



iJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** X **Month of publication:** October 2025

DOI: <https://doi.org/10.22214/ijraset.2025.74620>

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Unlocking the Mind: The Revolution of Neuro Technology in Modern Neuroscience

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Abstract: *Neurotechnology, the integration of neuroscience, engineering, and digital innovation, has revolutionized our ability to understand and interact with the human brain. This review explores the evolution of neurotechnology from early observational tools such as electroencephalography (EEG) and magnetic resonance imaging (MRI) to advanced brain-computer interfaces (BCIs), neuromodulation, and neuroimaging systems capable of real-time communication with neural circuits. The article highlights clinical applications in treating neurological and psychiatric disorders, including Parkinson's disease, epilepsy, and depression, as well as emerging uses in neurorehabilitation, cognitive enhancement, and mental health therapy. The convergence of neurotechnology with artificial intelligence (AI) has enabled more precise brain mapping, personalized neurotherapies, and improved diagnostic accuracy. However, the rapid pace of advancement raises pressing ethical, legal, and social concerns regarding brain privacy, cognitive manipulation, data ownership, and equitable access. Future directions emphasize the development of non-invasive, wireless BCIs, human-AI symbiosis, and large-scale brain mapping initiatives, while addressing technical, biological, and regulatory challenges. Overall, neurotechnology represents a transformative frontier in modern neuroscience—offering unprecedented potential to restore, enhance, and expand human capabilities while demanding responsible, ethically guided innovation.*

Keywords: *Neurotechnology, Brain-computer interface, Neuromodulation, Artificial intelligence, Cognitive enhancement, Brain privacy, Neuroethics.*

I. INTRODUCTION

Neurotechnology is the convergence of neuroscience, engineering, and digital technologies aimed at understanding and interacting with the brain. It includes innovations such as brain-computer interfaces, neuroimaging, and neural implants that allow scientists to record, stimulate, and even restore brain functions. [5,10]

Neurotechnology is considered a revolution in neuroscience because it shifts the field from passive observation to active intervention. It enables real-time communication with neural circuits, opening possibilities for treating disorders like Parkinson's disease, depression [6,7,8] and epilepsy [6,10] while also advancing human-machine interaction, cognitive enhancement, and artificial intelligence [12,17]. This integration of biology and technology is transforming both medicine and society.

In order to enhance function and treat neurological problems, neurotechnology [1,2,5] employs tools and techniques to record, modify, and comprehend the brain and nervous system. It includes both invasive and non-invasive approaches, such as implants for recording activity or stimulating the brain (such as deep brain stimulation for Parkinson's disease) [6] and brain imaging (MRI, fNIRS) [18]. Applications include safe biometric identification, cognitive enhancement, mental health treatment, and the restoration of function in crippled people.

Neuromodulation treatments have become effective techniques for regulating brain activity and regaining function in neurological diseases, in addition to imaging methods. For ailments ranging from Parkinson's disease and epilepsy [6,10] for the treatment-resistant depression [6,7,8], methods including vagus nerve stimulation (VNS), deep brain stimulation (DBS) [6,15], and transcranial magnetic stimulation [8] (TMS) provide focused therapies.

Neuromodulation treatments have the potential to reduce symptoms and enhance the quality of life for millions of people globally by altering abnormal brain circuits.

II. HISTORICAL BACKGROUND

A. Early Approaches to Brain Research

The primary purpose of the first neurotechnological instruments was observation, not intervention. Scientists were able to capture electrical activity in the brain with limited spatial resolution to techniques like Electroencephalography (EEG) which was established in the 1920s. Subsequent developments like magnetic resonance imaging (MRI) and computed tomography (CT scans) produced fine-grained structural pictures of the brain. Although these techniques transformed medical diagnoses, they were still unable to directly engage with neural circuitry or disclose real-time brain activity. [18]

These early approaches had serious shortcomings in spite of their significance. It was challenging to identify the exact brain areas causing activity since EEG had poor spatial localization and good temporal precision. While anatomical clarity was supplied by CT and MRI they did not reveal much about dynamic processes like behaviour, memory, or cognition. Therefore, rather of directly modifying brain activity, neuroscience continued to primarily concentrate on passive observation. [18]

Evolution Timeline: From Imaging to Brain-Computer Interfaces [5,10]

- 1920s–1950s: EEG [18] emerges as the first tool for recording brain activity.
- 1970s: CT and MRI [18] introduce structural imaging of the brain.
- 1980s–1990s: Functional MRI (fMRI) and Positron Emission Tomography (PET) [18] provide insights into brain activity during tasks.
- 2000s–Present: Development of Brain-Computer Interfaces [5,10] (BCIs) enables direct communication between neural signals and external devices, bridging neuroscience with engineering and digital technologies.

