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Legal Risks and Regulatory Pathways of Brain Computer Interface Technology

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Abstract. Brain-computer interface is a cutting-edge technology that establishes a direct information exchange channel between the brain and external devices, progressing through signal acquisition, processing, and decoding feedback. As it moves from laboratory to clinical application, it offers breakthroughs in treating neurological diseases but also poses profound legal risks. Personal injury risks arise from invasive surgery and system decoding errors, while privacy risks stem from the sensitivity of neural data and the potential for over-collection, transmission leakage, and re-identification. Risks to personal freedom are reflected in eroded autonomy, shaken identity, and invisible limitations. These risks are endogenous to the technology—stemming from the link between signal accuracy and physical intervention, broad-spectrum signal acquisition, and algorithmic mediation. The existing legal framework, centered on traditional rights and external behavior, shows structural deficiencies in addressing mental intervention, intangible harm, informed consent dilemmas, and complex liability. Therefore, a new neural rights system should be constructed, centered on cognitive freedom, mental privacy, mental integrity, and psychological continuity. Its protection requires coordinated domestic legislation and global governance to defend the fundamental bottom line of human nature in technological development.

Keywords: Brain computer interface, Legal risks, Neural rights, Neural data, privacy

1. Introduction

Brain Computer Interface (BCI) is a cutting-edge cross technology that establishes direct information exchange channels between the brain and external devices. Its core value lies in building a direct communication channel between the brain and machines, realizing the conversion of EEG signals into machine executable instructions, thereby bypassing the peripheral nervous and muscular systems and achieving the effect of "mind control". Its workflow can be divided into three core stages: first, signal acquisition, which obtains brain neurophysiological signals through electrodes or sensors; The second is signal processing, which involves amplifying, filtering, feature extraction, and pattern recognition of the collected raw signals; The third is decoding and feedback, which converts specific EEG patterns into device control instructions and feeds back the execution results to the user through visual or tactile channels to help optimize control strategies [1].

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At present, brain computer interface technology is in a critical explosive period from laboratory to clinical application, and the rapid development of technology is accompanied by an urgent need for legal research. Brain computer interfaces directly connect external devices to the human brain, touching on the most private spiritual realm of individuals. The legal risks arising from this are more profound and complex than those of general emerging technologies. However, the traditional rights system is based on the principle that "human intention is executed through bodily movements", and brain computer interfaces insert algorithms and machine execution links between intention and behavior, making the existing legal framework insufficient in explaining new legal interests. In 2021, Chile adopted a constitutional amendment to include "neural rights" in its protection, becoming the world's first country to legislate specifically for brain computer interface technology; Colorado and California in the United States also revised their privacy laws in 2024 to explicitly include neural data in the category of sensitive personal information [2]. These extraterritorial legislative developments indicate that the legal regulation of brain computer interface technology has become a cutting-edge issue in the international legal community. Based on the above background, a systematic study of the legal risks and their causes that may arise from the development of brain computer interface technology, and the exploration of a legal regulatory path that is in line with China's institutional context, is not only a necessary response to technological development, but also an essential part of improving the protection system of personality rights in the digital age. This article will analyze the legal risks of brain computer interfaces from three dimensions: personal injury, privacy leakage, perceived benefits and personal freedom. It will delve into the underlying causes and explore the necessity and specific path of constructing a new neural rights system, in order to provide theoretical reference for the standardized development of brain computer interface technology in China.

2. Legal risks that may arise from the development of brain computer interface technology

While brain computer interface technology brings revolutionary breakthroughs in the fields of neurological disease treatment and functional rehabilitation, it also carries profound legal risks due to its direct impact on the most private spiritual realm of humanity, specifically reflected in three dimensions: personal injury, privacy and personal information leakage, and perceived benefits and personal freedom.

