MSI Journal of
Medicine and Medical Research (MSIJMMR)

Assessing the Impact of Neuralink Technology on Human Health, Cognition and Ethics

Asadullah Eman[1*]

[1] Dean of Computer Science Faculty, Pamir University, Khost Afghanistan.

*** Correspondence:** Okpan Samuel Okpanocha

The authors declare that no funding was received for this work.

OPEN ACCESS

Received: 20-September-2025
Accepted: 30-September-2025
Published: 07-October-2025

This article is published in the **MSI Journal of Medicine and Medical Research (MSIJMMR)**
ISSN 3049-1401 (Online)

The journal is managed and published by MSI Publishers.

Volume: 2, Issue: 10 (October-2025)

ABSTRACT: This research explores the multifaceted impact of Neuralink technology on human health, cognition, and ethics. Neuralink, a brain-computer interface (BCI) developed by Elon Musk's neurotechnology company, aims to establish a direct communication link between the human brain and external devices. The study adopts a qualitative, literature-based methodology, relying on scholarly articles, ethical analyses, media reports, and official Neuralink publications to assess the promises and challenges of technology.

Findings indicate that Neuralink has significant potential for medical applications, including treating neurological disorders, restoring motor function, and enabling brain-based control of external systems. However, health-related risks including surgical complications, long-term device reliability, and biocompatibility remain areas of concern. From a cognitive perspective, Neuralink proposes capabilities such as memory enhancement and real-time communication, raising profound questions about identity, mental overload, and dependency.

Ethically, the study reveals urgent concerns regarding mental privacy, consent, inequality, and potential misuse in surveillance or behavioral control. Without comprehensive legal and ethical frameworks, these risks could undermine public trust and human dignity. The paper concludes that while

Neuralink may revolutionize how humans interact with technology, its development must be guided by interdisciplinary oversight, equitable access, and proactive regulation.

Keywords: *Neuralink, brain-computer interface, neurotechnology, cognitive enhancement, mental privacy, artificial intelligence*

Introduction

The rapid evolution of neuroscience and digital technology in the 21st century has led to the emergence of advanced brain-computer interfaces (BCIs), which allow direct communication between the human brain and external devices. Among the most ambitious and widely discussed BCI initiatives is **Neuralink**, a neurotechnology company founded by Elon Musk in 2016. Neuralink aims to create implantable devices capable of reading and interpreting brain signals, thereby enabling humans to interact with machines, restore lost neurological functions, and potentially enhance cognitive abilities.

While once considered science fiction, the idea of linking the brain with machines has now become a scientific reality. Neuralink's approach—using minimally invasive surgical robots to implant ultra-thin neural threads into the brain—has the potential to revolutionize medicine, artificial intelligence, and human-computer interaction. As Neuralink technology continues to develop, it raises important questions not only about its potential benefits but additionally about its broader impact on human health, mental functioning, privacy, and ethics.

This research is vital because Neuralink represents more than just technological advancement—it challenges our understanding of what it means to be human. While its medical potential is immense, offering hope to millions suffering from neurological disorders, the ethical and cognitive implications are profound and complex. This raises questions about data ownership, brain privacy, social inequality, and the consequences of enhancing or altering human cognition.

By exploring these aspects, this study provides a comprehensive assessment of Neuralink's influence on human life, contributing valuable insights for technologists, ethicists, medical professionals, and policymakers.

Neuralink Corporation focuses on creating a high-bandwidth, biocompatible BCI capable of recording brain activity and stimulating neural responses. Its core technology involves the surgical implantation of flexible electrode threads, connected to a small chip (Link), into specific areas of the brain. These chips communicate wirelessly with external devices, enabling two-way data flow between the brain and machines. The company's long-term vision includes helping individuals with paralysis regain motor function, developing cognitive enhancement tools, and possibly merging human intelligence with artificial intelligence (AI).

