A Comparative Mechanistic Analysis of Neuralink in Neurological and Psychiatric Disorders: Evaluating Efficacy and Limitations

Qianxun Ren*

Tabor Academy, Marion, MA, 02738, United States

*Corresponding author: qren27@taboracademy.org

Abstract. Over the past decades, brain-computer interface (BCI) technology has evolved from rudimentary attempts of recording neuronal firing rates to sophisticated systems capable of high-resolution data, but continued to face limitations regarding biocompatibility, flexibility, and signal fidelity. Addressing these challenges, Elon Musk introduced Neuralink in 2019, merging all the key elements into one integrated platform. Neuralink has outlined objectives of treating multiple neuropathologies including movement disorders (paralysis), neurodegenerative diseases (Alzheimer's, Parkinson's), psychiatric conditions (depression, addiction), and sensory impairments (blindness). While experts have remained skeptical about Neuralink's wide range of proposed applications, most commentaries tend to extrapolate the result broadly, making premature generalization. This paper addresses that gap through a comparative mechanistic analysis of Neuralink's three proposed applications, examining its key technological elements—thin-film polymer probes, high-density electrodes, robotic insertion, and machine-learning algorithms—and comparing them with existing research. By highlighting both reactive and proactive approaches demonstrated in the PRIME study, this paper evaluates how three disorder categories align with Neuralink's existing technological framework, concluding that sensory impairments represent the most feasible application. The result offers guidance for future research and therapeutic efforts that expand upon Nueralink's design, identifying the most promising directions for advancing Neuralink's design. However, based solely on theoretical mechanisms, this paper has limited discussion regarding the practical and ethical aspects, and lack robust empirical evidence supporting the conclusion drawn. In-depth, long-term clinical trials remain essential for truly validating the viability of Neuralink across the various disorders.

Keywords: Neuralink; neurodegenerative disease; brain-computer interface.

1. Introduction

Humans' understanding of the communication between neuronal activity and external devices for neurorehabilitation has evolved due to technological advancements and shifting research focuses. The first attempts were during the 1960s-1970s, when scientists first demonstrated that motor neuronal firing rates in monkeys could be voluntarily modulated through biofeedback [1,2]. The concept of "brain-computer interface (BCI)"—referred to as "brain-machine interface (BMI)" in invasive research—was formalized in the early 1970s, though most initial efforts were low-channel-count and proof-of-concept [3,4]. Then, around the 1980s, the non-invasive BCI rose with its application in neurorehabilitation [5]. Notably, electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS) were used to visualize abnormal areas and identify disorders. These non-invasive approaches work by recording the average neuronal activities across the skull, yet the signals were too coarse and couldn't reach deep structures, resulting in insufficient resolutions for complex control and thus shifting the focus to high resolution and fidelity. This sparked the evolution of invasive technologies like microelectrodes and rigid metal arrays, enabling the capture of spikes from single neurons and thus providing higher resolution than EEG. However, in clinical settings, these techniques still lacked enough biocompatibility—as the size and stiffness can cause immune responses or less device longevity when coming in contact with soft brain tissues—and coverage—as the electrode arrays can only be placed in specific areas, and their rigidity can prevent deep placement. The compromised thinner and more flexible electrodes, however, weren't stiff enough to

be inserted into the brain [6,7]. Finally, registered in 2016 and written as a White Paper report in 2019 by Elon Musk, the Neuralink project merged all the key elements—signal fidelity, flexibility, large coverage, and biocompatibility—into one integrated platform, designing a robotic system that inserts slender polymer probes—known as "threads"—independently and efficiently into multiple areas of the brain [6].

This study seeks to fill that gap by performing a comparative mechanistic analysis, focusing on how Neuralink might function within different pathological frameworks based on their distinct pathological mechanisms. By examining potential disease-specific mechanisms and existing examples, this study aims to clarify whether Neuralink's visions are feasible, where it is most likely to succeed, where its application may face significant limitations, and how these findings might shape future research and clinical implementation.