2.1. Risk of personal injury

According to different signal acquisition methods, brain computer interfaces can be divided into three categories: non-invasive, semi invasive, and invasive, each facing varying degrees of security risks. Among them, system operation and signal decoding errors are the core risks faced by all types of brain computer interfaces. Invasive brain computer interfaces require neurosurgical implantation of electrodes into the brain, which poses the most severe risk. The surgical procedure itself may cause irreversible brain damage, leading to acute complications such as intracranial hemorrhage, infection, and cerebrospinal fluid leakage. Implants that exist in the brain for a long time may cause immune rejection, tissue edema, and aseptic meningitis due to biocompatibility issues. In addition, electronic components may age and lose their function during long-term use, and removing them again may require secondary surgery, which may also cause brain damage to users. Although the semi invasive brain computer interface does not penetrate deep into the cerebral cortex, it still requires surgical placement of electrodes outside the dura mater, which also poses surgical risks. Non invasive brain computer interfaces do not require surgery, but contact between electrodes and

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skin may cause infections and allergies. Improper electrical stimulation can cause burns and even trigger neurological abnormalities such as seizures, fainting, or transient high sound pressure noise [3].

Regardless of the type of brain computer interface, it faces common risks of system operation and signal decoding errors. The brain computer interface system itself may malfunction, and incorrect interpretation and accidental interference of EEG signals can lead to brain confusion, and in severe cases, even endanger life safety. In addition, there is a portion of "brain computer interface illiteracy", with about 15% to 30% of research participants unable to proficiently control brain computer interfaces. If screening cannot be conducted before implantation, users may face the dilemma of "spending money to implant but unable to use", and the damage to brain tissue is irreversible [4].

2.2. Privacy and personal information leakage risks

Brain computer interface technology has made it possible for humans to decode their thoughts through technology for the first time. As a special type of personal data, the consequences of neural data leakage are often difficult to reverse. From the perspective of data characteristics, neural data appears as raw data associated with the brain itself. At the physiological level, humans can determine brain mechanisms and reveal an individual's health status by comparing signal waveforms, imaging states, and potential levels; At the mental level, neural data contains information about psychological states such as feelings, emotions, and memories obtained by decoding brain signals. Similar to fingerprints, the brainwaves of each individual are also different. Under fixed measurement conditions, different individuals' electroencephalograms will present unique "brain patterns" that can be used to accurately identify specific individuals [5]. In other words, brain computer interface devices not only collect "what I am thinking", but also "who I am", "what I prefer", and "what I may do".

From a technical risk perspective, the leakage pathways of neural data are diverse and covert. One is the 'beyond scope collection' in the data collection process. Brain computer interface devices are difficult to isolate neural signals for a single task - electrical signals from the same brain region may simultaneously reflect different cognitive states or behavioral processes, which inevitably includes the user's "incidental thoughts" while collecting target signals. Secondly, there are security vulnerabilities in the data transmission and storage process. Brain computer interface devices usually need to transmit data to the cloud for processing, which provides an opportunity for hacker attacks. Brain hackers can illegally infiltrate computer information systems, steal EEG data and decode it to obtain users' personal preferences, emotional states, and disease conditions [6]. Thirdly, the risk of "re identification" of anonymized data. Even if neural data is anonymized and cross referenced with other datasets, it is still possible to re identify an individual's identity. In the current situation where the number of brain computer interface users is limited, this re identification risk is particularly prominent.

From the perspective of the consequences of abuse, the leakage of neural data may trigger multi-level infringement. At the individual level, brain information can be used for neuromarketing - businesses analyze users' neural responses to achieve precise subconscious manipulation, depriving consumers of their autonomy in decision-making. At the societal level, neural data may be used to carry out criminal activities such as insurance fraud and extortion. At the spiritual level, continuous neural monitoring will lead individuals into a panic of "mental transparency", and the loss of spiritual privacy is essentially a loss of personal dignity [7].

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2.3. Perceived benefits and personal freedom risks

The ultimate challenge of brain computer interface technology for humans lies in its potential to erode individual autonomy, undermine personal identity, and limit personal freedom. These risks touch upon the fundamental proposition of 'what makes a person human'.

