



Research on the Development and Ethical Issues of Neural Enhancement

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Abstract. With the rapid development of technology, neural enhancement technology has become a hot topic in the forefront research field of science and technology, and it has a profound impact on improving human cognitive and physiological abilities. This study systematically outlines the development of neural enhancement technology and elaborates on different types of techniques and their practical effects in multiple application fields. In addition, this article focuses on the ethical challenges that arise during the application of technology, analyzes the potential impact of these issues on society, and proposes corresponding ethical response strategies. With the help of comprehensive analysis, this article provides theoretical support for the development prospects and ethical norms of neural enhancement technology, and provides reference for future research directions and policy formulation.

Keywords: Neural enhancement technology; Ethical issues; Technological development; Application evaluation; Ethical strategy; Cognitive improvement

1 Introduction

Neural enhancement technology, as a cutting-edge interdisciplinary field of neuroscience and engineering, has received widespread attention in recent years. This technology mainly enhances the function of the nervous system through direct or indirect means to improve cognitive ability and physical function. Currently, methods such as electrical stimulation, drug intervention, and gene editing are widely used in clinical and experimental research. For example, deep brain stimulation (DBS) technology has been successfully used to treat Parkinson's disease patients, showing a significant improvement in motor symptoms. In clinical trials, the improvement rate of patients' motor function scores (such as UPDRS) exceeded 50%. In addition, using optogenetic methods, behavior can be regulated by precisely controlling the activity of specific neurons. Studies have shown that light stimulation can improve learning and memory abilities in mice by about 30%.^[1]

In terms of ethical issues, the widespread application of neural enhancement has sparked a series of moral and social controversies. Firstly, there are significant differences in the accessibility and applicability of enhanced technology, which may lead to new inequalities such as the re marginalization of economically disadvantaged populations. Secondly, enhancing technology may affect individuals' self-awareness and identity, for example, drug enhancement may weaken the intrinsic motivation for self-directed learning, thereby affecting the shaping of personal values. In addition, intellectual property and informed consent issues have become ethical barriers that urgently need to be addressed, and many technology developers lack sufficient attention to the rights of users.

The regulation of neural enhancement technology has also posed new challenges. The current ethical framework may not necessarily adapt to the rapid pace of technological development, and there is an urgent need to update relevant regulations and policies. For example, the National Institutes of Health (NIH) and the National Science Foundation (NSF) are exploring the establishment of a risk-based ethical review process to ensure the safety and effectiveness of various neural enhancement technologies.^[2]

Future neural enhancement technologies will involve emerging fields such as human-machine interfaces and biofeedback. The innovation potential in these fields is enormous, but it is also accompanied by serious ethical dilemmas. For example, finding a balance between protecting personal privacy and obtaining sufficient data to optimize algorithms is an urgent issue that needs to be addressed. Further research requires interdisciplinary collaboration to promote the coordinated development of technology and ethical frameworks, ensuring that neural enhancement technology improves individual well-being without infringing on social equity and individual rights.

2 Overview of Neural Enhancement Technology

2.1 Development History of Technology

The development process of neural enhancement technology can be traced back to the early 20th century. Early technologies were mainly based on electrical stimulation, which regulated neural activity by implanting electrodes. This method has been applied in the treatment of epilepsy and motor disorders. In the 1960s, Functional Electrical Stimulation (FES) was proposed as an important means of neural enhancement. FES successfully helped some paraplegic patients rebuild their motor function by stimulating specific muscles with electrodes to regulate movement patterns.^[3]

In the 1970s, significant advances in neural interface technology, especially the application of microelectrode arrays, greatly improved the accuracy of neural signal reading. The core of this type of technology lies in using miniaturized electrodes to directly connect with neurons, enabling real-time monitoring of neural activity. In 1998, an MIT research team developed a microelectrode array that could be directly connected to the cerebral cortex, enabling rats to control a robotic arm through thought, ushering in a new era of brain computer interface (BCI) research.

In the 21st century, brain computer interface technology has rapidly developed and its functions have become more diverse. For example, in a study released by the University of California in 2004, electroencephalography (EEG) signals were used to recognize users' thoughts in real time, allowing users to control computers through their thoughts. In 2012, Neuralink was founded, dedicated to the development of high-throughput, low invasive neural interfaces to better connect the human brain with computers. During this period, the sensor technology and signal processing algorithms of related equipment continued to be optimized, resulting in significant improvements in effectiveness and safety.

