovereign state non-compliance. Turning to economic and social rights, a different pair of explanations emerges.

In contrast to regional legal systems like the ECHR, the United Nations Human Rights Committee lacks binding authority. The ECHR, in fact, states clear legally binding judgments under Article 46 so that the legal framework can "facilitate the rapid and effective correction of a defect identified in the national system of human-rights protection"(ECHR). Similarly, the Inter-American Human Rights System is capable of practicing specific structural legal reforms, emergency provisional measures, and mandatory reparations. Therefore, while regional legal systems like the ECHR and IACHR restrict sovereign autonomy through formal judicial enforcement, the UN covenant framework overly relies on voluntary compliance, leaving the legal system ineffective against determined state non-compliance.

Economic and Political rights are strongly connected and are interdependent. When states suppress freedom of expression and silence political dissent, its government won't be held accountable, resulting in the lack of necessities for life. Conversely, socioeconomic deprivation limits states' citizens ability to fully exercise their political freedom.

Across the case studies, Burundi offers the clearest support for the hypothesis that lack of resources stimulates noncompliance with Economic, Social and Cultural Rights obligations. As one of the most impoverished nations in the world, Burundi ranks 187th out of 193 countries on the 2024 Human Development Index and holds the lowest nominal GDP per capita globally. Though there is a formal ratification of the ICESCR, the state's capacity to fulfil the adequate standard of living from Article 11 is highly unprotected by the covenant. This hypothesis is supported not only by the existence of poverty, but also by its structural origins: decades of civil conflicts disrupted agricultural production and the development of infrastructure, leaving the state with a genuinely limited amount of resources. The United States, by contrast, demonstrates that resource scarcity cannot be the whole story.



The case study of the United States provides proper support for the hypothesis that lack of political commitment engenders noncompliance with Economic, Social and Cultural Rights. The United States case complicates a purely resource-based explanation, as poverty persists there despite the state's evident capacity to address it. Sengupta's analysis of extreme poverty in the US demonstrates that the severity of deprivation does not correlate with the resources available to the state, indicating that policy choices and political prioritisation, rather than material capacity, are the primary constraints on compliance. Read together, the Burundi and US cases suggest that noncompliance with economic and social rights obligations follows two distinct pathways rather than one: a state may fail to comply because it genuinely lacks the resources to do so, or because it has the resources but lacks the will.

Part VI: Recommendations

Ultimately, the recommendations all call for stronger enforcement and eventually better compliance with international human rights treaties. As the previous case study revealed, international legal systems like the International Covenant on Civil and Political Rights (ICCPR) and the International Covenant on Economic, Social and Cultural Rights (ICESCR) are extremely vulnerable to global politics and domestic interests. Consequently, they are often pushed to the bottom of government agendas.

First, to improve the compliance of the ICESCR, especially poverty, regional organizations should focus on providing resources to states where human rights violations due to lack of resources persist. To do this, regional institutions must ensure that the funds they provide are used properly to alleviate the citizen's standard of living. Hence, they should first condition financial flow for the states, to ensure that the states are actually using the money to reduce poverty.

This proposal is indeed a well intentioned strategy; however, this approach has several critical limitations. First, cutting off funding in response to states violating the ICESCR will exacerbate the human rights situation because ordinary citizens are likely to be more harmed than the leaders of the country. Second, regional states to states monitoring has a vulnerability of countries abusing credibility for global politics.

To mitigate these risks, regional organizations should establish a multilateral monitoring system, where neighboring states collectively judge compliance and fund allocation. By allocating oversight across multiple states rather than a single state that has a risk of credibility abuse, this mechanism reduces the political manipulation and ensures the practical enforcement of the funding system.

Second, the United Nations Human Rights Committees should define specific terms of the ICCPR and the ICESCR clearly in order to prevent states finding loopholes within the treaty, especially regarding religion and national security. Inspired by General Comments that the United Nations Human Rights Committee published, interpretations and clear borders of the treaty should be defined within the international legal framework. This approach is far more effective than drafting entirely new treaties, which would likely face lower adoption rates from member states.

This recommendation faces some practical limitations. First, General Comments are interpretive guides rather than legally binding papers, which means that states still have the choice to neglect the new and clear interpretations without facing legal consequences. Additionally, clarifying the text doesn't completely solve the United Nation's lack of enforcement mechanisms but simply suggest new interpretations.

To strengthen the enforcement of the ICCPR and ICESCR, states should expand individuals' access to justiciability by incorporating the UN human rights treaty body as a persuasive and eventually binding authority within the domestic courts. Rather than bypassing the domestic judicial system directly, this approach will render domestic courts a substantive weight to the committee findings, particularly involving



the cases of corruption of government and misconduct of the high-level commissions, reducing the current reliance on domestic compliance with the international rulings.

To build durable domestic pressure for compliance, educational systems should incorporate content on human rights violations and practical avenues for civic response, rather than treating human rights as an abstract legal subject disconnected from lived experience. This approach would render future generations better equipped to recognise violations as they occur and to engage with both domestic and international accountability mechanisms, rather than solely relying on the government's enforcement. By providing an educational system on general human rights as a compulsory education, citizens would be able to know if their government is failing to meet its obligations provided by the ICCPR and ICESCR, rather than remaining unaware that such protections exist at all. International courts and treaty bodies should support this process by actively partnering with domestic human rights movements, such as providing technical resources and platforms.

Conclusion

For civil and political rights, the main issue is the lack of enforcement and vague treaty interpretations that states can easily exploit. For economic and social rights, the main issues are the lack of resources and the lack of states' political will. After thorough analysis of several human rights violation cases, it is now apparent that states use the vague "national security" laws to restrict political rights. Certain states simply lacked the resources to provide adequate living standards while some simply lacked the political commitment to end poverty. Ultimately, these cases reveal how states most of the time prioritize their own sovereignty and domestic interests rather than international human rights agreements.

The thesis is strongly proven by the case studies. For political rights, South Korea and Iran didn't simply neglect international human rights law with the excuse of sovereignty but the vague definition of "national security" to justify their actions. This proves that the real problem is the lack of compliance and enforcement rather than the balancing of sovereignty and international legal systems itself. For the economic and social rights, national sovereignty is more invalid. Burundi's failure to provide adequate living standards is not a choice to protect its sovereignty but a result of the lack of resources. One might argue that the United States has the resources but it still has poverty. Well, that is mostly due to the lack of political will to solve poverty. Therefore, even though sovereignty is respected, the lack of compliance gap is persistent because of specific issues of enforcement, resources, and political commitment.