B. Clinical Neuroscience

One of the most impactful applications of neurotechnology [1,2,5] lies in clinical neuroscience, where it provides therapeutic solutions for previously intractable neurological disorders. Deep Brain Stimulation (DBS) [6,15] has become a standard treatment for movement disorders such as Parkinson's [6] disease, offering significant improvements in motor function and quality of life. Similarly, responsive neurostimulation devices have shown efficacy in controlling epileptic seizures by detecting abnormal neural activity and delivering corrective stimulation in real time. Neurostimulation is also being explored in the treatment of major depressive disorder, where repetitive Transcranial Magnetic Stimulation (rTMS) [8] has been approved as a non-invasive therapy for patients resistant to medication. Beyond these conditions, BCIs [5,10] offer new hope for individuals with paralysis [9,10], enabling them to control robotic prosthetics or communicate through neural signals.

C. Applications for Mental Health

The use of neurotechnology [1,2,5] in psychiatry and mental health is growing. Techniques for non-invasive brain stimulation, such as TMS [8] and tDCS [7], are being researched as supplemental treatments for addiction, generalized anxiety disorder, and post-traumatic stress disorder (PTSD). These therapies provide alternatives to pharmaceutical methods and may lower relapse rates by altering the brain circuits responsible for reward, stress, and fear. New therapy approaches for illnesses originating from maladaptive cognitive and emotional processes are made possible by emerging technology like real-time fMRI [18] neurofeedback [7,15], which enables patients to deliberately control their own brain activity.

D. Improvement of Cognitive Function

Neurotechnology is being used to improve normal cognitive processes in addition to treating diseases. It has been demonstrated that stimulation methods like tDCS [7] temporarily enhance working memory, learning, and attention, pointing to potential uses in instruction and skill development. By giving real-time feedback on brain activity, neurofeedback [7,15] devices also help people improve their mental performance and focus. Although these methods are still debatable because of ethical [12,13,20] reservations over "neuro-enhancement," they highlight how neurotechnology [1,2,5] can be used to increase human cognitive abilities.

E. Recovery and Rehabilitation

In neurorehabilitation [4,5], especially after a stroke or severe brain damage, neurotechnology [1,2,5] is essential. By encouraging cortical reconfiguration and fortifying neural circuits, BCIs [5,10], robotic exoskeletons, and neural feedback enable patients to restore lost motor performance. Neurorehabilitation based on virtual reality significantly improves motor training program participation and adaptation. In addition to regaining bodily function, these technologies are shedding light on the brain's extraordinary ability for rehabilitation and plasticity.

F. Applications of Neuro-monitoring in Research

Unprecedented insights into brain activity in real time are being made possible by developments in neuro-monitoring devices. Continuous brain state monitoring is made possible by high-density EEG [18], wearable neuroimaging technology, and wireless brain-computer interfaces (BCIs) [5,10]. These tools may be used for everything from epilepsy [6,10] diagnosis to the early detection of neurodegenerative disorders like Alzheimer's.

G. Integration with Artificial Intelligence

The integration of Artificial Intelligence [12,17] has revolutionized this domain by enabling advanced analysis, prediction, and interaction between machines and the human brain. Neurotechnology, which deals with monitoring, interacting, or enhancing the functions of the brain and nervous system, traditionally relied on complex biological and electrical studies [12,17] techniques, particularly machine learning and deep learning, allow massive neural data to be processed and interpreted, something that traditional methods cannot efficiently achieve. However, the human brain generates an enormous amount of neural data that is often too vast and complex for traditional computational analysis. This is where [12,17] plays a transformative role.

