Neuroscience Research 219 (2025) 104951



Contents lists available at ScienceDirect

Neuroscience Research

journal homepage: www.sciencedirect.com/journal/neuroscience-research





Ethical, legal, social, and cultural implications of the non-clinical use of transcranial direct current stimulation (tDCS) in Korea and Japan

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ARTICLE INFO

Keywords:
TDCS
Workflow
Ethics
Safety
Reinforcement
Government regulation

ABSTRACT

Transcranial Direct Current Stimulation (tDCS) is a non-invasive neuroscience technique that modulates brain activity by applying a weak electric current to the scalp. tDCS is already used in hospitals to alleviate symptoms of neurological diseases and mental disorders. However, it can also be purchased over the Internet without medical authorization or oversight. In such cases, experts have raised concerns about potential health side effects and unforeseen social issues resulting from the misuse of tDCS and called for a thorough analysis of the broad societal implications of its non-clinical use. To address these concerns, this study explored the ethical, legal, social, and cultural issues related to the use of tDCS outside its authorized medical applications, focusing on South Korean and Japanese societies as case studies. We employed an Integration Workflow and XYZ approach specifically designed to analyze the implications of emerging neurotechnologies. Our findings highlighted several areas of concern: safety, effectiveness, fairness, lack of regulation in both sports and non-sports sectors, insufficient critical information from device manufacturers, hype and exaggerated claims, and use for enhancement in meritocratic competitions. We anticipate that our study's findings will inform the future development of tDCS devices and encourage public engagement through discussions involving key stakeholders, including device manufacturers and policymakers.

1. Introduction

Transcranial Direct Current Stimulation (tDCS) is a non-invasive brain modulation technique that uses a pair or more electrodes placed on the scalp to deliver a small electrical current, modulating brain activity (Truong et al., 2018). The device typically consists of a headgear, a current stimulation controller, and a disposable electrolyte solution (Truong et al., 2018). When tDCS was first introduced, it did not gain much attraction due to doubts about its effectiveness and the availability of alternative medications. However, in the early 2000s, Nitsche and colleagues in Germany pioneered scientific research into tDCS, elucidating its mechanism of action, and the technology's portability and ease of use fueled a resurgence of interest (Nitsche et al., 2000; Nitsche et al., 2001). tDCS has been used in the treatment and rehabilitation of neurological disorders, including the restoration of motor function in stroke patients, and in the treatment of psychiatric disorders, such as depression (Fregni et al., 2005; Fregni et al., 2006). Furthermore, numerous studies have demonstrated tDCS's potential to enhance various cognitive functions, including attention, language, working memory, and mathematical skills. In addition to these exciting findings, tDCS has become a particularly attractive brain modulation technology due to its relative safety, minimal side effects, low cost, and ease of use

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https://doi.org/10.1016/j.neures.2025.104951
Received 14 March 2025; Received in revised form 5 August 2025; Accepted 6 August 2025
Available online 6 August 2025
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compared to other comparable technologies. This accessibility has contributed to its growing popularity. For example, unlike Transcranial Magnetic Stimulation (TMS), which requires a large machine to generate magnetic fields, tDCS is designed as a headband with easily attachable electrodes for the scalp, allowing for mobility during use. While the stimulation intensity is lower than TMS, tDCS offers greater portability and convenience. In addition, instructions for assembling or building a tDCS device are readily available online, and fully manufactured devices can be purchased on the market.

There have been several stories that brought tDCS beyond the realm of scientific research and into the public eye as a significant social issue. In 2016, the U.S. Ski and Snowboard Federation reported that ski jumpers used a tDCS device from Halo Neuroscience in a potential attempt to enhance performance (Reardon, 2016)[1] That same year, a research team at the University of Kent in the UK, led by Mauger, demonstrated that applying tDCS over specific brain regions could reduce lower body fatigue in cyclists, leading to improved performance (Angius et al., 2016; Reardon, 2016) Their findings also suggested that, unlike traditional drug doping, tDCS produced statistically significant performance improvements without leaving a detectable trace. These results are completely outside the technical scope of conventional drug doping and current anti-doping activities.