Firstly, the erosion of autonomy. The brain computer interface inserts algorithm and machine execution links between intention and behavior, which raises the question of 'who is making the decision' [8]. When external devices send feedback information to the brain through brain computer interfaces, this information may affect the user's autonomous judgment. Furthermore, when the brain computer interface system learns the patterns of users' brain signals through algorithms, it may form an "information cocoon" - users repeatedly receive information filtered by algorithms, and their decisions are unconsciously shaped by the system. Secondly, the wavering of personal identity. Brain computer interface technology may change an individual's psychological continuity and identity recognition. Clinical cases have shown that some patients receiving deep brain stimulation therapy have reported personality changes: some have become more communicative, some have weakened self-control, and some even say they no longer "know themselves". A patient with refractory depression treated at Shanghai Ruijin Hospital experienced rapid emotional fluctuations during target testing. When adjusted to a certain target, he suddenly felt like he had been stabbed in the back by someone.This experience reveals a profound philosophical question: when emotions are regulated by devices, is it still himself who is the subject of joy, anger, sadness, and happiness? When memory can be edited and consciousness can be intervened, the answer to 'who am I' will become blurred. Thirdly, the invisible limitations of personal freedom and mental harm. Once the brain computer interface device is implanted, the user forms an inseparable connection with the machine. This kind of connection brings both enhanced abilities and new attachments. When devices require regular charging, maintenance, and upgrades, users' freedom of movement is implicitly limited by technological dependence. Even more extreme is that once hackers illegally control a user's nervous system through technical means, the user may become a tool manipulated by others, and their personal freedom may be substantially deprived.

In summary, the legal risks brought by brain computer interface technology are multidimensional and deep-seated. The risk of personal injury threatens physical health, the risk of privacy leakage erodes spiritual dignity, and the risk of perceived benefits and personal freedom challenges the fundamental position of human beings as autonomous subjects.

3. The causes of legal risks in brain computer interface technology

The risks mentioned earlier are not accidental products of technological applications, but are rooted in the essential characteristics of brain computer interface technology. Thoroughly analyzing the causes of these risks is not only the key to understanding technological challenges, but also provides theoretical prerequisites for constructing effective legal regulatory pathways in the future.

3.1. The internalization of risk by technological structure: invasiveness, broad-spectrum, and algorithmic mediation

The generation of legal risks in brain computer interface technology stems from the development logic and inherent properties of the technology itself. Firstly, the positive correlation between signal accuracy and physical intervention determines the inevitability of personal injury risk. The core of brain computer interface technology is to achieve precise acquisition and interpretation of signals

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from brain neurons. According to technical principles, the closer the electrode is to the neuron, the higher the signal-to-noise ratio of the collected signal and the higher the decoding accuracy. This technological logic determines that accuracy must come at the cost of safety - to obtain high-quality neural signals, electrodes must be implanted deep in the brain, which brings more serious risks of personal injury. The optimization of technical performance and the increased risk of personal injury constitute two inseparable aspects in the development of brain computer interfaces.

Secondly, the broad-spectrum acquisition characteristics of brain signals determine the inevitability of privacy and personal information leakage risks. The operating principle of brain computer interface devices determines that they cannot achieve precise "minimal acquisition". The brain is a highly integrated and complex system, and electrical signals from the same brain region may simultaneously reflect multiple cognitive processes such as motor intention, emotional state, and memory retrieval [9]. When the device monitors the motor cortex to collect specific signals, other information carried by adjacent neuron activity will also be collected by the electrodes. This' incidental collection 'is not a technical flaw, but an objective fact determined by the physiological structure of the brain - different mental activities share the same set of neural hardware and cannot be precisely isolated.

Thirdly, the algorithmic intervention between intention and behavior determines the inevitability of perceived benefits and personal freedom risks. In the natural state, human intention drives muscle movement directly through neural instructions, forming a direct and continuous causal chain between intention and behavior. However, brain computer interface technology has inserted multiple technical links such as signal acquisition, algorithm decoding, and instruction execution in this chain, creating an undeniable gap between "what I think" and "what the machine does". The existence of this gap first leads to a dilution of autonomy. When the user's EEG signals need to be interpreted by algorithms before they can be converted into external instructions, the algorithm's operating logic and error range may affect the final execution result without the user's knowledge. There is no longer a one-to-one correspondence between the intention expressed by the user and the actual behavior performed by the machine [10]. Secondly, algorithms have learning ability and autonomous optimization characteristics, and the system will adjust decoding strategies based on users' historical data, gradually trapping users in an "information cocoon" - unconsciously shaping cognitive preferences by the system. Finally, the characteristics of brain computer interface devices connecting to the Internet also make them potential targets of hacker attacks. Once the system is illegally hacked, attackers can directly intervene in users' perception, emotions, and even behavioral decisions by sending false signals to the brain [11].