Problem Statement

The emergence of Neuralink technology—a brain-computer interface (BCI) developed to connect the human brain directly with machines—marks a revolutionary shift in how humans interact with technology. By enabling direct neural communication with computers, Neuralink has the potential to restore lost functions in patients with neurological conditions, enhance cognitive capabilities, and redefine the boundaries of human potential.

Despite its groundbreaking promise, Neuralink additionally presents significant challenges and uncertainties. The long-term health effects of implantable brain devices are still unknown, and the enhancement of cognition through artificial means raises philosophical and ethical dilemmas. Moreover, concerns about data privacy, consent, and the potential for social inequality emerge as critical issues in the deployment of such advanced neurotechnology.

This study aims to critically assess the multifaceted impact of Neuralink technology, focusing on its medical applications, its potential to alter cognitive functioning, and its broader ethical implications in society.

Research Objectives

1. **To evaluate** the potential health benefits and medical applications of Neuralink, particularly in the treatment of neurological disorders such as paralysis, epilepsy, and Parkinson's disease.
2. **To examine** the cognitive implications of Neuralink, including its ability to enhance memory, learning, and human-computer interaction.
3. **To explore** the ethical concerns related to brain-machine interfaces, including issues of consent, privacy, mental autonomy, and the risk of misuse.
4. **To analyze** the societal implications of Neuralink, including its impact on inequality, accessibility, and human identity.
5. **To investigate** public perception, acceptance, and awareness of Neuralink technology and similar neurotechnological innovations.

Scope and Limitations

This study focuses primarily on the theoretical and practical impacts of Neuralink technology on three key areas: health, cognition, and ethics. The research draws on existing literature, expert opinions, case studies, and Neuralink's publicly available data. Due to the emerging nature of the technology, empirical clinical results remain limited, which may constrain certain analyses. Furthermore, the study does not involve primary experimentation but relies on secondary qualitative data to draw conclusions.

Literature Review

As the boundary between human biology and digital technology narrows, the development of brain-computer interfaces (BCIs) like Neuralink has drawn significant attention across fields such as neuroscience, bioethics, artificial intelligence, and clinical medicine. This literature review examines the historical context, technological foundations, medical applications, cognitive implications, and ethical challenges of Neuralink, as well as the gaps that this research aims to address.

Brain-computer interfaces have been a subject of scientific inquiry since the 1970s, when early experiments focused on allowing paralyzed individuals to control devices using brain signals (Wolpaw et al., 2002). These early BCIs were non-invasive and limited in capability, using electroencephalography (EEG) to detect electrical signals on the scalp. Over time, research shifted toward more invasive techniques that provide greater precision by placing electrodes directly on or in the brain.

Advancements in neuroscience and computing power have made it feasible to decode brain activity with increasing accuracy. This progress laid the foundation for commercial ventures such as Neuralink, which aims to miniaturize and refine invasive BCI technologies for widespread clinical and consumer use.

Founded in 2016 by Elon Musk, Neuralink seeks to develop ultra-high bandwidth BCIs that enable direct brain-to-device communication. Its primary technological innovation lies in implanting ultra-thin, flexible electrode threads into the cerebral cortex using a robotic surgical system (Musk & Neuralink, 2019). Each implantable chip, called the "Link," includes thousands of electrodes capable of detecting and stimulating neural activity wirelessly.

Neuralink's long-term vision is to bridge humans and artificial intelligence by enabling rapid data exchange between the brain and machines. In the short term, its stated goals include restoring movement in patients with paralysis and providing therapeutic interventions for neurological disorders.

One of the most promising aspects of Neuralink lies in its potential to transform the treatment of neurological conditions. Studies suggest that BCIs could help individuals with spinal cord injuries regain control of limbs by bypassing damaged neural pathways (Bouton et al., 2016). Similarly, the ability to directly stimulate brain regions may assist in treating disorders such as epilepsy, depression, and Parkinson's disease (Lozano et al., 2019).

Neuralink's flexible electrodes and advanced signal processing could provide more precise brain mapping, enabling tailored treatments. However, concerns remain regarding long-term biocompatibility, risk of infection, and potential brain tissue damage due to prolonged implantation (Jiang & Zhong, 2021).