2. Rationale

Neuralink has outlined potential applications for its technology in treating neurodegenerative diseases such as Alzheimer's and Parkinson's, and expanded its scope in 2022 to include mood and psychiatric disorders like depression and addiction. The company has also highlighted the potential of its technology in addressing sensory impairments, suggesting possibilities such as restoring vision even for individuals born blind. Most significantly—and the area in which Neuralink has demonstrated tangible progress thus far—is its research into addressing movement disorders, including paralysis and spinal cord injuries, proposing that its technology could eventually enable muscle movement in individuals who currently lack mobility.

In all, not only has Neuralink aimed for a broad range of applications, but it has also set the goal of "curing" certain diseases.

Feeling overoptimistic for many people, the comments have remained mixed even after the first successful human trial (known as the "PRIME Study") performed in January 2024 and announced successful in February. With the first patient fully recovered and able to "move a mouse around the screen just by thinking," this undoubtedly marked a milestone for Neuralink's technology in the clinical setting. However, many also expressed concerns about its long-term durability—if the neuronal signals would degrade over time, as common in existing devices—and safety regarding data transparency, privacy, and autonomy.

One aspect most commentaries have yet to concern is the generalizability of this breakthrough of the PRIME study: whether positive or negative, media and scientific reports tend to extrapolate the result broadly, implying that it bodes well for other Neuralink's aiming applications. Such generalization is premature for the following reasons:

First, although some general technical advances like higher signal fidelity can readily predict smoother use for those other applications, the signals themselves need to be read or written differently according to different neurological conditions [8]. Therefore, without extensive new research and validation, the BCI signals identified for one task—for example, decoding motor cortex activity to move a cursor or robotic limb—cannot simply be "reused" for another task—like feeding visual information to the visual cortex or encoding memories.

Second, the difference in neural targets for distinct neurological diseases is also important to highlight. It is unlikely that the systems successfully targeting motor cortex or spinal cord interface—for paralysis as in the PRIME Study—can be generalized to treat blindness involving the visual cortex or optic pathway, or Alzheimer's with hippocampus and related memory circuits impaired.

In a word, it's incautious and inaccurate to assume that since Neuralink works for paralysis, it'll likely work for blindness, Alzheimer's, and all those conditions stated as its missions.

3. Overview of Neuralink's Technology

3.1. Technical Overview and Engineering Advancement

Neuralink differs from other BCI companies in its innovative technologies. The system has three major components: the N1 implant (a BCI implant), the R1 Robot (a surgical robot) and the N1 User App (BCI software) [9]. The R1 Robot surgically places the cosmetically invisible N1 implant into targeted regions of the brain. Once implanted, the N1 system records neural activity and transmits signals to the N1 User App, where the signals are decoded and translated into actionable outputs for control of the external computer.

This section of the paper examines the distinctive technological features of the Neuralink system—particularly its implantable device and robotic surgical platform—that enable its potential application in addressing a variety of psychiatric disorders within clinical settings.

3.1.1 Thin-film Polymer Probes & High Channel-Count Threads

The Neuralink device employs an array of 96 thin, flexible electrode threads, each with 32 independent electrodes, totaling 3,072 electrodes per array [6]. The probes are fabricated using ultra-fine polymers, avoiding the low bending stiffness in traditional thin-film threads. Polyimide—a dielectric material—is used as the main substrate, encasing a thin gold film trace. More than 20 distinct thread and electrode types are designed, with nominal thicknesses of 4-6μm and sizes ranging from 5μm to 50μm. This wide range of geometries offers great design flexibility.

Recording from up to 3,072 electrodes requires high channel counts, which Neuralink achieves through microfabrication methods—primarily stepper lithography that supports submicron resolution, enabling small features to be patterned. These high channel counts enable wide coverage, allowing high-density neural recordings from dispersed brain regions.

Furthermore, since thin-film polymer probes more closely resemble the mechanical characteristics of the brain than silicon probes, the polymers used as implant materials are greatly biocompatible, facilitating stable recordings over longer durations and increasing the longevity of implants.