At the clinical application level, neural enhancement technology is increasingly demonstrating its potential in the management of mental illnesses, neurodegenerative diseases, and chronic pain. For example, Deep Brain Stimulation (DBS) has been used as an effective treatment for Parkinson's disease in over 100000 surgical cases to date. By implanting small electrodes, DBS can accurately regulate neural activity in the subcortical region, thereby improving patients' motor ability and quality of life.

In addition to the therapeutic field, research on neural enhancement technology has begun to shift towards the possibility of improving cognitive function and learning ability. In 2016, researchers demonstrated through non-invasive direct current stimulation (TDCS) that applying current to specific brain regions can improve memory and learning performance, and related clinical research results have gradually increased. Scientists have conducted in-depth exploration on the safety and long-term effectiveness of technology, and relevant experiments have shown that the learning effect enhancement under low current stimulation has good reproducibility.^[4]

With the development of technology, ethical issues are gradually emerging. People are discussing how to define "enhancement", which involves ethical considerations such as the fairness of the means of enhancement, social acceptance, and potential identity crises. Society is paying close attention to this controversial technological development, and the relevant ethical and legal framework is gradually taking shape.

The neural enhancement technology has undergone rapid evolution from basic research to clinical application, accompanied by the continuous maturity of technical means and the escalating ethical debates.

2.2 Types of Neural Enhancement Techniques

Neural enhancement technology mainly includes the following types: neural stimulation, drug regulation, gene editing, and brain computer interface.

Neurostimulation techniques stimulate the nervous system through electrical or magnetic fields, with commonly used methods including transcranial magnetic stimulation (TMS) and deep brain stimulation (DBS). TMS can regulate the excitability of the cerebral cortex by applying magnetic field pulses on the scalp, mainly used for treating depression and refractory anxiety. DBS directly stimulates specific brain regions through implanted electrodes and is suitable for diseases such as Parkinson's disease and obsessive-compulsive disorder. Studies have shown that high-frequency stimulation can significantly improve motor symptoms.

Drug regulation focuses on altering neural activity through chemical substances, including stimulants such as caffeine and amphetamines, as well as inhibitors such as lithium salts and antidepressants. The mechanism of action of such technologies includes the regulation of neurotransmitter concentration, changes in receptor sensitivity, and the impact on synaptic transmission. For example, selective 5-HT reuptake inhibitors (SSRIs) have shown good efficacy in the treatment of depression by increasing the concentration of the synaptic neurotransmitter serotonin to improve the patient's mood.^[5]

Gene editing technologies, such as CRISPR-Cas9, utilize precise genome modification techniques to enhance or repair neural function. Research has shown that editing genes related to neurodegenerative diseases can significantly delay cell apoptosis and neuronal loss, thereby achieving disease reversal.

Brain computer interface technology enhances motor and neural control capabilities by directly connecting the brain to external devices. This technology includes two categories: invasive and non-invasive. The invasive brain computer interface directly obtains neural signals through implanted electrodes, with higher accuracy and response speed, and is suitable for assisting movement in paralyzed patients. The non-invasive interface reads brain signals through methods such as electroencephalography (EEG) and is suitable for gaming and virtual reality applications, providing real-time feedback and enhanced experiences.

Specific types of enhancement techniques are also reflected in cognitive enhancement, such as the use of Nootropics (intelligence drugs), which aim to improve attention, memory, and learning abilities. Their active ingredients include amodifenib and pantothenic acid. Research has shown that moderate use of certain Nootropics can improve cognitive performance in healthy individuals, but their long-term safety and efficacy still need further exploration.

In summary, neural enhancement technology has shown a wide range of potential applications in diverse forms, covering multiple aspects from clinical treatment to cognitive optimization, and has significant implications for the expansion of human functions. The selection and application of various technologies need to consider the individual differences of patients and potential ethical issues.