Beyond therapeutic uses, Neuralink envisions enhancing human cognition. For instance, real-time access to information stored in external devices could radically change how we learn, work, and think. This concept aligns with the idea of **transhumanism**, which advocates for the use of technology to extend human capabilities.

Researchers argue that high-resolution BCIs could improve memory, attention, and learning by directly stimulating or recording brain signals associated with these functions (Lebedev & Nicolelis, 2017). However, others warn of unintended consequences, such as cognitive overload, dependency, or changes in self-perception (Farah, 2012).

Neuralink's proposal to enable "brain typing" or thought-to-text input could revolutionize communication, especially for those with speech impairments. Yet, this blurring of boundaries between mind and machine requires thoughtful consideration of the psychological and social implications.

The ethical challenges of Neuralink are as significant as its technical achievements. Central to the debate are questions of mental autonomy, consent, and privacy. Unlike traditional data, brain signals are deeply personal, and unauthorized access or manipulation could threaten individual freedom (Ienca & Andorno, 2017).

There are moreover concerns regarding the commodification of brain data by private corporations, which may not be bound by strict health data laws. Furthermore, unequal access to such technologies could lead to **"neurodivides"**, where only the wealthy benefit from cognitive enhancements, exacerbating social inequality (Yuste et al., 2017).

Philosophers have questioned whether BCI-mediated cognition alters personal identity or challenges the nature of consciousness. If thoughts can be decoded or modified externally, what remains of free will and human uniqueness?

Methodology

This chapter outlines the research methodology used to assess the impact of Neuralink technology on human health, cognition, and ethics. Given the conceptual and exploratory nature of the topic, a **qualitative, literature-based approach** was adopted. The study draws from a diverse body of existing academic work, ethical analyses, case reports, and industry publications related to brain-computer interfaces (BCIs), neuroscience, and emerging neurotechnology.

The research employs a **descriptive and analytical design**, suitable for examining emerging technologies where empirical data is still limited. This design allows for a critical evaluation of Neuralink's conceptual framework, potential applications, and implications by synthesizing findings from multiple credible secondary sources.

The key objectives of the design were to explore existing medical and scientific literature on BCI applications and Neuralink, and to review ethical and philosophical discussions related to human enhancement and neural data privacy. Even to analyze media coverage and official corporate communications to understand the technology's development and public discourse.

Data Collection Methods

Rather than relying on surveys, interviews, or experiments, this study used desk research to gather data. Relevant information was collected from peer-reviewed journals, books and eBooks on neuroscience, neuroethics, and AI, as well as official Neuralink documents and presentations.

News outlets and science reporting platforms (e.g., Wired, The Guardian, MIT Technology Review) Research databases such as Google Scholar, PubMed, JSTOR, and IEEE Xplore. The sources were selected based on their relevance, credibility, and academic rigor. Preference was given to materials published within the last 10 years to ensure contemporary relevance, especially considering the recent emergence of Neuralink.

The collected materials were examined using **thematic analysis.** This qualitative technique involved the identification, coding, and categorization of recurring themes and patterns related to health applications (e.g., treatment of neurological diseases), Cognitive enhancement (e.g., memory and learning augmentation), ethical and societal concerns (e.g., privacy, autonomy, inequality)

The findings were synthesized into structured arguments and categorized according to the study's objectives. Cross-referencing was used to compare differing expert opinions and interpretations. Since this research did not involve human participants, no formal ethics approval was required. However, academic integrity and ethical scholarship were maintained throughout the process. All sources of information were properly cited in APA format to avoid plagiarism and uphold transparency.

Findings and Discussion

This chapter presents the key findings of the study, structured around the three core domains of impact: **human health, cognitive enhancement,** and **ethical considerations**. Each section integrates evidence from scientific literature, case studies, and expert analyses to provide a comprehensive and critical discussion. Neuralink's technology is still in early development, but its implications are already profound. This chapter outlines both the promises and the challenges associated with this innovative brain-computer interface.