3.1.2 Robotic Insertion Approach

Neuralink's robotic insertion system is engineered to address the challenges posed by flexible, thin-film polymer probes, whose low bending stiffness complicates manual implantation. A 400 x 400 x 150 mm travel range, coupled with an interchangeable needle-pincher, enables precise placement of large numbers of probes while avoiding vasculature, thereby minimizing tissue damage and inflammation. This design also enables recording from widely distributed brain regions and supports sterile surgical environments through protective shrouding and ultrasonic cleaning of the needle.

High-speed, automated insertions allow up to six threads—192 electrodes—per minute in autoinsertion mode. A rapid linear motor and high retraction acceleration of up to 30,000 mm/s² help ensure clean separation of the threads from the needle, thereby facilitating reliable, efficient deployment. Through these combined features, the robotic platform addresses both the technical and biological challenges of inserting large arrays of flexible electrodes [10].

3.1.3 Implantations and surgical advancement

Over the 19 surgeries performed, Neuralink has an average insertion success rate of 87.1& (SD 12.6%). Manual adjustments to avoid microvasculature on the cortical surface slightly reduced the insertion speed from its maximum. The insertion time is approximately 45 minutes total, with a rate of ~29.6 electrodes per minute [6].

In summary, Neuralink's high channel counts polymer threads and robotic insertion system allow a high-density, accurate, and safe recording process.

3.2. Neurobiological Basis & Machine Learning Mechanisms

Neuralink's decoding approach integrates the neurobiological principles of neuronal firing with advanced machine learning algorithms. While the following mechanism is not unique to Neuralink but applies broadly to various BCI systems, the goal is to predict and evaluate the potential usage of Neuralink from its underlying mechanisms.

3.2.1 Signal Capturing Stage

In the initial measurement stage, signals are captured in the form of neuronal "spikes"—or each action potential of a neuronal firing—by the decoder's electrodes. Neuralink's direct implantation, high channel counts, and flexible threads (as previously discussed) ensure high clarity and minimal distortion.

This process differs in animals and human studies in that while animal subjects—for example, Neuralink's famous monkey and pong game demonstration—are required to perform certain movements for recording of brain activities, the signals in human brains are only captured when they intend or imagine an action, in order to output a representation of the user's thoughts in terms of neuronal "spikes".

3.2.2 Signal Processing Stage—Raw Signal Amplification & Filtering

After the initial recording, the raw signals are amplified and digitized by the Link's electronics via transmission of data to an external computer as a stream of digital signals representing the brain's activities.

In this stage, one feature specific to Neuralink is that it performs immediate filtering of the vast data (over a thousand channels) with low latency, minimizing the delay between brain activity recording and translation into digital data [6].

3.2.3 Decoder Training Stage—Learning & Calibration

At this stage, the decoder is trained to identify and interpret underlying patterns within neural signals—a process driven by machine learning algorithms.

Specifically, by analyzing neural activity recorded during tasks—such as monkeys operating a joystick or humans imagining particular movements—the decoder learns to associate distinct neural patterns with intended actions. The learning mechanism used by the decoder spans across various models. While early BCI systems relied on classical approaches like linear regression or Kalman filters, Neuralink's decoder builds on these principles, either applying a linear weighting of each electrode's firing rate to predict X-Y cursor velocities or using nonlinear transformations to map neural signals to cursor movements. Like many other modern BCIs, Neuralink might also utilize deep learning—convolutional neural networks (CNNs) and recurrent neural networks (RNNs)—to identify patterns in large populations of neural firing [11].

As a result, the system will establish a mapping between patterns of neural firing and specific intended actions.

Over time, as neural signals gradually shift due to various factors, machine learning facilitates adaptive mechanisms by continuously comparing the decoder's output with the intended outcome and minimizing error, making adjustments after detecting any deviations.

3.2.4 Output Translation Stage

Ultimately, the decoder will be able to predict the user's intended motion from brain activity alone, allowing physical movements via thoughts—the key to improving the lives of patients suffering from motion diseases like paralysis.