Addressing these compliance gaps requires solutions tailored to each cause of non-compliance, rather than a single solution. Where states exploit vague terms like "national security" to restrict human rights, UN human rights committees should define these terms more precisely through General Comments, narrowing the interpretive loopholes that currently let states justify restrictions, even though such guidelines remain non-binding. Where enforcement itself is the barrier, domestic courts should treat treaty body findings as persuasive and, eventually, binding authority, giving individuals a path to hold their own government accountable without relying on international treaty bodies with limited enforcement power. Where the problem is resource scarcity, as in Burundi, regional institutions should condition financial assistance on demonstrated poverty reduction outcomes, while there is a risk that withdrawing funds over noncompliance could end up harming ordinary citizens more. And when the problem is the political will, as in the United States, sustained compliance ultimately depends on public pressure. Hence, embedding human rights education in schools and having international courts actively support domestic rights movements matters as much as financial support.

Taken all together, these recommendations support a broader shift in how compliance should be pursued, not asking states to give up their sovereignty, but narrowing its specific gaps – vague treaty language, weak



enforcement, resource shortages, and absent political will – which let governments justify their non-compliance behind sovereignty. By treating each predicament as a separate and addressable problem, the ICCPR and ICESCR can turn from an idealised text into an enforceable commitment.

The research paper mainly focuses on the freedom of expression and opinion under the ICCPR treaty and an adequate standard of living or poverty under the ICESCR. Despite the rights covered in this research paper being essential, because of the specific focus of this study, countless other human rights listed in international legal frameworks that are being violated could not be addressed. Therefore, future researchers in this field are encouraged to conduct further research into these other human rights violations. For example, future studies could explore specific pathways of how regional human rights systems or domestic courts apply international human rights law into enforceable mechanisms to the full realisation of human rights as designed by the ICCPR and ICESCR covenant.

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References

- Amnesty International. (1991, April 30). South Korea: Prisoner of conscience: Kim Keun-tae. <https://www.amnesty.org/en/documents/asa25/012/1991/en/>
- Baig, K. (2024). Analyzing the enforceability of the provisions of ICCPR (case study non-derogable rights in the public emergency). *Pakistan Research Journal of Social Sciences*, 3(2). <https://prjss.com/index.php/prjss/article/view/107>
- BBC. (2018, January 2). Iran protests: Why is there unrest? BBC News. <https://www.bbc.com/news/world-middle-east-42544618>
- Carpenter, D. (2017). So made that I cannot believe: The ICCPR and the protection of non-religious expression in predominantly religious countries. *Chicago Journal of International Law*, 18(1), Article 6.
- Cerqueira, D. (2016, February 3). Enforceability of economic, social and cultural rights: Historical background, legal basis and misleading assumptions. O'Neill Institute for National and Global Health Law. <https://oneill.law.georgetown.edu/enforceability-of-economic-social-and-cultural-rights-historical-background-legal-basis-and-misleading-assumptions/>
- Chira, S. (1988, September 2). Seoul journal; Tortured dissenter lives to see far better days. *The New York Times*. <https://www.nytimes.com/1988/09/02/world/seoul-journal-tortured-dissenter-lives-to-see-far-better-days.html>
- Concern Worldwide. (n.d.). Burundi. <https://www.concern.net/where-we-work/burundi>
- Council of Europe. (n.d.-a). Freedom of expression: Landmark judgments. <https://www.coe.int/en/web/human-rights-convention/expression1>
- Council of Europe. (n.d.-b). Guide on Article 46 of the European Convention on Human Rights: Binding force and execution of judgments. https://ks.echr.coe.int/documents/d/echr-ks/guide_art_46_eng



Davenport, K. (2025, February). The Joint Comprehensive Plan of Action (JCPOA) at a glance. Arms Control Association. <https://www.armscontrol.org/factsheets/joint-comprehensive-plan-action-jcpoa-glance>

Denning, L. (2026, March 22). Everything you need to know about poverty in Burundi. The Borgen Project. <https://borgenproject.org/about-poverty-in-burundi/>

European Court of Human Rights. (2013, July 16). Nagla v. Latvia (Application no. 73469/10). <https://hudoc.echr.coe.int/eng?i=001-122374>

Government of India. (1950). The Constitution of India. Legislative Department, Ministry of Law and Justice. <https://www.legislative.gov.in/constitution-of-india/>

Gunatilleke, G. (2020). Justifying limitations on the freedom of expression. *Human Rights Review*, 22(1), 91–108. <https://doi.org/10.1007/s12142-020-00608-8>

Hafner-Burton, E. M. (2012). International regimes for human rights. *Annual Review of Political Science*, 15(1), 265–286. <https://doi.org/10.1146/annurev-polisci-031710-114414>

Hameed, S., & Naveen, S. (2024). Violation of freedom of speech and expression: A critical study on the arrest and detention of the Indian journalist, Sidheeq Kappan. *European Journal of Arts, Humanities and Social Sciences*, 1(6), 144–152. [https://doi.org/10.59324/ejahss.2024.1\(6\).15](https://doi.org/10.59324/ejahss.2024.1(6).15)

Heymann, J., Sprague, A., Raub, A., & Moseneke, D. (2020). The right to education: A foundation for equal opportunities. In *Advancing equality: How constitutional rights can make a difference worldwide* (1st ed.). University of California Press. <http://www.jstor.org/stable/j.ctv1f8854w.13>

Howie, E. (2017). Protecting the human right to freedom of expression in international law. *International Journal of Speech-Language Pathology*, 20(1), 12–15. <https://doi.org/10.1080/17549507.2018.1392612>

Human Rights Committee. (1981). CCPR general comment No. 3: Article 2 (Implementation at the national level). United Nations.