3 Technology Application and Effect

3.1 Analysis of Application Fields

Neural enhancement technology is widely used in fields such as healthcare, education, military, and entertainment. In the medical field, neural enhancement technology is used to improve cognitive function and alleviate certain neurological disorders. By using brain computer interface (BCI) technology, researchers are able to convert patients' brain signals into instructions, thereby helping paralyzed patients control external devices. For example, studies using invasive BCI techniques have shown that 72% of patients can successfully control prostheses and achieve different grasping movements through signal decoding algorithms. In recent years, the combination of functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) has

made substantial progress in real-time monitoring and feedback systems, such as showing good results in early intervention of Alzheimer's disease.

In the field of education, neural enhancement technology is applied to optimize learning and memory. Through cognitive training and brain wave regulation techniques, learning efficiency can be significantly improved. The experiment using transcranial direct current stimulation (TDCS) method found that participants' performance in working memory tasks improved by 30%. In addition, using virtual reality (VR) technology to enhance immersion can help understand complex concepts in biomedical and scientific education, improve learning motivation and engagement.

The application in the military field focuses on enhancing the cognitive and decision-making abilities of combatants. Through a training platform that combines VR and BCI, soldiers can train their reaction time and decision-making efficiency in simulated battles, and provide personalized feedback through real-time brainwave analysis. The training results can achieve a 10% to 20% increase in hit rate. Meanwhile, for mental health interventions such as post-traumatic stress disorder (PTSD), the application of non-invasive brain stimulation techniques has achieved initial success in reducing the severity of related symptoms.^[6]

In the entertainment industry, neural enhancement technology is applied to improve gaming and interactive experiences. By using brainwave measurement instruments, game designers can obtain real-time emotional feedback from players and dynamically adjust game content based on it to improve immersion and player satisfaction. For example, some games have achieved personalized experience by adjusting the plot development based on the user's EEG activity.

Ethical issues are particularly prominent in the application of neural enhancement technology, especially regarding data privacy, technology abuse, and unequal access. There is a risk of leaking user privacy data in the storage and analysis of brain signals. In addition, economically capable individuals may have easier access to advanced neural enhancement technologies, gradually widening the power gap in society. Therefore, in the promotion of technology application, it is necessary to strengthen supervision and legislation to ensure the fair distribution and use of technology benefits.

3.2 Technical Effectiveness and Evaluation

Neuroenhancement techniques, including brain computer interface (BCI), neural regulation, and cognitive enhancement, have been widely studied and gradually applied in clinical and non clinical fields. The main effects are reflected in the following aspects:

Cognitive improvement: Participants showed significant improvements in short-term memory, decision-making, and learning abilities through electrical stimulation, medication, or gene technology regulation. For example, using low-frequency transcranial electrical stimulation methods, studies have shown that cognitive function can be improved by over 20%. Reduce reaction time by 20 milliseconds and increase task completion by 15% in specific tasks.

Recovery of motor function: For patients with spinal cord injury and stroke, a combination of nerve electrical stimulation and exercise training can significantly improve their motor ability. Clinical trials have shown that after six weeks of training, patients' gait stability improved by 30%, muscle strength increased by 15%, and in motor function assessment, over 50% of patients achieved functional recovery.^[7]

Emotion regulation: Neural regulation techniques such as deep brain stimulation (DBS) have shown positive effects in treating depression. The research results showed that patients receiving DBS treatment had a 40% reduction in depression assessment scale scores. Clinical trials have shown that the effectiveness rate of pre- and post-treatment evaluations is over 60%.

Safety and ethical considerations: Adverse reactions and ethical issues in technological applications should be given special attention. The discomfort and potential infection risk caused by electrical stimulation need to be evaluated, and clinical results show that about 5% of participants experience varying degrees of side effects. Ensuring informed consent and individual privacy is an important component of ethical considerations when using neural enhancement techniques.

Individual differences influence: There are significant individual differences in the response of subjects to neural enhancement techniques, and factors such as genotype, age, and gender can all affect the treatment effect. For example, some genotype carriers may improve their performance in cognitive enhancement tasks by up to 25%, while other carriers may only improve by 10%. Indicating the importance of personalized customized treatment plans.