The tantalizing prospect of no-trace motor enhancement has prompted researchers to explore tDCS's potential for cognitive improvement in health subjects. Fregni et al. (2015) showed that tDCS stimulation of the prefrontal cortex improved working memory. Coffman et al. (2014) reported that tDCS improved memory and learning, as well as attention span. Chrysikou et al. (2013) also reported that stimulating the right prefrontal cortex with tDCS enhanced cognitive flexibility and creativity. These findings suggest that tDCS can be used by the general public for non-clinical purposes, especially for cognitive enhancement, in fields other than sports, and raise substantial concerns, including the issues of safety, potential misuse, and misleading advertisement by device companies.

Given its accessibility and ease of use, there is a critical need to examine ethical, legal, social, and cultural implications (ELSCI) of using tDCS for enhancement purposes in our society. ELSI research, representing the ethical, legal, and social implications of new scientific advancements, is a multidisciplinary approach to analyze the broader societal consequences of pioneering research, particularly in biomedicine (Ogbogu and Ahmed, 2022). This framework prompts a thorough examination of potential ethical dilemmas, legal challenges, and social changes that may arise from novel scientific endeavors and technological innovations. More recently, there is a growing recognition within the research community that the societal impact of emerging biotechnologies is not uniform and can vary significantly depending on cultural contexts, values, and practices. This has led to the introduction of "culture" as a distinct component alongside ethical, legal, and social implications in some analytical frameworks (e.g., the IEEE Neuroethics Framework (https://brain.ieee.org/publications/ieee-neuroethics-framework/) (Accessed June 25, 2025)). A concrete example in which cultural differences clearly influence the public acceptance of science and technology can be found in postmortem brain research and the operation of brain banks. Studies have pointed out significant differences in social acceptance between East Asian countries and Western countries, particularly the United States, and the understanding of ethical and social issues also varies greatly depending on cultural contexts (Global Neuroethics Summit Delegates et al., 2018). Such cases clearly illustrate the need to incorporate culture as a distinct dimension in ELSI analysis.

This study aims to analyze the issues related to the non-clinical use of tDCS across these four domains: ethical, legal, social, and cultural implications by utilizing the XYZ matrix approach, a new tool for the neuroethical analysis of emerging neurotechnologies, developed by the authors in a preceding study (Jwa et al., 2023b.).

2. Methods

2.1. Integration workflow

This study employed the Integration Workflow and the XYZ matrix approach (Jwa et al., 2023b.) (Fig. 1), which was developed to investigate and evaluate the ethical, legal, social, and cultural aspects of the broader impacts of emerging neuroscience on society. In step 1, it is posited that the general public may acquire tDCS devices online and utilize them for cognitive enhancement. In Step 2, a review panel of South Korean and Japanese researchers from various fields, including ethics (philosophy), law, sociology, and medicine, was organized. These researchers are the authors of this study. In Step 3, neuroengineers, neuroscientists, neuroanatomists, and neurosurgeons were invited to give a presentation on the composition, mechanism, etc. of tDCS, and a medical doctor on the panel analyzed the technical aspects, safety, and effectiveness of tDCS based on the presentations to create a written opinion. In Step 4, the opinions from Step 3 were shared with the entire panel in advance, and a plenary meeting was held to determine the topics that each expert on the panel would cover in the analysis. This process is intended to avoid duplication of efforts among the experts. In Step 5, over a period of two months (from May to July 2023), each researcher conducted an analytical study of ELSCI based on the topics identified by the panel. In Step 6, each expert's findings were synthesized into an opinion paper and shared with the entire group. In Step 7, a second plenary meeting was held to review and discuss the opinions of