Human Rights Committee. (1998, November 3). Kim v. Republic of Korea (Communication No. 574/1994). United Nations. <https://juris.ohchr.org/casedetails/804/en-US>

Human Rights Committee. (2001, August 31). CCPR general comment No. 29: Article 4: Derogations during a state of emergency. United Nations. <https://www.refworld.org/legal/general/hrc/2001/30676>

Human Rights Committee. (2011, July 29). General comment No. 34: Article 19 (Freedoms of opinion and expression). United Nations. <https://www.ohchr.org/en/documents/general-comments-and-recommendations/general-comment-no34-article-19-freedoms-opinion-and>

Human Rights Guide. (n.d.). Nagla v. Latvia. <https://www.ljudskaprava.hr/case-law/nagla-v-latvia>

Human Rights Watch. (2019). World report 2019: Burundi. <https://www.hrw.org/world-report/2019/country-chapters/burundi>

Humanists International. (2017, June 13). Anti-terrorism court hands down death sentence over "blasphemous" Facebook post. Humanists International. <https://humanists.international/2017/06/anti-terrorism-court-hands-death-sentence-blasphemous-facebook-post/>



Inter-American Commission on Human Rights. (n.d.). The Inter-American human rights system. Organization of American States. <https://www.oas.org/en/IACHR/jsForm/?File=/en/iachr/caribe/iahrs.asp>

Iran Human Rights Documentation Center. (2025, July). Dawn of a new era in Iran: Protests of December 2017–January 2018. <https://iranhrdc.org/dawn-of-a-new-era-in-iran-protests-2017-2018/>

Li, L. (2024). Research on the interaction between international law and domestic law based on the perspective of international politics. SHS Web of Conferences, 200, 01017. <https://doi.org/10.1051/shsconf/202420001017>

Nixon, A. G. (2020). "Non-religion" as part of the "religion" category in international human rights. Religions, 11(2), 79. <https://doi.org/10.3390/rel11020079>

Robertson, R. E. (1994). Measuring state compliance with the obligation to devote the "maximum available resources" to realizing economic, social, and cultural rights. Human Rights Quarterly, 16(4), 693–714. <https://doi.org/10.2307/762565>

Rouf, A., & Azah, N. (2025). Enforcement challenges in human rights protection under international law. International Journal of Law, 1. <https://journal.berkahopungpungan.com/index.php/IJL/article/view/52>

Salomon, M. E. (2011). Why should it matter that others have more? Poverty, inequality, and the potential of international human rights law. Review of International Studies, 37(5), 2137–2155. <http://www.jstor.org/stable/41308448>

Sengupta, A. (2010). Extreme poverty and human rights: A case study of the United States of America. The Bangladesh Development Studies, 33(1/2), 275–310. <http://www.jstor.org/stable/23339889>

Ssenyonjo, M. (2017). The influence of the International Covenant on Economic, Social and Cultural Rights in Africa. Netherlands International Law Review, 64(2), 259–289. <https://doi.org/10.1007/s40802-017-0091-4>

Strydom, H. (2019). The protection of economic, social and cultural rights in international law. Constitutional Review, 5(2), 222–247. <https://doi.org/10.31078/consrev522>

Supreme Court of India. (1985). Olga Tellis v. Bombay Municipal Corporation, 1985 SCR (3) 545.

The Straits Times. (2017, August 8). Atheist Republic members need to be tracked down, says Malaysian cabinet minister. The Straits Times. <https://www.straitstimes.com/asia/se-asia/atheist-republic-members-need-to-be-tracked-down-says-malaysian-cabinet-minister>

United Nations. (1966a). International Covenant on Civil and Political Rights. <https://www.ohchr.org/en/instruments-mechanisms/instruments/international-covenant-civil-and-political-rights>

United Nations. (1966b). International Covenant on Economic, Social and Cultural Rights. <https://www.ohchr.org/en/instruments-mechanisms/instruments/international-covenant-economic-social-and-cultural-rights>

United States Census Bureau. (2025, September 9). Poverty in the United States: 2024. <https://www.census.gov/library/publications/2025/demo/p60-287.html>

United States Commission on International Religious Freedom. (n.d.-a). Ahmad Al-Shamri. <https://www.uscirf.gov/religious-prisoners-conscience/forb-victims-database/ahmad-al-shamri>



United States Commission on International Religious Freedom. (n.d.-b). Kasra Nouri.
<https://www.uscirf.gov/religious-prisoners-conscience/forb-victims-database/kasra-nouri>

Ventura, M. (2026). Tensions of social human rights in ensuring access to medicines. *Ciencia e Saude Coletiva*, 31(1). <https://doi.org/10.1590/1413-81232026311.14302025en>

Verner, D., Kuttner, S., Egset, W., & World Bank. (2007). Conclusion: Breaking out of the conflict-poverty trap. In *Social resilience and state fragility in Haiti*. World Bank.
<http://www.jstor.org/stable/resrep02483.10>

Voorhoof, D. (2013). European Court of Human Rights: Case of Nagla v. Latvia.
https://www.researchgate.net/publication/293819065_European_Court_of_Human_Rights_Case_of_Nagla_v_Latvia

Winsor, M. (2017, June 8). ISIS claims deadly attacks on Iran parliament, shrine. ABC News.
<https://abcnews.go.com/International/isis-claims-deadly-attacks-iran-parliament-shrine/story?id=47882328>

World Bank. (2024). Poverty, prosperity, and planet report 2024: Pathways out of the polycrisis.
<https://www.worldbank.org/en/publication/poverty-prosperity-and-planet>

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Human Health Effects of Environmental Micro and Nanoplastic (MNP) Exposure: Linking Hippocampal Memory and Neurodegenerative Mechanisms

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Abstract

Microplastics and nanoplastics (MNPs) have become a serious matter because of their widespread prevalence in the environment and accumulation in human tissues, including the brain. Animal studies indicated that MNP exposure impaired hippocampal learning and memory through oxidative stress, neuroinflammation, mitochondrial dysfunction, and blood-brain barrier (BBB) disruption, but evidence in humans remains inadequate. This proposed study will investigate the relationship among MNP exposure, hippocampal memory, and potential neurodegenerative mechanisms using complementary behavioral and cellular approaches. A cross-sectional behavioral study will compare hippocampus-dependent memory between plastic factory workers with high occupational MNP exposure and matched workers with lower exposure using the Mnemonic Similarity Task (MST). The Montreal Cognitive Assessment (MoCA) will be used as a measure of cognitive function. A human induced pluripotent stem cell (iPSC)-derived BBB model containing brain microvascular endothelial cells, astrocytes, pericytes, and hippocampal neurons will be exposed to MNPs to evaluate oxidative stress, mitochondrial dysfunction, neuroinflammation, synaptic impairment, apoptosis, and neuronal viability. The behavioral arm is expected to determine whether occupational exposure is associated with differences in hippocampus-dependent memory, while the cell culture arm is expected to characterize cellular responses to controlled MNP exposure. We expect highly exposed workers to demonstrate lower memory performance than matched controls. We also expect MNP-treated cell cultures to show changes consistent with cellular stress, impaired neuronal function, and neurodegenerative processes. Because the two study arms use different samples, their findings will be interpreted as complementary evidence rather than as a direct individual-level relationship between cellular changes and memory performance. By combining human behavioral assessment with evidence from human-derived cell culture models, this study aims to reduce the gap between existing animal research and human health. The findings may contribute to understanding the potential neurological effects of chronic MNP exposure and provide a basis for future studies of exposure reduction and neurological health.