4. Current Application: Movement Disorders (Paralysis & Spinal Cord Injury)

4.1. PRIME Study

Restoration of movements and communication for paralyzed (e.g. quadriplegia from spinal injury or ALS) is one of Neuralink's top priorio ties. Starting with animal trials in early 2021—demonstrated notably by a monkey playing Pong—Neuralink subsequently advanced to human clinical studies, specifically targeting patients with quadriplegia, spinal cord injuries, or amyotrophic lateral sclerosis (ALS). This ongoing clinical study is known as the PRIME study.

The study's FDA approval took 3 years, and in January 2024, Neuralink conducted the first clinical trial in a paralyzed human, who ended up being able to play online chess and Sid Meier's Civilization VI using Neuralink's BCI [12,13]. The study is soon registered on ClinicalTrials, the online repository required to ensure transparency and adherence to ethical principles for protection of human participants [14]. Subsequently, in August, the second participant reportedly demonstrated the capability to play video games and utilize computer-aided design (CAD) software to create three-dimensional objects. Most recently, Neuralink obtained regulatory approval from Health Canada and initiated a third clinical trial involving a Canadian patient diagnosed with amyotrophic lateral sclerosis (ALS).

4.2. Mechanistic Analysis

Neuralink addresses movement disorders through two main approaches. The first is reactive: decoding motor commands to operate cursors or robotic limbs. The second is proactive: reestablishing neural connections by creating a "digital bridge" between the brain and the spinal cord.

4.2.1 Decoding Motor Commands to Operate cursors or Robotic Limbs

Electrodes are implanted into the premotor area of the motor cortex and measure brain activities as the patient imagines writing letters. The deep-learning model RNN learns the neural activity patterns associated with each character and transmits the information to an algorithm predicting the letters from brain activities in the subsequent trials.

4.2.2 Reestablishing Neural Connections Between Brain and Spinal Cord

While all three human trials adopted the reactive approach, the proactive approach—re-bridging the brain and spinal cord—remains feasible and represents a more fundamental solution—the key to addressing a broader range of neurological conditions beyond movement disorders.

The core of this method is to bypass the damaged area and stimulate the other motor neurons instead. The first couple of steps remain the same—recording and learning neural activity associated with intended movements; transmitting recorded signals to an external processing unit—a computer, in most cases—and decoding the indented motor commands. Then, the processed signals are relayed to a spinal cord stimulator implanted below the site of injury, where the stimulator delivers electrical impulses to motor neurons other than those in the damaged area, effectively bypassing the injured portion completely. This therefore recreates an artificial neural pathway between the brain and the spinal cord while leaving the malfunctional part untouched.

This is proved feasible by previous studies utilizing similar concepts. The famous Swiss study in 2023 developed an brain-spine interface employing a similar proactive approach with electrodes placed over the dorsal root entry zones in the lumbar region of the spinal cord, selectively activating the motor neuron pools responsible for different muscle groups controlling walking. When tested on a man with paralysis, the system successfully enabled him to stand and walk [15].

Although still unable to address the fundamental injury, the proactive method provides a generalizable concept that can be applied to various other diseases Neuralink aims to address—to bypass the injured region while creating an alternative neural pathway. The following section will discuss Neuralink's feasibility in targeting other non-movement disorders based on its current mechanisms.

5. Potential Future Applications: Comparative Mechanistic Feasibility

It's important to note that this paper offers a theoretical analysis of Neuralink's application in various neuropsychiatric disorders based on its potential mechanisms and similar studies or techniques. More information and clinical trials are needed to make any certain statements.

5.1. Neurodegenerative Diseases: Alzheimer's and Parkinson's

The primary therapeutic approach for neurodegenerative disorders such as Alzheimer's disease (AD) and Parkinson's disease (PD) has been deep brain stimulation (DBS), a technique involving the targeted delivery of electrical pulses to dysfunctional neural circuits. Following the proactive approach of rewiring neural circuits, Neuralink can work in a way similar to DBS—intercepting or altering dysfunctional neural signals to reduce symptoms.