One of the most remarkable applications of [12,17] in neurotechnology [1,2,5] is

- 1) Brain-computer interfaces (BCIs) [5,10] - which establish a direct communication pathway between the brain and external devices. With [12,17]-powered algorithms, BCIs [5,10] can decode brain signals in real-time, helping patients with paralysis [9,10] control robotic limbs, wheelchairs, or even type text using thought.
- 2) Diagnosis of Neurological Disorders - [12,17] has significantly improved the early detection and monitoring of neurological conditions such as Parkinson's [6] disease, Alzheimer's disease, epilepsy [6,10], and stroke.
- 3) Neuroimaging and Brain Mapping - Modern neuroimaging technologies generate massive datasets that require sophisticated tools for interpretation.
- 4) Personalized Neurotherapies - Every individual's brain responds differently to treatments [12,17] enables the design of personalized neurotherapies, such as adaptive deep brain stimulation (DBS) [6,15], where stimulation parameters are adjusted in real-time based on brain activity. This makes treatments for conditions like epilepsy [6,10], depression [6,7,8], or chronic pain more effective and safer compared to traditional one-size-fits-all methods.

III. ETHICAL, LEGAL, AND SOCIAL IMPLICATIONS (ELSI) OF NEUROTECHNOLOGY: BRAIN PRIVACY, DATA OWNERSHIP, AND COGNITIVE MANIPULATION

The rapid advancement of neurotechnology [1,2,5] in modern neuroscience has led to significant progress in understanding and interacting with the brain. However, this progress also brings with it a host of ethical [12,13,20], legal, and social implications (ELSI) that need careful consideration to ensure these technologies are used responsibly and for the benefit of all. Among the most pressing concerns are issues related to brain privacy, data ownership, cognitive manipulation, and equity of access.

A. Brain Privacy & Data Ownership

The brain-computer interfaces, we can now access and interpret private thoughts. This raises critical questions about brain privacy and who owns the data. Should individuals have full control over their neural information, or can companies or governments access it. There are not yet clear laws to protect this sensitive data, creating a risk of misuse. This information could reveal personal traits, behaviors, and emotions, leading to concerns about surveillance without consent. We urgently need new legal frameworks to protect our neurological data.

B. Risks of Cognitive Manipulation

Neurological advancements, such as deep brain stimulation (DBS) [6,15] and transcranial magnetic stimulation [8] (TMS), are raising serious concerns about potential misuse beyond their therapeutic applications for treating conditions like Parkinson's disease or depression [6,7,8]. These technologies, which can alter brain activity, could be used to manipulate an individual's mood, memory, or behaviour without their consent.

The non-therapeutic use of neuromodulation [6,7,8], whether for cognitive enhancement or emotional control, presents complex ethical [12,13,20] challenges. It raises critical questions about how to protect people from the potential for coercion, particularly in military or corporate environments. There is a pressing need to define the boundary between what constitutes a legitimate medical therapy and what is considered an enhancement, all while safeguarding the autonomy of individuals whose minds may be susceptible to external influence.

C. Equity Access

The development of neurotechnology [1,2,5] is raising concerns about equity of access, as these advanced tools are often limited to wealthy people, private companies, and high-income countries. This could create a neurotechnology [1,2,5] divide, worsening existing social inequalities where only a select few can benefit from cognitive enhancements and medical treatments, while others are left behind. To prevent this, global cooperation and investment are needed to ensure these technologies are distributed to benefit everyone, especially marginalized and underprivileged communities.

D. Neuro Rights

The development of neurotechnology [1,2,5] is raising concerns about equity of access, as these advanced tools are often limited to wealthy people, private companies, and high-income countries. This could create a neurotechnology [1,2,5] divide, worsening existing social inequalities where only a select few can benefit from cognitive enhancements and medical treatments, while others are left behind. To prevent this, global cooperation and investment are needed to ensure these technologies are distributed to benefit everyone, especially marginalized and underprivileged communities.

IV. FUTURE TRENDS IN NEUROTECHNOLOGY

The rapid development of neurotechnology [1,2,5] is shaping a future where the boundaries between human cognition, artificial intelligence [12,17], and digital systems are becoming increasingly blurred. As brain-computer interfaces (BCIs) [5,10] and related technologies mature, their applications extend beyond medicine into areas of communication, education, productivity, and even human evolution. Several promising trends highlight where the field is heading.

A. Wireless and Non-Invasive BCIs [5,10]

Traditional BCIs [5,10] often rely on invasive electrodes implanted into the brain, which raises safety and ethical [12,13,20] concerns. Future advancements are moving toward wireless and non-invasive systems that can monitor brain activity through wearable headsets, advanced EEG [18] caps, or optical imaging technologies. These devices aim to provide high-resolution data without requiring surgery, making them more accessible for everyday use..