Keywords

Micro- and Nanoplastic (MNPs); Neurodegenerative Diseases; Hippocampal Memory; Mnemonic Similarity Task; Human iPSC-Derived Neurons

Introduction

The practicality of plastic has led to an annual global production of over 390 million tons (Zuri et al., 2023). Although it leads to serious environmental issues, plastic is still commonly used. Disposed plastic waste accumulates in environments and gradually fragments into microplastics and nanoplastics (MNPs). Microplastics are plastic particles ranging from 1 μm to 5 mm, which can further degrade into nanoplastics, which are smaller than 1 μm (Gao et al., 2025).

More attention has shifted from environmental impacts toward understanding the consequences of chronic MNP exposure on human health, as plastic contamination continues to increase. In addition, many studies emphasize the urgency to study the molecular mechanisms of how the accumulation of MNPs contributes to the progression of neurodegenerative diseases (Lee et al., 2022). Understanding these potential mechanisms is important because MNP exposure can occur through food, water, and air.

Humans can be exposed to MNPs through ingestion of contaminated food and water and inhalation of particles from indoor and outdoor air (Figure 1) (Zuri et al., 2023). An average adult is estimated to take in tens of thousands of plastic particles a year from diet alone, and more once inhaled particles are included (Cox et al., 2019).

After ingestion, MNPs disrupt the intestinal barrier and enter the bloodstream. Smaller particles penetrate the blood-brain barrier (BBB) through diffusion, endothelial uptake, or transcytosis. They also enter the brain through the olfactory nerve. In the brain, they mostly accumulate in different regions, including the hippocampus and cerebral cortex, as proven in animal studies (Gao et al., 2025).

Figure 1. Major Routes of Human Exposure to Micro- and Nanoplastics (MNPs).

Humans are exposed to micro- and nanoplastics through ingestion of contaminated food and water, inhalation of particles, and infant feeding. These can result in lifelong exposure. Adapted from Zuri et al. (2023).

Some groups of people may experience substantially greater occupational exposure to MNPs due to their work environment. For example, workers in plastic manufacturing and recycling environments may experience higher exposure than individuals without occupational contact with plastic materials. Previous studies have found a significant amount of MNPs on and in plastic factory workers' bodies, indicating occupational exposure to MNPs in these settings (Shahsavari et al., 2023). However, even in the same factory, the exposure is not spread evenly. Studies have also concluded that cutting and shredding plastics throws more microparticles into the air, exposing these specific workers to higher airborne particle concentrations than the surrounding background (Swinerton et al., 2024).

Previous studies have already detected MNPs in various biological samples, including human stool, blood, and brain tissue after death (Leslie et al., 2022; Nihart et al., 2025; Schwabl et al., 2019). These findings demonstrate that human exposure can result in internal exposure, although the extent to which MNPs reach specific brain regions remains uncertain.

Previous research also showed that some MNPs particles can reach the human brain. Specifically, more MNPs had been detected in the brain than in the liver or kidney (Nihart et al., 2025). However, this research focused on the frontal cortex, not the hippocampus. Therefore, although MNPs have been detected in human brain tissue, whether they reach the human hippocampus remains uncertain.

Evidence concerning hippocampal effects currently comes primarily from animal studies. When mice were exposed to polystyrene MNPs over several weeks to months, particles accumulated in the brain, including the hippocampus, and exposed mice performed worse on learning and memory tasks (Jin et al., 2022; Lee et al., 2022). These studies also reported BBB disruption, neuroinflammation, and altered memory-related signaling in exposed animals (Jin et al., 2022; Lee et al., 2022). These findings provide biological motivation for investigating whether a similar association can be observed in humans, although animal findings cannot be assumed to translate directly to human health.

The hippocampus is relevant for one of its important functions of pattern separation. It is the ability to distinguish between similar memories so that they remain distinct (Stark et al., 2019). Since this ability depends on the hippocampus, it is one of the first to weaken when the hippocampus is damaged, and it can be used as an indicator of hippocampal damage. To date, no study has yet tested whether real-world MNP exposure is linked to hippocampus-dependent memory in humans.

Environmental agents such as pesticides and industrial solvents can increase neurological risk through mechanisms involving oxidative stress and neuroinflammation. Oxidative stress can contribute to mitochondrial dysfunction, neuronal injury, and synaptic dysfunction (Ma et al., 2025). Animal studies of MNP exposure have similarly demonstrated hippocampus-dependent learning and memory impairment (Jin et al., 2022; Lee et al., 2022).

These mechanisms have been associated with neurodegenerative diseases, including Alzheimer's disease, Parkinson's disease, multiple sclerosis, and amyotrophic lateral sclerosis (Cannon & Greenamyre, 2011). Recent research has also reported greater concentrations of plastic particles in the brains of individuals with dementia than in those without dementia, although these observations do not establish that MNP exposure caused dementia (Nihart et al., 2025).

The present proposal therefore addresses two related but distinct questions. First, is occupational MNP exposure associated with hippocampus-dependent memory performance in humans? Second, can MNP exposure produce cellular responses relevant to neuronal dysfunction in a human-derived BBB model?

Our study will investigate the relationship between occupational MNP exposure and human learning and memory through the MST. We will also examine human-derived neuronal cells exposed to MNPs to study neurodegeneration-related changes, mitochondrial dysfunction, oxidative stress, neuroinflammation, and neuronal damage. This study will combine two complementary approaches. A behavioral study will evaluate hippocampus-dependent memory in workers with different occupational exposure levels. A human-derived BBB cell culture model will examine potential mechanisms of MNP-induced neurotoxicity at a cellular level. Because these two arms involve different samples, the study is designed to provide complementary evidence rather than directly connect a cellular measurement to memory performance within the same individual.