There are two major mechanical differences between the two. First, while DBS only exerts open-loop stimulation (constant stimulation regardless of the brain's state), Neuralink decoder's connection with the external unit enables stimulation in a closed-loop fashion (optimal stimulation based on real-time neural signals)—essentially an "adaptive DBS," dynamically adjusting and fine-tuning stimulation according to the patient's state. This would mark an improvement in treatment for both AD and PD.

Second, while DBS only produces broad stimulation of a tissue via one whole contact area, Neuralink's microwire electrodes and high channel counts can enable more sophisticated control algorithms. In PD patients, this represents better fine-tuning and rewiring of the damaged (motor) circuit. AD, however, involves much more widespread neurodegeneration and memory loss, which is harder to address with focal stimulation resembling DBS. Therefore, even though other various techniques like "memory prosthesis" offer hope [16], far more studies are needed for confirmation. Neuralink's mission to "cure" dementia or Alzheimer's thus remains speculative.

5.2. Psychiatric Disorders: Depression and Addiction

Neuralink's potential treatment for depression and addiction also focuses on the proactive aspect. Besides medications, the major neurotechnological treatment for this type of disorders has also been DBS. Similar to the neurodegenerative diseases, this connects to Neuralink's approach in the possibility of "adaptive DBS". In fact, in 2021, researchers at UCSF identified specific brain activity patterns that signaled depressive states in a patient and delivered targeted pulses to interrupt these states, suggesting the feasibility of a closed-loop DBS [17].

In theory, Neuralink's device can follow the same path: training the decoder to learn patterns for depression or addiction, continuously monitoring brain activity, and providing stimulation once these patterns are detected. However, being only a conceptual application, one challenge faced by this approach is the high patient-to-patient variability that leaves no common areas to target in every patient, as each patient likely has their own biomarkers of depression or addiction. These two conditions—especially depression—are also often a secondary effect from another major disorder, further complicating the treatment.

5.3. Sensory Impairments: Blindness

Treatment for sensory impairments most closely resemble that of movement disorders—a mix of reactive and proactive approach. In September 2024, Neuralink revealed that its vision-restoring device—"Blindsight"—received an FDA "Breakthrough Device" designation—a status to speed development of promising, urgent technologies. Elon Musk has claimed that this device will enable those who have lost both eyes and optic nerves to see. "Blindsight" works by developing a "retinal prosthesis" by bypassing the damaged area and stimulating the visual cortex with electrical signals collected from an artificial external camera—essentially reestablishing the neural pathway between retina and visual cortex with an external device replacing the malfunctioning retina or visual pathway. Figure 1 represents a simplification of the specific steps.

Despite the lack of human trials, "Blindsight" has strong preclinical backing: a 2023 study involving the implantation of 1024-channel microelectrode arrays into the visual cortex of monkeys over a period exceeding three years demonstrated that electrical stimulation of these electrodes could reliably evoke visual percepts. However, the study also identified challenges, including the progressive deterioration in signal quality and tissue immune responses associated with the high-density electrode configuration [18].