B. Symbiosis (Cyborg Potential) [12,17]

Rather than of [12,17] replacing human intelligence, the future points to [12,17] becoming an extension of our cognitive abilities. Through advanced BCI [5,10]s, humans could interact with [12,17] assistants at the speed of thought, bypassing traditional input methods like typing or speaking. This could lead to a “cyborg potential,” where humans enhance memory, decision-making, and learning capabilities by continuously interfacing with intelligent machines. Such integration raises profound questions about identity, agency, and what it means to be human.

C. Expanding Cognitive Abilities Beyond Natural Limits

Beyond therapeutic uses, neurotech could one day enable us to augment our minds, such as expanding our memory capacity, accelerating learning, or even giving us new senses. This raises questions about equity and access..

D. Role in Brain Mapping Projects

Global initiatives such as the Human Brain Project [19] (Europe) and the BRAIN [12,17] Initiative (United States) are laying the foundation for future neurotechnology [1,2,5]. These large-scale projects aim to map the complexities of neural networks with unprecedented detail, leading to better understanding of cognition, consciousness, and neurological disorders. The data and insights gained will drive the design of more sophisticated BCIs [5,10] and therapies. Additionally, brain mapping [19] provides a blueprint for simulating brain processes on supercomputers, potentially paving the way for artificial consciousness or digital twins of the human brain.

V. CHALLENGES AND LIMITATIONS OF NEUROTECHNOLOGY

Neurotechnology, though promising in transforming healthcare, cognition, and human-machine interaction, faces several critical challenges and limitations. These issues span across technical, biological, data-driven, and regulatory domains, which collectively determine the safety, effectiveness, and ethical [12,13,20] deployment of such technologies.

A. Technical Limitations

Despite rapid advances, many neurotechnological tools suffer from practical constraints. For instance, invasive brain-computer interfaces [5,10] (BCIs) [5,10] often demand surgical procedures, which are costly and risky. Even non-invasive methods struggle with resolution and signal clarity, as brain activity is complex and difficult to measure with precision. Additionally, device maintenance, battery life, and long-term stability pose barriers to large-scale application.

B. Biological Barriers

The human brain presents unique biological challenges. Implants may provoke immune responses or tissue damage, which limit their ability to function over long durations. Neural plasticity—the brain's ability to adapt and reorganize—also complicates device calibration, as the interface may become less accurate over time. Ensuring biocompatibility without hindering neural function remains a major hurdle.

C. Data Management

Neurotechnology generates vast datasets, especially in brain mapping [19] and BCI [5,10] research. Managing, storing, and analyzing such massive amounts of neural data requires advanced computational infrastructure and machine learning techniques. Moreover, ensuring data privacy [13,20] and preventing misuse is critical, as brain data represents highly personal and sensitive information.

D. Regulatory and Safety Concerns

The regulation of neurotechnology [1,2,5] lags behind its rapid development. There are unresolved questions regarding clinical safety standards, long-term effects, and ethical [12,13,20] oversight. Without robust regulations, patients and users may face potential health risks or data exploitation. Ensuring compliance with international safety guidelines and establishing neuro-rights are essential to safeguard individuals in the face of emerging innovations.

VI. CONCLUSION

Neurotechnology represents a groundbreaking convergence of neuroscience, engineering, and digital innovation that is reshaping our understanding of the brain and revolutionizing its interaction with the external world. From its early roots in observational tools like EEG [18] and MRI [18] to cutting-edge applications such as brain-computer interfaces [5,10], neuromodulation [6,7,8], and real-time neuroimaging, the field has evolved rapidly, offering transformative solutions for neurological disorders, mental health conditions, cognitive enhancement, and neurorehabilitation [4,5]. The integration of artificial intelligence [12,17] has further amplified these capabilities, enabling the interpretation of complex neural data, personalized therapies, and seamless communication between the brain and machines. However, this rapid progress also brings significant ethical [12,13,20], legal, and social challenges—particularly in areas of brain privacy, cognitive manipulation, data ownership, and equitable access. As we look to the future, the development of non-invasive BCIs [5,10], symbiosis, cognitive augmentation, and large-scale brain mapping [19] projects promises to push the boundaries of human potential. Yet, the success of neurotechnology [1,2,5] will ultimately depend on addressing its technical limitations, biological risks, data management demands, and the establishment of comprehensive regulatory frameworks. Ensuring responsible innovation grounded in ethical [12,13,20] principles and inclusivity will be essential for neurotechnology [1,2,5] to fulfill its promise—transforming not only medicine but also the very fabric of human experience.