We hypothesize that individuals with higher occupational MNP exposure will demonstrate lower hippocampus-dependent memory performance on the MST, while human-derived BBB cultures exposed to MNPs will exhibit increased oxidative stress, neuroinflammation, mitochondrial dysfunction, apoptosis, and impaired synaptic function.

Methods

Behavioral Test

Experimental Design

This study will use a cross-sectional research design to compare hippocampus-dependent memory between workers with high and low occupational MNP exposure. Within a single plastic manufacturing or recycling facility, workers will be divided into two groups according to their primary daily task. The high-exposure group will consist of workers whose primary responsibilities involve cutting or shredding plastics. Cutting and shredding can release substantial quantities of airborne plastic particles (Swinerton et al., 2024). The low-exposure group will consist of workers whose primary responsibilities do not involve mechanically breaking plastics, such as packaging, inspection, or warehouse work.

These groups will be matched by age, sex, education, and job tenure to reduce differences in major background characteristics. Workers with diagnosed neurological or psychiatric conditions, a significant history of head injury, uncorrected visual impairment, or heavy alcohol use will be excluded.

The behavioral study will aim to recruit 128 participants, with 64 participants in each exposure group. This target is based on an a priori two-group comparison designed to provide approximately 80% statistical power to detect a moderate standardized difference in LDI between exposure groups at a two-sided $\alpha = 0.05$ significance level. The final sample-size calculation will be refined using pilot data if available before recruitment begins.

In addition to the categorical exposure groups, each participant will receive an occupational exposure score from 0 to 3 based on their primary task: 0 for non-cutting office or inspection work, 1 for packaging or plastic handling, 2 for occasional cutting or shredding, and 3 for cutting or shredding as the primary job. This score represents an occupational exposure proxy rather than a direct measurement of each participant's internal MNP burden. The exposure contrast will be informed by previous measurements of airborne particle release during plastic cutting and shredding (Swinerton et al., 2024).

Because workers performing different tasks may also experience different levels of dust, heat, noise, fumes, or other occupational exposures, these factors represent potential confounders. Where feasible, information about major occupational co-exposures will be collected and considered in sensitivity analyses.

Ethical Considerations

Before recruitment, the behavioral study will obtain approval from the appropriate institutional review board or research ethics committee. All participants will provide informed consent after receiving an explanation of the study procedures, risks, benefits, confidentiality protections, and their right to withdraw without penalty. Participant data will be coded and analyzed without directly identifying information.

MST and MoCA results will be coded before statistical analysis, and the personnel responsible for scoring or analyzing the cognitive outcomes will be masked to occupational exposure groups whenever feasible.

Survey and Visual Screening

Participants will also complete a visual screening procedure to confirm that they can clearly see the digital MST stimuli and do not have an uncorrected visual impairment that could interfere with performance.

Montreal Cognitive Assessment

Each participant will complete one session of the Montreal Cognitive Assessment (MoCA), a brief screening test of general cognitive function (Nasreddine et al., 2005). The five-point delayed-recall component will be removed from the total score and analyzed separately as MoCA-without-memory. This measure will be included as a covariate to account for differences in general cognitive ability that could influence MST performance.

The MoCA will be administered by trained personnel following standardized administration procedures.

Mnemonic Similarity Task

Each participant will complete the optimized MST for efficient administration (Stark et al., 2023). The MST consists of two phases. During the first phase, participants will view images of everyday objects and make a simple indoor/outdoor judgment. They will not be explicitly instructed to memorize the images.

During the second phase, participants will view a new set of images and classify each image as "new," "old," or "similar." The test includes exact repetitions, completely new images, and visually similar images.

Two primary outcomes will be obtained. The Lure Discrimination Index (LDI) measures the ability to distinguish similar images from previously viewed images and serves as a hippocampus-sensitive measure of pattern separation. The Recognition Index (REC) measures the ability to distinguish repeated images from new images and serves as a control measure of general recognition memory.

A trained study administrator will provide standardized instructions and a brief practice session before the scored MST. MST scoring will be automated or performed according to the standardized scoring procedure, with exposure-group information unavailable to the analyst.

Behavioral Testing Procedure

Each participant will be tested individually in a quiet room under standardized conditions. The session will begin with the survey and visual screening, followed by the MoCA. Participants will then complete a brief MST practice session before completing the scored MST. Testing order, instructions, environmental conditions, and testing equipment will be standardized across participants.

Data Quality and Exclusion

Participants with an REC score below 0.5 will be excluded from the primary analysis because this score may indicate inadequate understanding of the recognition component of the task. Additional exclusions will be applied only according to predefined criteria established before data analysis, such as incomplete testing or technical failure.

Behavioral Statistical Analysis

The primary behavioral outcome will be the difference in LDI between the high- and low-exposure groups. An independent-samples t-test will be used for the primary comparison if the assumptions of the test are met. If normality or variance assumptions are substantially violated, an appropriate nonparametric alternative will be used.

REC scores will be compared between the two groups using the same approach to determine whether group differences are specific to hippocampus-sensitive pattern separation rather than general recognition memory.

An analysis of covariance (ANCOVA) will additionally be used to compare LDI between exposure groups while adjusting for MoCA-without-memory and other prespecified covariates such as age, sex, education, and job tenure if necessary after matching.

The occupational exposure score will be analyzed as an ordinal exposure measure. Spearman rank correlation will be used to assess the association between exposure score and LDI because the exposure score consists of four ordered categories. A linear regression model may additionally be used to estimate the change in LDI associated with increasing exposure score while adjusting for relevant covariates.

Sex will not be analyzed as completely separate samples for the primary analysis because doing so would substantially reduce statistical power. Instead, sex will be included as a covariate, and an exposure-by-sex interaction will be examined as an exploratory analysis to determine whether the association differs by sex.

Statistical significance will be set at $p < 0.05$, with effect sizes and confidence intervals reported where appropriate.

Cell Culture Study

Human iPSC-Derived BBB Model

A human iPSC-derived BBB model will be used to simulate key components of the human neurovascular unit and investigate cellular responses to MNP exposure. The model will include iPSC-derived brain microvascular endothelial cells (BMECs), astrocytes, pericytes, and hippocampal neurons (Figure 2).