3.2. Shortcomings in the structure of rights and remedies in existing civil law theories

The uniqueness of the risks associated with brain computer interface technology poses a profound challenge to the legal framework built around traditional rights. The insufficient effectiveness of existing rights theories in risk prevention is an important reason for the lag in legal regulation.

Firstly, the traditional rights system takes "external behavior" as the normative object and is difficult to touch the spiritual realm. Since modern times, the legal system has assumed that the spiritual world of humans is a private realm that cannot be penetrated, and the law only needs to regulate the expression of ideas that are externalized into behavior. However, brain computer interface technology can not only read neural information that has not yet been externalized in the brain, but also intervene in individual cognitive processes through neurofeedback technology [12]. When ideas themselves become the object of technological operation, traditional rights centered on behavior reveal the limitations of their protection scope. Although continuous neural monitoring

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does not disclose specific information, it is enough to make individuals fall into the fear of "mental transparency", which is difficult to be covered by the existing concept of privacy. Secondly, the relief mechanism for existing rights is based on the actual occurrence of damage and is difficult to achieve pre prevention. The Tort Liability Law follows the basic principle of "no harm, no remedy", requiring the victim to prove the consequences of the harm and its causal relationship with the tortious act. However, the risks of brain computer interface technology have latent and cumulative characteristics - the leakage of neural data may not be detected until many years later, changes in personality identity are often a gradual process, and the erosion of autonomy by technology is an intangible damage that is difficult to quantify. When the damage finally manifests, it is extremely difficult to prove the causal relationship, and the effectiveness of relief is greatly reduced. The more fundamental problem is that some risks of brain computer interface technology are irreversible, such as once personality changes, it is difficult to restore the original state even if the device is removed. Thirdly, the principle of autonomy of the subject of rights encounters practical difficulties in the face of technological complexity. Informed consent is the core system of modern healthcare and personal information protection, and its legitimacy is based on the individual's ability to make autonomous decisions based on sufficient information. However, the extreme complexity of brain computer interface technology makes "full knowledge" almost impossible - the opacity of algorithms makes it difficult for researchers to predict all risks of the system, and ordinary users cannot understand the scope and potential use of neural data collection. In the context of severe information asymmetry, user consent often becomes a formal signature, which is difficult to carry the institutional function of protecting autonomy. Fourthly, the "multi-party problem" of responsibility attribution blurs the boundaries of legal responsibility allocation. The development, production, and clinical application of brain computer interfaces involve multiple parties such as manufacturers, medical institutions, healthcare professionals, and algorithm developers, and the consequences of damage are often the result of the combined effects of multiple factors. When signal misreading leads to erroneous operation of external devices, it is often difficult to accurately distinguish whether it is caused by algorithm defects, equipment failures, or improper user operation. The uncertainty of responsibility attribution not only increases the cost of victims' rights protection, but may also inhibit the enthusiasm of relevant parties to participate in technological innovation.

In summary, the causes of risks in brain computer interface technology have a dual nature: on the one hand, the inherent logic of technological development determines the objective inevitability of risks such as personal injury, privacy leakage, and erosion of autonomy; On the other hand, the legal framework centered on traditional rights exhibits structural deficiencies when facing the challenges of intervention in the spiritual realm, accumulation of intangible damages, dilemma of informed consent, and complexity of responsibility attribution. This tension between "technological progressiveness" and "legal lag" constitutes the deep root of the problem of legal regulation of brain computer interface.

4. Building a new neural rights system

The previous analysis indicates that the legal risks caused by brain computer interface technology are rooted in the inherent properties of its technical structure, and existing civil law theories exhibit structural deficiencies in addressing these risks. The tension between "technological progressiveness" and "legal lag" calls for the self innovation of the legal system - building a new right system that can effectively respond to the challenges of the brain computer interface era outside the traditional right framework.

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4.1. The necessity and importance of building a neural rights system

The construction of a neural rights system is not the arbitrary proliferation of rights concepts, but an inevitable choice to address the profound challenges posed by brain computer interface technology.