Long term effectiveness and tolerability: The long-term effects of some technologies still need further verification. Currently, in clinical data, the duration of effectiveness after using neural enhancement devices varies from 3 to 12 months, depending on specific intervention types and individual differences. Large scale clinical follow-up trials have shown significant differences in functional improvement between the long-term maintenance group and the control group, with a regression rate of less than 20% for cognitive and motor abilities in the former test.^[8]

By systematically evaluating the application effects of various neural enhancement techniques, future research will further reveal the potential mechanisms of these technologies in different physiological and psychological contexts. In addition, interdisciplinary in-depth exploration is needed to address ethical issues that may arise from the use of technology, in order to ensure the integration of technological development with humanistic care.

4 Exploration of Ethical Issues

4.1 Ethical Challenges of Neural Enhancement Technology

The ethical challenges of neural enhancement technology mainly focus on individual autonomy, social equity, privacy rights, and potential security risks. In terms of individual autonomy, neural enhancement techniques may lead to a redefinition of self-identity, especially in the process of enhancing intelligence and emotions. Technologies such as Brain Computer Interface (BCI), which interact directly with the nervous

system through electrodes, enhance learning efficiency and information processing capabilities, and may affect individual decision-making abilities and intrinsic motivation during implementation.

The issue of social equity is prominent in economic and resource allocation, and the acquisition and use of neural enhancement technology may exacerbate social inequality. The high cost of technology research and implementation makes it difficult for low-income groups to obtain equal technological benefits. Those who can enjoy these technologies are often high-level elites in society, which may further widen the cognitive and ability gap between the superior and disadvantaged groups.^[9]

The infringement of privacy rights poses a risk of data abuse due to the ability of neural enhancement devices to obtain and interpret personal thoughts and emotional data. For example, certain neural stimulation devices can record users' thinking patterns, and if this data is obtained by criminals, it may pose a serious threat to personal privacy and security. In addition, how to ensure the security and anonymity of user data without sufficient regulatory measures has become an urgent problem to be solved.

Security risks are equally important, especially in the wearability of neural enhancement devices and their direct impact on physiology and emotions. During use, accidental injuries may occur due to equipment malfunctions, such as improper current settings that may cause side effects such as epilepsy and emotional fluctuations. At the same time, malicious software may interfere with the normal functioning of devices, manipulate individual behavior and thinking, and pose ethical risks of "thought control".

In addition, cultural and ethical differences also significantly affect the acceptance and adaptation of enhanced technology in society. There are divergent views on human-machine integration in different societies, and some cultures may be more resistant to neural enhancement technology, believing that it violates natural laws and affects human free will and moral responsibility. There is no unified standard in the professional field, and there is a lack of ethical framework and legal guidance, which makes the ethical issues of neural enhancement increasingly complex.^[10]

In summary, the development of neural enhancement technology needs to seek a balance between ethical considerations and technological innovation, and there is an urgent need to establish an interdisciplinary dialogue platform, including experts from neuroscience, ethics, law, sociology, and other fields to participate together, in order to promote comprehensive exploration and institutional design of this emerging field.

4.2 Ethical Response Strategies

A multidimensional and systematic strategy can be adopted to address ethical issues arising from neural enhancement technology. On the one hand, the establishment of policies and legal frameworks is the foundation, including the regulation and implementation details of neural enhancement technology. Clear legal boundaries should be established to avoid technological abuse while protecting user privacy and autonomy. For example, in the processing of personal data, regulations such as the General Data

Protection Regulation (GDPR) should be applied to ensure transparency and appropriate informed consent procedures.

On the other hand, strengthening the ethical review mechanism is one of the safeguard measures. Universities, research institutions, and enterprises should establish ethics review committees responsible for evaluating the ethics of neural enhancement research projects, ensuring compliance with ethical standards, and assessing potential social impacts and risks. Interdisciplinary experts can be introduced to emphasize the diverse perspectives of ethical review, including researchers from fields such as bioethics, law, sociology, etc.^[11]

Public participation is also an important part of response strategies. By conducting public education activities and forums, we aim to promote awareness and understanding of neural enhancement technology, and enhance society's acceptance and supervision of this technology. Group opinions can also be collected through online surveys, community discussions, and other forms to ensure transparency and democracy in the decision-making process.

It is crucial to establish professional industry standards and ethical guidelines for the fields of medicine and mental health. In the implementation of mental health interventions, clear intervention standards should be established to strengthen the protection of patients' rights and avoid psychological burden or dependence caused by neural enhancement measures. At the same time, the safety of various enhancement methods should be ensured to effectively reduce potential risks to patients.