BMECs form the BBB and its tight junctions, which regulate molecular permeability. Astrocytes support BBB formation and maintenance. Pericytes contribute to vascular stability and endothelial cell support. Hippocampal neurons will provide a human-derived neuronal component through which potential effects on neuronal function can be evaluated (Naik & Cucullo, 2013).

The planned model does not include microglia or other immune cells. Therefore, although inflammatory responses can be measured in the model, it will not fully reproduce the immune-cell-mediated component of neuroinflammation in the human brain.

Figure 2. Human iPSC-Derived Blood–Brain Barrier (BBB) Model. Schematic representation of the planned model containing iPSC-derived brain microvascular endothelial cells, astrocytes, pericytes, and hippocampal neurons. Microglia are not included in the proposed model.

Cell Culture Conditions

The four cell types will be maintained using appropriate culture media and supplements under standardized cell culture conditions. Cultures will be maintained in a humidified CO₂ incubator under manufacturer- and protocol-recommended temperature, pH, and CO₂ conditions.

Cell density, number of cells seeded, culture medium and supplements, temperature, CO₂ concentration, humidity, pH, plate format, and handling procedures will be standardized across treatment groups.

Experimental Design and MNP Exposure

BBB cultures will be randomly assigned to a control group or one of three MNP exposure groups.

Table 1. Study Design for Control and Experimental Groups with MNP Exposure Conditions

Group	MNP Concentration
Negative control	0 mg/g
Low exposure	0.010 mg/g
Medium exposure	0.015 mg/g
High exposure	0.025 mg/g

Each treatment condition will contain at least three independent biological replicates.

The MNP treatment used in this proposal will consist of polystyrene particles with a nominal diameter of 1 µm. Because particles at this size are classified as microplastics rather than nanoplastics, this experimental arm specifically evaluates microplastic exposure; effects of particles in the nanoscale range will require a separate experiment.

The particles will be applied to the vascular side of the BBB model to simulate exposure from the bloodstream. The control group will undergo the same handling procedures without MNP addition.

Three exposure durations will be evaluated: 24, 48, and 72 hours. Separate culture wells will be allocated to each time point so that destructive assays do not affect measurements at later time points.

Outcome Measurements

Cell cultures will be evaluated at baseline and after 24, 48, and 72 hours of exposure.

Cell viability and metabolic activity will be assessed using an MTT assay. MTT reduction to formazan will be quantified by measuring absorbance at 570 nm using a microplate reader. Cellular morphology and growth will also be monitored using phase-contrast microscopy.

Reactive oxygen species (ROS) production will be assessed using a DCFH-DA fluorescence assay. Fluorescence intensity will be measured and reported as relative fluorescence units (RFU) after normalization to appropriate controls.

Cellular ATP production will be measured using an ATP assay to evaluate changes associated with mitochondrial function.

Changes in neuronal function and synaptic plasticity will be assessed through gene-expression analysis using reverse transcription quantitative polymerase chain reaction (RT-qPCR). Relative expression will be calculated in comparison with the control group.

Changes associated with neuroinflammation will be assessed through gene-expression analysis and, where feasible, protein-level analysis using appropriate immunoassays.

Neurodegeneration-related cellular changes will be assessed using immunocytochemistry and fluorescence microscopy.

Apoptotic cell changes will be evaluated using immunocytochemistry, with the proportion of apoptotic cells quantified through microscopy.

Cell Culture Statistical Analysis

Data from biological replicates will be summarized as mean $\pm$ standard deviation.

Because the cell culture experiment contains two independent experimental factors—MNP concentration (control, low, medium, and high) and exposure duration (24, 48, and 72 hours)—a two-way ANOVA will be used to evaluate the main effects of concentration, duration, and their interaction.

An appropriate post hoc multiple-comparison test will be performed when significant effects are detected.

The concentration $\times$ duration interaction will determine whether the effect of MNP concentration changes depending on exposure duration. This will allow the study to distinguish concentration-dependent effects from time-dependent effects.

The relationship between MNP concentration and each measured biological outcome will additionally be examined using scatterplots and dose-response curves. Because concentration is an experimentally controlled continuous variable, Pearson correlation or regression analysis will be used where assumptions are satisfied to assess linear associations between concentration and cellular outcomes.

Statistical significance will be set at $p < 0.05$.

Results and Discussion

Expected Outcome

Because this manuscript describes a proposed investigation, no empirical results have yet been collected. The following outcomes represent the study's prespecified hypotheses rather than observed findings.

Behavioral Test

The primary prediction is that the high-exposure group will demonstrate a lower LDI score than the low-exposure group, indicating poorer hippocampus-sensitive pattern separation among workers with greater occupational exposure. This prediction is informed by animal studies reporting impaired hippocampus-dependent learning and memory following MNP exposure (Lee et al., 2022; Jin et al., 2022), human studies detecting MNPs in brain tissue (Nihart et al., 2025), and research associating plastic exposure with poorer cognitive function (Zhu et al., 2024).

The two groups are expected to show relatively similar REC scores. If LDI differs between groups while REC does not, this pattern would be consistent with a more selective difference in hippocampus-sensitive memory rather than a broad impairment in recognition performance. However, such a pattern would not by itself establish that MNPs specifically caused hippocampal dysfunction.

The study also predicts a graded relationship between occupational exposure score and LDI. As exposure score increases from 0 to 3, LDI is expected to decrease. Because the exposure score is an occupational

proxy rather than a direct measurement of individual MNP burden, any dose-response pattern would be interpreted as an association with occupational exposure intensity rather than a direct biological dose-response relationship.

The study will also explore whether the exposure-memory association differs by sex. Based on previous human and animal studies suggesting possible sex-related differences in the cognitive effects of plastic exposure (Lee et al., 2022; Zhu et al., 2024), an exposure-by-sex interaction may be observed; however, this will be considered exploratory rather than a primary hypothesis.

Because no prior research has measured MST performance in humans according to occupational MNP exposure, these predictions describe expected directions and trends rather than specific numerical values.

Figure 3. Predicted direction of the behavioral results. LDI is expected to be lower in the high-exposure group while REC remains approximately similar between groups (left), and LDI is expected to decrease as occupational exposure score increases from 0 to 3 (right). These are hypothetical predictions and do not represent observed data.