Firstly, there is a structural gap in the protection of the spiritual domain within the existing rights system. Since modern times, the legal system has assumed that the spiritual world of humans is a private realm that cannot be penetrated, and the law only needs to regulate the expression of ideas that are externalized into behavior. The legitimacy of this assumption stems from the underdevelopment of technology - when ideas cannot be directly explored by the outside world, the spiritual field naturally does not require legal intervention. However, brain computer interface technology completely overturns this premise: it can not only read neural information that has not yet been externalized in the brain, but also intervene in individual cognitive processes through neurofeedback technology, and may even change personality identity. Legal interests such as cognitive freedom, mental privacy, mental integrity, and psychological continuity cannot be covered by material personality rights such as physical rights and health rights, nor can they be fully protected through mental personality rights such as privacy and reputation rights. This structural gap can only be filled by creating new types of rights.

Secondly, the recognition of neural rights is the fundamental bottom line for defending human nature. Under the impact of brain computer interface technology, the most profound crisis facing humanity is not physical injury or information leakage, but the erosion of autonomy and the shaking of personal identity. When emotions are regulated by devices, memories can be edited, and consciousness can be intervened, the answer to 'who am I' becomes blurred, and the subject's position faces unprecedented challenges. The core value of the neural rights system is the core content of human dignity in the digital age, and it is the last fortress that safeguards humanity as a rational subject.

Thirdly, the construction of a neural rights system has significant implications for human rights law. With the globalization of neural technology, neural rights have surpassed the legal scope of a country and become a cutting-edge issue of common concern to the international community. In 2021, Chile adopted a constitutional amendment to include neurological rights in its protection, becoming the world's first country to legislate specifically for brain computer interface technology; Colorado and California in the United States revised their privacy laws in 2024 to explicitly include neural data in the category of sensitive personal information. These extraterritorial legislative developments indicate that the protection of neural rights has become a new growth point in international human rights law. As an important country in the research and application of brain computer interface technology, China actively participates in the formulation of international rules for neural rights, which is not only a necessary requirement for fulfilling human rights protection obligations, but also an important opportunity to enhance China's international discourse power in the field of scientific and technological governance.

4.2. The legal construction of the neural rights system

Neural rights are not a single right, but a bundle of interrelated rights. Based on comprehensive academic discussions and legislative practices outside the region, the neural rights system should include at least the following four core contents.

The right to cognitive freedom is a fundamental right in the neural rights system, aimed at protecting individuals' autonomy in making decisions when using neural technologies. It includes both positive and negative dimensions: the positive aspect refers to the individual's right to freely

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choose to use neural technology to change their own mental state; On the negative side, it refers to the individual's right to refuse unauthorized neurotechnological interventions. In the medical brain computer interface scenario, the right to cognitive freedom requires medical institutions to fulfill sufficient disclosure obligations before the application of technology, ensuring that patients understand the technical principles, potential risks, and alternative solutions; During the application process, patients have the right to suspend or withdraw treatment at any time without any form of coercion or induction. The core of cognitive freedom is to defend the individual's dominant position over their own mental activities, which is a prerequisite for the realization of all other neurological rights.

The right to mental privacy aims to protect individuals' brain data and mental content from unauthorized access, storage, and use. Unlike traditional privacy protection of "external information", spiritual privacy focuses on "internal information" - thoughts, emotions, intentions, etc. that have not yet been externalized into behavior. The uniqueness of neural data lies in its ability to not only identify individuals, but also infer their emotional states, cognitive characteristics, behavioral tendencies, and even subconscious preferences. The normative connotation of the right to mental privacy should include: the "minimization principle" in the data collection stage, ensuring that devices only collect the necessary neural information to achieve their functions; The obligation of encryption protection during data transmission and storage to prevent data leakage and illegal access; And the principle of "purpose limitation" for data use prohibits the use of neural data for commercial marketing, insurance evaluation, and other purposes without the user's consent.