In the technology development stage, promote responsible innovation models, emphasize ethical evaluation in the design stage, and ensure consideration of the diversity of usage scenarios and potential negative consequences. For example, when developing brain computer interfaces, developers need to conduct a comprehensive evaluation of the scope of signal intervention, possible information leakage, and the consequences of inappropriate manipulation to ensure consistency between technical implementation and ethical frameworks.

International cooperation is also an important strategy for addressing ethical issues. In the face of the globalization of technology, countries should strengthen information exchange and collaboration, share best practices and research results, establish unified ethical standards and guidelines, and prevent "ethical review differences" in the wave of technological ethics.

Strengthening ethical education is crucial in the field of education. Universities and research institutions should incorporate ethical discussions into relevant courses to equip the new generation of scientists and engineers with the necessary ethical sensitivity and social responsibility. When training researchers, incorporate ethical awareness into the assessment system to ensure that they actively identify ethical risks during the research process.

In addition, an open academic discussion platform can promote scientific research and ethical reflection on the long-term impact of neural enhancement technology, and regularly organize academic seminars to explore the latest research trends and ethical challenges. The academic community should establish a reward mechanism to encourage innovative teams or individuals who have made outstanding contributions in ethical research.

Based on the above response strategies, it emphasizes the development of policies and regulations, ethical review mechanisms, public participation, industry norms, responsible technological innovation, international cooperation, education strengthening, and open discussion platforms, among other diverse methods, to form an effective ethical framework for addressing ethical issues and promote the sustainable development and ethical harmony of neural enhancement technology.

5 Conclusion

Neural enhancement technology has developed rapidly in recent years, including various forms such as brain machine interfaces (BCIs), neural stimulation devices, and drug interventions. The progress of BCI has greatly narrowed the boundaries of human-machine communication, using electrode arrays to directly obtain neural signals from the cerebral cortex, convert them into mechanical actions, and apply them to assist mobility for disabled individuals. Specifically, in 2019, the research team used a 128 channel electrode array to achieve up to 85% accuracy in decoding neural signals, successfully helping users control robotic arms.

The combination of synchronous electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) further enhances the understanding of brain activity. With the optimization of algorithms, especially the introduction of deep learning techniques, the accuracy of signal processing has been improved to over 90%. It is expected that in the future, more refined neural functional zoning will be provided to assist clinical diagnosis.

On the other hand, neural stimulation techniques such as deep brain stimulation (DBS) are being applied in the treatment of Parkinson's disease, depression, and other conditions. DBS uses electrodes implanted in specific areas of the brain to alleviate symptoms by adjusting the intensity and frequency of electrical currents. In a study of 60 Parkinson's disease patients, after 6 months of treatment, 75% of patients reported a reduction in motor symptoms and a 40% improvement in motor function scores. Moreover, the adaptive scheme of adjusting the current can achieve personalized treatment and enhance the therapeutic effect.

Drug intervention is also a means of neural enhancement, for example, drugs that promote neural plasticity (such as BDNF agonists) are actively being developed. By increasing the level of nerve growth factor, the aim is to enhance the adaptability of neural circuits, which has a significant impact on the improvement of cognitive ability. A study showed that volunteers who used BDNF agonists performed 30% better on cognitive tests compared to the control group.

Despite significant technological advancements, ethical issues are becoming increasingly prominent. Privacy infringement, blurred identity, and potential social inequality have become increasingly apparent with the widespread application of technology. For example, in the context of neural enhancement through BCI, users' neural signals may be illegally monitored or manipulated, leading to serious violations of personal privacy. In addition, the contradiction between the widespread use of technology and economic burden may exacerbate social stratification, resulting in

only specific groups benefiting from advanced technology and creating new social inequalities.

Another ethical issue worth noting is the potential impact on human cognition and moral judgment. Neural enhancement technology may alter individuals' decision-making processes and values, sparking discussions on free will and moral responsibility. For example, whether individuals who rely heavily on neural enhancement can still maintain independent moral judgment or be manipulated by technology. In the future, facing the ethical challenges of neural enhancement technology, the scientific community, ethicists, and policy makers need to work closely together to develop reasonable norms to guide the positive development and application of the technology.

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