Cell Culture Study

We expect MNP exposure to produce concentration- and time-dependent effects in the human-derived BBB model. Compared with negative controls, cultures exposed to higher MNP concentrations or longer exposure durations are expected to show reduced cell viability, metabolic activity, and growth. These changes may be reflected by lower MTT absorbance and altered cellular morphology.

MNP-exposed cultures are also expected to demonstrate increased intracellular ROS levels, indicating greater oxidative stress, and reduced ATP production, indicating impaired mitochondrial function. RT-qPCR is expected to reveal changes in the expression of genes associated with synaptic function. Neuroinflammation-related and neurodegeneration-related cellular responses are also expected to change following MNP exposure, consistent with reported activation and stress responses in human astrocytes exposed to polystyrene MNPs (Kiran et al., 2025). Immunocytochemistry is expected to demonstrate a higher proportion of apoptotic cells in MNP-treated cultures than in controls.

If these outcomes are observed, they would provide evidence that MNP exposure can induce cellular responses associated with oxidative stress, mitochondrial dysfunction, neuroinflammation, altered synaptic function, and apoptosis in the human-derived model. However, these cellular findings would not independently demonstrate that MNP exposure causes hippocampal memory impairment or neurodegenerative disease in humans.

Discussion

Mice are valuable models for studying human disease because some aspects of brain structure, cellular organization, and disease-related pathways are evolutionarily conserved. Mice and humans share several neuronal and non-neuronal cell classes, including excitatory neurons, inhibitory neurons, astrocytes, microglia, oligodendrocytes, endothelial cells, and pericytes. The organization of some cortical cell types is conserved despite species-specific differences in gene expression (Hodge et al., 2019).

The hippocampus also has conserved anatomical organization between mice and humans, including the dentate gyrus, CA3, and CA1 regions. The BBB, which regulates molecular transport between the bloodstream and brain, also shares important structural features across species. However, these similarities do not eliminate important differences in gene expression, cellular physiology, and disease susceptibility. Many genes involved in neuronal signaling, neurotransmitter receptors, ion channels, and cell adhesion exhibit species-specific expression patterns that can influence neurological disease mechanisms (Perlman, 2016).

With observational studies still unable to determine whether MNP accumulation causes neurological disease, human-based research is needed (Nihart et al., 2025). The proposed study addresses this gap through two complementary approaches: behavioral assessment in occupationally exposed humans and mechanistic testing in a human iPSC-derived BBB model.

The two experiments test different aspects of the research question, and neither can answer the entire question independently. The behavioral arm tests whether occupational MNP exposure is associated with weaker hippocampus-sensitive memory in humans, but it cannot determine the biological mechanisms responsible for any observed association. The cell culture arm tests whether MNP exposure can produce cellular changes relevant to neuronal dysfunction in a human-derived model, but it cannot demonstrate an effect on memory in living humans.

Accordingly, the findings from the two arms should be interpreted as complementary rather than as evidence of a direct biological link between cellular changes and memory performance. If both arms produce results consistent with the hypotheses, the findings would strengthen the overall evidence that MNP exposure warrants further investigation as a potential neurological risk factor. However, concordant findings would not establish that the cellular changes observed in vitro are the mechanism responsible for any memory differences observed in the behavioral study because the two experiments involve different samples and experimental conditions.

The behavioral study has several important limitations. Cutting and shredding plastics do not only produce MNPs; these activities may also involve increased dust, heat, noise, and fumes that could affect cognitive performance independently. Therefore, a lower LDI among cutting and shredding workers could reflect a combination of occupational exposures rather than MNP exposure alone. Furthermore, because participants are classified according to job tasks rather than individual measurements of airborne MNP concentration or internal MNP burden, exposure misclassification is possible. Individual exposure may vary within each occupational group.

Because the behavioral study is cross-sectional, it can identify associations but cannot establish temporal sequence or causation. Longitudinal studies with direct measurements of personal MNP exposure would be needed to determine whether chronic MNP exposure predicts subsequent changes in hippocampus-dependent memory.

The cell culture model also has limitations. The BBB model is a simplified representation of the human neurovascular system and cannot reproduce the complete process of MNP ingestion, absorption, metabolism, circulation, excretion, and brain accumulation. Although the model includes multiple human-derived cell types, it cannot reproduce the full complexity of the living human brain or interactions among multiple brain regions.

The absence of microglia and other immune-cell populations is another limitation. Consequently, inflammatory responses observed in the model may not fully represent neuroinflammation in the human brain. In addition, the proposed exposure duration of 24–72 hours is substantially shorter than the years or decades of exposure experienced by humans. Therefore, acute or subacute cellular responses may not accurately predict long-term effects.

Another limitation is that the proposed cell culture experiment uses 1 μm polystyrene particles, which represent microplastics rather than nanoplastics. Therefore, the cellular findings should not automatically be generalized to all MNPs or to nanoscale particles. Future experiments should examine multiple polymer types, particle sizes, shapes, surface properties, and environmentally relevant concentrations.

Most importantly, although human-derived cell models provide greater human relevance than animal models, findings should be validated through additional experimental and clinical research before conclusions about human neurodegenerative disease can be made.

Future studies should develop methods to determine whether MNPs are present specifically in the human hippocampus. Current research has detected MNPs in human brain tissue, including the frontal cortex, but direct evidence concerning hippocampal accumulation remains limited. Direct measurement of hippocampal MNP burden, where ethically and technically feasible, would help clarify whether exposure is associated with particle accumulation in the brain region underlying the memory process examined in this study.

Future research should also use longitudinal human studies, direct personal exposure measurements, and more physiologically complex human neural models containing immune cells. Such approaches could help determine whether the cellular mechanisms identified in vitro are relevant to long-term neurological outcomes.