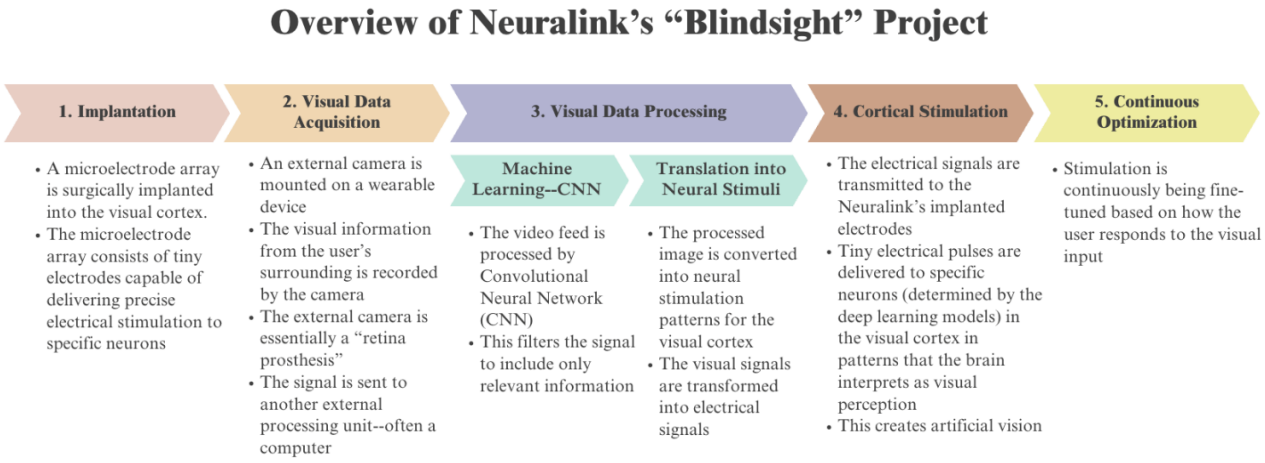

Fig. 1 A simplified overview of Neuralink's "Blindsight" project

5.4. Summary

Table 1 below summarizes the three categories of disorders discussed. It is important to emphasize that this analysis is theoretical, based solely on potential mechanisms and existing research; other considerations, such as ethical implications, are not addressed.

Table 1. Summary of the Disorders Discussed

	Neurodegenerative Diseases: Alzheimer's and Parkinson's	Psychiatric Disorders: Depression and Addiction	Sensory Impairment: Blindness
(Potential) Mechanism	"Adaptive" (closed-loop) DBS	"Adaptive" (closed-loop) DBS	"Retinal prothesis" bypassing the damaged area and stimulating the visual cortex with signals from an external camera
Reactive / Proactive	Proactive	Proactive	Mix
Existing study	None	UCSF researchers detected brain patterns of depression and interrupted them using targeted pulses, indicating the feasibility of closed-loop DBS.	Neuralink's "Blindsight" project
Challenges	The focal and specific stimulation might not be suitable for widespread neurodegeneration in AD.	1. High patient-to-patient variability 2. These two conditions might be the secondary effects of other disorders	Progressive deterioration in signal quality, tissue immune responses, etc.
Feasibility	Not so feasible	Theoretically feasible, but more evidence needed	Has the most feasibility

6. Conclusion

This paper presents a comparative analysis of Neuralink's potential applications across various neurological and psychiatric disorders. Grounded in Neuralink's core technological components—system-level thin-film polymer probes, high channel-count electrodes, robotic insertion techniques, and algorithmic mechanisms employing machine learning to decode neuronal spikes into actionable commands—this analysis evaluates current advancements in treating movement disorders. Building on these basics, the paper assesses Neuralink's feasibility for addressing neurodegenerative diseases (AD and PD), psychiatric disorders (depression and addiction), and sensory impairments (blindness). Specifically, when analyzing the mechanism used by Neuralink in the PRIME study for paralysis, the paper highlights both the reactive and proactive approaches. Then, it categorizes the potential treatment mechanisms for the three types of disorders into reactive and proactive, analyzing their alignment with the existing framework of Neuralink. The analysis concludes that Neuralink's approach for sensory impairments shows the greatest promise.

Therefore, given Neuralink's ambitious objective of targeting a wide range of conditions and the limited examination of the generalizability of Neuralink's success in the PRIME study, this analysis clarifies the area where it has the most feasibility. Besides, the mechanistic perspective also demonstrates how Neuralink's engineering and algorithmic framework can be adapted to different neuropathologies, offering valuable guidance for research or therapies that expand upon Neuralink's design. As such, this analysis stands as a critical reference for future investigations, underscoring the importance of disease-specific research protocols and caution against overgeneralizing early clinical successes to all target conditions.