1. Neuralink's Impact on Human Health

1.1 Neurological Treatment and Restoration

Neuralink's primary goal is therapeutic—to treat neurological conditions by directly interfacing with the brain. Early studies in brain-computer interfaces (BCIs) have shown potential for restoring motor function in patients with spinal cord injuries and neurodegenerative diseases. For example, studies have demonstrated how electrodes implanted in the motor cortex can allow quadriplegic individuals to control robotic limbs (Bouton et al., 2016). Neuralink builds on this concept by using flexible, high-density electrodes that reduce inflammation and enhance signal clarity over time (Musk & Neuralink, 2019).

Potential clinical applications include the following:

- "Restoration of limb control in spinal injury patients through neural signal bypass"
- "Alleviation of neurological symptoms in diseases such as Parkinson's, epilepsy, and dystonia via electrical stimulation"

- "Improved brain mapping during surgery, leading to more precise treatment of tumors and brain trauma"

1.2 Risks and Medical Challenges

Despite the promise, Neuralink's implantation carries several **medical risks**:

- **Biocompatibility issues:** Although Neuralink uses thin, flexible threads, long-term implantation may still trigger immune responses or scarring (Jiang & Zhong, 2021).
- **Surgical complications**: Even with robotic precision, brain surgery is invasive, with risks of hemorrhage, infection, or damage to healthy tissue.
- **Device failure**: Implanted electronics may degrade over time or stop working, requiring additional surgeries.

Additionally, most existing research is conducted on **animals**, and human trials are still in very early stages. Longitudinal data on safety and efficacy are still lacking.

2. Neuralink's Cognitive Implications

2.1 Cognitive Enhancement Possibilities

One of Neuralink's most ambitious goals is **enhancing cognitive function**, not merely restoring it. This vision includes:

- **Real-time memory retrieval**: Enabling people to access and replay stored memories or learn complex topics quickly.
- **Direct brain-to-brain communication:** Theoretical ability to "send thoughts" from one person to another, bypassing language barriers.
- **Rapid human-computer interaction**: Users could control computers, devices, or even entire environments through thought.

This idea aligns with the philosophy of **transhumanism**, which advocates for using technology to extend human capabilities beyond biological limits (Bostrom, 2005).

2.2 Psychological and Behavioral Concerns

These enhancements raise serious concerns:

- **Mental overload:** A constant influx of information may impair decision-making or focus rather than enhance it (Farah, 2012).
- **Loss of natural cognitive boundaries:** When the brain can outsource memory or attention to a machine, traditional mental skills may deteriorate.
- **Identity disruption:** Altering the brain's function may change a person's behavior or perception of self, leading to psychological conflict.

Without robust safeguards, the boundary between human cognition and artificial intelligence could blur in problematic ways.

3. Ethical and Societal Implications

3.1 Mental Privacy and Consent

Unlike traditional data, **neural data** captures thoughts, intentions, and emotional states. If improperly accessed or manipulated, it could result in violations of **mental privacy**, a new frontier in human rights (Ienca & Andorno, 2017).

Consent becomes complex when individuals do not fully understand the technology's risks, or when devices are used on vulnerable populations such as the elderly or those with mental illness.

Neuralink has not yet published comprehensive policies on how data is collected, stored, or protected — a gap that must be addressed before public rollout.

3. 2 Inequality and Neurocapitalism

If only wealthy individuals can afford cognitive enhancements, **neurotechnology could widen social divides**, creating a "neuro-elite" class. Access to enhanced intelligence, memory, or creativity could provide unfair advantages in education, employment, and influence.

Moreover, corporate control over cognitive data poses significant risks. As with social media, neurodata could be monetized or used for behavioral manipulation, but with far more intimate insights into a person's mind.

3. 3 Autonomy and Free Will

There are philosophical concerns that brain implants may **erode autonomy**. If an external device can influence decision-making or mood, where does human free will begin and end? Even subtle changes caused by algorithms or stimulation may affect ethical agency and responsibility.