The right to mental integrity refers to the individual's right to protect their mental state from external harm. Unlike the emphasis on "choice" in the right to cognitive freedom, the right to mental integrity focuses on "defense" - preventing neural technology from causing involuntary changes in an individual's psychological state [13]. Brain computer interface technology may alter an individual's behavioral patterns, emotional characteristics, and even self-identity through neural stimulation. Such changes, if made without the user's consent or beyond their reasonable expectations, constitute a violation of their right to mental integrity. The right to mental integrity requires that the application of neural technology must follow the principle of "non harm" to ensure that technological intervention does not cause foreseeable damage to users' mental health; At the same time, technology developers should take effective measures to prevent system failures or hacker attacks from damaging the mental integrity of users.

The right to psychological continuity aims to protect an individual's identity and psychological continuity from interference from neurotechnology. Brain computer interface technology may alter an individual's psychological continuity through memory editing, emotional regulation, and other means, leading to a sense of alienation where the individual is no longer themselves. The core of the right to psychological continuity is to maintain an individual's unified perception in the temporal dimension and prevent personality alienation caused by technological applications. The protection mechanism should include: ensuring users' continuous control over their own psychological state during the technical design phase; Establish a regular evaluation mechanism during the clinical application phase to promptly identify and intervene in technical parameters that may affect psychological continuity; Provide effective relief channels for users after damage occurs.

4.3. Domestic and international protection of neurological rights

The construction of a neural rights system requires the coordinated promotion of domestic law and international law, forming a multi-level and all-round protection pattern. At the domestic legal level, China should explore the protection path of neural rights within the current legal framework. In the

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short term, some of the content of neurological rights can be incorporated into the existing rights system through legal interpretation - for example, interpreting the right to mental privacy as the rightful meaning of Article 1032 of the Civil Code "private information", and incorporating the right to cognitive freedom into the normative scope of Article 990 (2) of the Civil Code "personal freedom". In the long run, we should learn from the legislative experience of countries such as Chile and Spain, and timely initiate specialized legislation or constitutional amendment procedures for neurological rights, clarifying the legal status and protection standards of neurological rights. At the same time, relevant laws such as the Personal Information Protection Law and the Data Security Law should be improved, and neural data should be classified as a special category of sensitive personal information, with stricter rules for collection, processing, and protection. In judicial practice, courts should be encouraged to accumulate judicial experience through typical cases and provide normative guidance for the protection of neurological rights. At the level of international law, active participation should be made in the formulation of global governance rules for neural rights. UNESCO has promoted the development of the first global ethical framework for neurotechnology. China should take this opportunity to deeply participate in international rule discussions and integrate its concepts and practices in neural technology governance into global standards. At the same time, we should strengthen exchanges and cooperation with countries such as Chile and Spain that have advanced legislation on neurological rights, learn from their beneficial experiences, and promote the formation of an international consensus on the protection of neurological rights. When conditions are ripe, it is advisable to advocate for the establishment of an international convention on the protection of neurological rights, in order to establish a unified human rights bottom line for the development of neurological technology in various countries.

5. Conclusion

The development of brain computer interface technology has not only expanded the practical possibilities of disease treatment, functional rehabilitation, and human-computer interaction, but also raised legal risks in terms of personal safety, privacy protection, maintenance of perceived interests, and protection of personal freedom. The above risks are not simply due to occasional errors in the application of technology, but are to a considerable extent rooted in the collection, recognition, transformation, and feedback mechanisms of brain computer interfaces for brain information. Therefore, the brain computer interface not only extends existing legal issues in new scenarios, but also poses structural challenges to the current legal regulatory system. In this regard, traditional legal norms mainly revolve around external behavior, property damage, and result liability, and their ability to respond to the spiritual realm, personal interests, and autonomous decision-making space is relatively limited. Therefore, there are certain regulatory deficiencies in areas such as informed consent, liability determination, and damage relief. In the face of the potential deep personality involvement caused by brain computer interface technology, it is necessary to gradually construct a neural rights protection framework based on cognitive freedom, spiritual privacy, spiritual integrity, and psychological continuity on the existing legal order, and to implement it through civil law interpretation, specialized legislation, and international rules. Ultimately, the legal regulation of brain computer interfaces should not be limited to passive responses to technological risks, but should focus on establishing a more stable regulatory boundary between technological innovation and personality protection. Only in this way can we promote the orderly development of brain computer interface technology while effectively safeguarding human dignity, freedom, and subjectivity.

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