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References

- Cannon & Greenamyre (2011). The role of environmental exposures in neurodegeneration and neurodegenerative diseases. *Toxicological Sciences*, 124(2), 225–250. <https://doi.org/10.1093/toxsci/kfr239>
- Cox, K. D., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., & Dudas, S. E. (2019). Human consumption of microplastics. *Environmental Science & Technology*, 53(12), 7068–7074. <https://doi.org/10.1021/acs.est.9b01517>
- Gao, H.-T., Zhou, H.-Q., Ji, H.-N., Shen, J. Z., Yin, D.-M., & Wu, D.-H. (2025). From exposure to neurotoxicity induced by micro-nanoplastics with brain accumulation and cognitive decline. *Ecotoxicology and Environmental Safety*, 291, 119114. <https://doi.org/10.1016/j.ecoenv.2025.119114>
- Hodge, R. D., Bakken, T. E., Miller, J. A., Smith, K. A., Barkan, E. R., Graybuck, L. T., Close, J. L., Long, B., Penn, O., Yao, Z., Eggermont, J., Holtt, T., Levi, B. P., Shehata, S. I., Aeversmann, B., Beller, A., Bertagnolli, D., Brouner, K., Casper, T., ... Tasic, B. (2019). Conserved cell types with divergent features in human versus mouse cortex. *Nature*, 573(7772), 61–68. <https://doi.org/10.1038/s41586-019-1506-7>
- Jin, H., Yang, C., Jiang, C., Li, L., Pan, M., Li, D., Han, X., & Ding, J. (2022). Evaluation of neurotoxicity in BALB/c mice following chronic exposure to polystyrene microplastics. *Environmental Health Perspectives*, 130(10), 107002. <https://doi.org/10.1289/EHP10255>
- Kiran, S., Thilanka, U., Xue, Y., & Sang, Q.-X. A. (2025). Polystyrene micro- and nanoplastic exposure triggers an activation and stress response in human astrocytes. *International Journal of Molecular Sciences*, 26(23), 11273. <https://doi.org/10.3390/ijms262311273>
- Lee, C.-W., Hsu, L.-F., Wu, I.-L., Wang, Y.-L., Chen, W.-C., Liu, Y.-J., Yang, L.-T., Tan, C.-L., Luo, Y.-H., Wang, C.-C., Chiu, H.-W., Yang, T. C.-K., Lin, Y.-Y., Chang, H.-A., Chiang, Y.-C., Chen, C.-H., Lee, M.-H., Peng, K.-T., & Huang, C. C.-Y. (2022). Exposure to polystyrene microplastics impairs hippocampus-dependent learning and memory in mice. *Journal of Hazardous Materials*, 430, 128431. <https://doi.org/10.1016/j.jhazmat.2022.128431>

- Leslie, H. A., van Velzen, M. J. M., Brandsma, S. H., Vethaak, A. D., Garcia-Vallejo, J. J., & Lamoree, M. H. (2022). Discovery and quantification of plastic particle pollution in human blood. *Environment International*, 163, 107199. <https://doi.org/10.1016/j.envint.2022.107199>
- Ma, Q., Lei, J., Pang, Y., Shen, Y., & Zhang, T. (2025). Neurotoxicity of micro- and nanoplastics: A comprehensive review of central nervous system impacts. *Environment & Health*, 4(1), 4–24. <https://doi.org/10.1021/envhealth.5c00087>
- Naik, P., & Cucullo, L. (2013). In vitro blood–brain barrier models: Current and perspective technologies. *Journal of Pharmaceutical Sciences*, 102(4), 1337–1354. <https://doi.org/10.1002/jps.23022>
- Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L., & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*, 53(4), 695–699. <https://doi.org/10.1111/j.1532-5415.2005.53221.x>
- Nihart, A. J., Garcia, M. A., El Hayek, E., Liu, R., Olewine, M., Kingston, J. D., Castillo, E. F., Gullapalli, R. R., Howard, T., Bleske, B., Scott, J., Gonzalez-Estrella, J., Gross, J. M., Spilde, M., Adolphi, N. L., Gallego, D. F., Jarrell, H. S., Dvorscak, G., Zuluaga-Ruiz, M. E., ... Campen, M. J. (2025). Bioaccumulation of microplastics in decedent human brains. *Nature Medicine*, 31, 1114–1119. <https://doi.org/10.1038/s41591-024-03453-1>
- Perlman, R. L. (2016). Mouse models of human disease: An evolutionary perspective. *Evolution, Medicine, and Public Health*, 2016(1), 170–176. <https://doi.org/10.1093/emph/eow014>
- Schwabl, P., Köppel, S., Königshofer, P., Bucsics, T., Trauner, M., Reiberger, T., & Liebmann, B. (2019). Detection of various microplastics in human stool: A prospective case series. *Annals of Internal Medicine*, 171(7), 453–457. <https://doi.org/10.7326/M19-0618>
- Shahsavari-pour, M., Abbasi, S., Mirzaee, M., & Amiri, H. (2023). Human occupational exposure to microplastics: A cross-sectional study in a plastic products manufacturing plant. *Science of the Total Environment*, 882, 163576. <https://doi.org/10.1016/j.scitotenv.2023.163576>
- Stark, S. M., Frithsen, A., & Stark, C. E. L. (2023). Optimizing the Mnemonic Similarity Task for efficient, widespread use. *Frontiers in Behavioral Neuroscience*, 17, 1080366. <https://doi.org/10.3389/fnbeh.2023.1080366>
- Stark, S. M., Kirwan, C. B., & Stark, C. E. L. (2019). Mnemonic Similarity Task: A tool for assessing hippocampal integrity. *Trends in Cognitive Sciences*, 23(11), 938–951. <https://doi.org/10.1016/j.tics.2019.08.003>
- Swinnerton, S., Su, J., & Tsai, C. S. J. (2024). The emission and physicochemical properties of airborne microplastics and nanoplastics generated during the mechanical recycling of plastic via shredding. *Scientific Reports*, 14, 23276. <https://doi.org/10.1038/s41598-024-73775-0>
- Wang, S., Han, Q., Wei, Z., Wang, Y., Xie, J., & Chen, M. (2022). Polystyrene microplastics affect learning and memory in mice by inducing oxidative stress and decreasing the level of acetylcholine. *Food and Chemical Toxicology*, 162, 112904. <https://doi.org/10.1016/j.fct.2022.112904>
- Zhu, Y., Wu, Y., Shi, L., Yang, Y., Wang, Y., Pan, D., He, S., Wang, L., & Li, J. (2024). Association of plastic exposure with cognitive function among Chinese older adults. *Journal of Alzheimer's Disease*, 101(3), 1015–1025. <https://doi.org/10.3233/JAD-240746>
- Zuri, G., Karanasiou, A., & Lacorte, S. (2023). Microplastics: Human exposure assessment through air, water, and food. *Environment International*, 179, 108150. <https://doi.org/10.1016/j.envint.2023.108150>