This is especially troubling in military or surveillance contexts, where BCIs could be weaponized or used for behavior control.

4. Public Perception and Media Influence

Much of the public's understanding of Neuralink comes from **media coverage,** which often presents it as either revolutionary or dystopian. While Elon Musk promotes Neuralink as a tool to "achieve symbiosis with AI," many neuroscientists urge caution due to lack of peer-reviewed clinical trials (Lozano et al., 2019).

This contrast creates **misinformation** and unrealistic expectations. People may either fear the technology excessively or embrace it without critical evaluation.

Conclusion

Neuralink represents a significant leap in the field of neurotechnology, blending neuroscience, artificial intelligence, and advanced biomedical engineering to create a direct communication pathway between the human brain and computers. This study sought to assess Neuralink's potential impact in three primary areas: **human health, cognition,** and **ethics.**

The findings indicate that Neuralink holds tremendous promise for medical applications, especially in treating neurological disorders such as paralysis, Parkinson's disease, and epilepsy. Its flexible electrode design and robotic implantation procedure are advancements that could improve the safety and accuracy of brain-machine interfaces. However, the technology remains in early stages, and long-term health implications are still unknown due to the limited scope of human trials.

In terms of cognitive enhancement, Neuralink's vision of memory augmentation, thought-to-text communication, and direct brain-based computing may redefine human capabilities. While these possibilities are intellectually exciting, they raise complex psychological, philosophical, and behavioral concerns, such as mental overload, dependency on machines, and identity alteration.

Ethically, Neuralink confronts society with unprecedented dilemmas. Mental privacy, digital autonomy, informed consent, and the potential for inequality in access to neuroenhancement are issues that require immediate attention from policymakers, ethicists, and technologists alike. The absence of a global ethical framework for brain-computer interface technologies amplifies the urgency for regulation and oversight.

Overall, Neuralink represents both a revolutionary innovation and a source of deep concern. It has the potential to improve lives and unlock new human capabilities, but it additionally has the capacity to challenge our understanding of what it means to be human.

Suggestions

Based on the research findings, the following recommendations are proposed to guide the ethical development, application, and governance of Neuralink and similar brain-computer interface technologies:

1. Promote Transparent and Peer-Reviewed Research

Neuralink and other developers should publish their methodologies and findings in peer-reviewed journals to enable scientific scrutiny and build trust among the academic and medical communities.

2. Implement Ethical and Legal Regulations

Governments and international organizations must develop **neuroethics guidelines** and **legal frameworks** to govern the collection, use, and sharing of neural data. These frameworks should address issues such as:

- Data protection and encryption
- Consent protocols
- Ownership of neural information
- Rights to disconnect or opt out

3. Ensure Equitable Access

Neurotechnology should not become a privilege of the wealthy. Policies must be developed to ensure **universal accessibility**, especially for individuals with medical needs. Public funding or health insurance models could help make therapeutic applications more inclusive.

4. Conduct Long-Term Human Trials

Before mass adoption, Neuralink must conduct **multi-phase clinical trials** with diverse populations to assess the safety, efficacy, and psychological effects over time. Monitoring must include:

- Device performance
- Brain health
- Psychological well-being
- Patient-reported outcomes

5. Establish Interdisciplinary Ethics Committees

Neuralink should consult not only scientists and engineers but additionally **bioethicists, sociologists, philosophers, and legal experts**. Interdisciplinary boards can help anticipate long-term societal impacts and prevent misuse of the technology.

6. Raise Public Awareness and Education

Educational programs should inform the public about the benefits and risks of neurotechnology. Media and tech companies must present accurate, balanced information to prevent fear-based resistance or blind acceptance.

7. Monitor Psychological and Cognitive Outcomes

As devices interface more intimately with the brain, constant assessment of **mental health** and **cognitive changes** is critical. Neuralink must include post-implantation monitoring for symptoms such as identity disturbance, dependency, or emotional instability.

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