However, this paper is based solely on the theoretical mechanisms and has limited discussion regarding the realistic and ethical aspects. The existing empirical evidence supporting this analysis is also limited, meaning that more research is needed to substantiate the conclusion drawn in this paper. Therefore, moving forward, this paper can only serve as guidance for research direction—in-depth, long-term clinical trials are essential for truly validating the viability of Neuralink in the various diseases. By integrating perspectives from engineering, neuroscience, and clinical medicine, future research will better evaluate or even realize Neuralink's ambitions of "curing" certain diseases.

References

[1] FETZ E E. Operant Conditioning of Cortical Unit Activity[J]. Science, 1969, 163(3870): 955–958.

[2] FETZ E E, FINOCCHIO D V. Operant Conditioning of Specific Patterns of Neural and Muscular Activity[J]. Science, 1971, 174(4007): 431–435.

[3] VIDAL J J. Toward Direct Brain-Computer Communication[J]. Annual Review of Biophysics and Bioengineering, 1973, 2(1): 157–180.

[4] PISARCHK A N, MAKSIMENKO V A, HRAMOV A E. From novel technology to novel applications: Comment on 'An integrated brain-machine interface platform with thousands of channels' by Elon Musk & Neuralink (Preprint)[J]. Journal of Medical Internet Research, 2019, 21(10).

[5] FARWELL L A, DONCHIN E. Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials[J]. Electroencephalography and Clinical Neurophysiology, 1988, 70(6): 510–523.

[6] MUSK E. An Integrated Brain-Machine Interface Platform with Thousands of Channels (Preprint)[J]. Journal of Medical Internet Research, 2019, 21(10).

[7] CHOROVER S L, DELUCA A M. A sweet new multiple electrode for chronic single unit recording in moving animals[J]. Physiology & Behavior, 2003, 9(4): 671–674.

[8] ROSENFELD J V, WONG Y T. Neurobionics and the brain–computer interface: current applications and future horizons[J]. Medical Journal of Australia, 2017, 206(8): 363–368.

[9] Neuralink. PRIME-Study-Brochure [EB/OL]. (2025-03-11) [2025-03-11]. Available: https://neuralink.com/pdfs/PRIME-Study-Brochure.pdf.

[10] FIANI B, REARDON T, AYRES B, CLINE D, SITTO S R. An Examination of Prospective Uses and Future Directions of Neuralink: The Brain-Machine Interface[J]. Cureus, 2021, 13(3).

[11] DONG Y, WANG S, HUANG Q, BERG R W, LI G, HE J. Neural Decoding for Intracortical Brain–Computer Interfaces[J]. Cyborg and Bionic Systems, 2023, 4.

[12] PARIKH P M, VENNIYOOR A. Neuralink and Brain–Computer Interface—Exciting Times for Artificial Intelligence[J]. South Asian Journal of Cancer, 2024.

[13] Neuralink. Neuralink Blog [EB/OL]. (2025-03-11) [2025-03-11]. Available: https://neuralink.com/blog/.

[14] ClinicalTrials.gov. Neuralink Clinical Trial [EB/OL]. (2025-03-11) [2025-03-11]. Available: https://clinicaltrials.gov/study/NCT06429735?term=neuralink&rank=1.

[15] LORACH H, et al. Walking naturally after spinal cord injury using a brain–spine interface[J]. Nature, 2023, 618(618): 1–8.

[16] BERGER T W, HAMPSON R E, SONG D, GOONAWARDENA A, MARMARELIS V Z, DEADWYLER S A. A cortical neural prosthesis for restoring and enhancing memory[J]. Journal of Neural Engineering, 2011, 8(4): 046017.

[17] SCANGOS K W, et al. Closed-loop neuromodulation in an individual with treatment-resistant depression[J]. Nature Medicine, 2021, 27: 1–5.

[18] WAISBERG E, ONG J, LEE A G. The potential to restore vision with Neuralink's 'Blindsight' neural interface technology[J]. The Pan-American Journal of Ophthalmology, 2024, 6(3).