VII. ACKNOWLEDGEMENT

I would like to thank Ms Lopamudra Chakravarty ma'am Asst.Prof in Calcutta Institute Of Pharmaceutical Technology & Allied Health Sciences for guiding me.

REFERENCES

- [1] Abbott A. The ethics of neurotechnology [1,2,5]: safeguarding mental privacy. *Nature*. 2022;606(7912):218–20.
- [2] Anderson ML, Oates J. Neuroethics and brain-computer interface [5,10]s. *Neuroethics*. 2019;12(3):167–80.
- [3] Ang KK, Guan C, Phua KS, Wang C, Zhao L, Teo WP, et al. Brain-computer interface-based robotic rehabilitation for stroke patients: clinical perspectives. *IEEE Rev Biomed Eng*. 2015;8:44–60.
- [4] Fetz EE. Restoring motor function with bidirectional neural interface [4,5]s. *Prog Brain Res*. 2015;218:241–52.
- [5] Lebedev MA, Nicolelis MAL. Brain-machine interfaces: From basic science to neuroprostheses and neurorehabilitation [4,5]. *Physiol Rev*. 2017;97(2):767–837.



- [6] Lozano AM, Lipsman N. Probing and regulating dysfunctional circuits using deep brain stimulation [6]. *Neuron*. 2013;77(3):406–24.
- [7] Brunoni AR, Moffa AH, Fregni F, Palm U, Padberg F, Blumberger DM, et al. Transcranial direct current stimulation for acute major depressive episodes: meta-analysis of individual patient data. *Br J Psychiatry*. 2016;208(6):522–31.
- [8] Hallett M. Transcranial magnetic stimulation: a primer. *Neuron*. 2007;55(2):187–99.
- [9] Hochberg LR, Bacher D, Jarosiewicz B, Masse NY, Simeral JD, Vogel J, et al. Reach and grasp by people with tetraplegia using a neurally controlled robotic arm. *Nature*. 2012;485(7398):372–5.
- [10] Shih JJ, Krusienski DJ, Wolpaw JR. Brain–computer interfaces in medicine. *Mayo Clin Proc*. 2012;87(3):268–79.
- [11] He B, Gao S, Yuan H, Wolpaw JR. Brain–computer interfaces. In: *Neural Engineering*. 3rd ed. Springer; 2020. p. 385–414.
- [12] Yuste R, Goering S, Arcas B, Bi G, Carmena JM, Carter A, et al. Four ethical [12,13,20] priorities for neurotechnologies and AI [12,17]. *Nature*. 2017;551(7679):159–63.
- [13] Ienca M, Andorno R. Towards new human rights in the age of neuroscience and neurotechnology [1,2,5]. *Life Sci Soc Policy*. 2017;13(1):5.
- [14] Pascual-Leone A, Amedi A, Fregni F, Merabet LB. The plastic human brain cortex. *Annu Rev Neurosci*. 2005;28:377–401.
- [15] Guger C, Allison BZ, Lebedev MA. Brain–computer interface research: a state-of-the-art summary. *Springer Nature*; 2020.
- [16] Koyama T, Kawagoe R, Takikawa Y, Kobayashi Y, Lauwereyns J. Neural correlates of reward expectation in the human brain. *Neuron*. 2004;45(1):125–38.
- [17] Sajda P, Cichocki A, Muller KR. Toward data-driven neurotechnology [1,2,5]: advances in brain–computer interface [5,10] signal processing [17]. *IEEE Signal Process Mag*. 2021;38(4):8–11.
- [18] Schomer DL, da Silva FL. *Niedermeyer's Electroencephalography: Basic Principles, Clinical Applications, and Related Fields*. 7th ed. Oxford University Press; 2018.
- [19] Marcus DS, Harwell J, Olsen T, Hodge M, Glasser MF, Prior F, et al. Informatics and data mining tools and strategies for the Human Connectome Project. *Front Neuroinform*. 2011;5:4.
- [20] Glannon W. Ethical issues with brain–computer interface [5,10]s. *Front Syst Neurosci*. 2014;8:136.



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