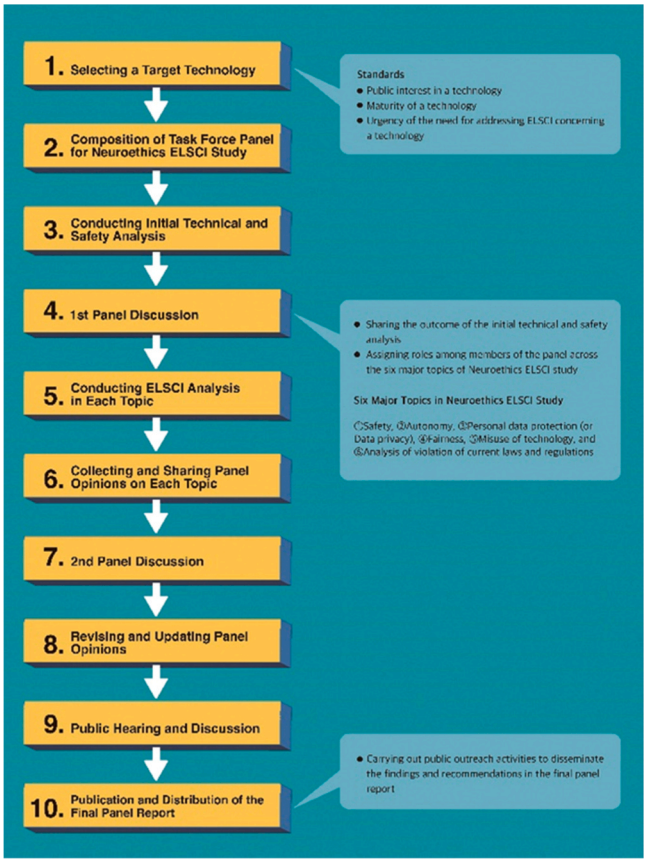


Fig. 1. Integration Work Flow for Emerging Neuroscience and Technology ELSCI Implementation. (Jwa et al. Experimental Neurobiology 2023 32 (1), 8–19.).

[1] Halo Neuroscience was merged into another neurostimulation device company, Flow Neuroscience (www.flowneuroscience.com), in 2021.

the experts. During this process, the experts summarized the exchanges of opinions and checked whether any important points were missed in their analyses. In Step 8, the experts documented the discussions from Step 7 and added the missed points. The current study reflects findings from completing Steps 1–8. A public hearing (Step 9) is planned to be held, and the comments discussed at the hearing will be summarized and added to current findings to develop a report for the general public (Step 10).

2.2. Matrix approach for tDCS technology positioning

The matrix convergence approach consisting of the X, Y, and Z axes was used for the analysis, given that this study focuses on the general public's use of tDCS to enhance cognitive functions outside of a clinical context (Fig. 2. First, tDCS was positioned on the X axis as a target technology. The Y axis, representing the maturity of the technology, was set at the ninth stage – the market entry without restriction. The Z axis denotes the four core areas of analysis – ethical, legal, social, and cultural implications of the technology – that the members of the panel members examined based on their expertise. However, it is important to note that new government policies or regulations may be introduced to oversee the manufacturing and use of tDCS for non-clinical purposes, in light of potential ELSCI concerns which will be discussed in later sections. If such measures are implemented, the XYZ Matrix would reflect this by shifting the developmental stage of tDCS (Y-axis) back to "Market entry (with restriction) stage."

3. Results

3.1. Technical analysis

3.1.1. Product configuration

The construction of the device is relatively simple. A pair of electrodes, an anode and a cathode, are connected to a current source that generates a constant current to flow between them. This current, ranging from 1 to 2 mA, passes through the electrodes placed on the head, travels through the scalp, and into specific areas of the brain. The mechanism of tDCS involves increased activity in brain regions under the positive pole (+) and decreased activity in regions under the negative pole (-). Although the precise scientific mechanism behind this effect is not fully understood, a common theory suggests that the polarization induced by tDCS affects the cell membranes of neurons in the cortical areas, altering the threshold for action potentials and making them either more or less likely to occur. Before 2015, multichannel systems with pairs of electrodes, primarily positive and negative poles, became the standard. Depending on the type of current used for stimulation, there are several forms of transcranial stimulation: transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS), and transcranial random noise stimulation (tRNS).

In South Korea, two products have been licensed for medical use, and similar products are available for purchase online through platforms such as Amazon in the United States. In Japan, tDCS devices have not been approved as medical devices by the Ministry of Health, Labour and

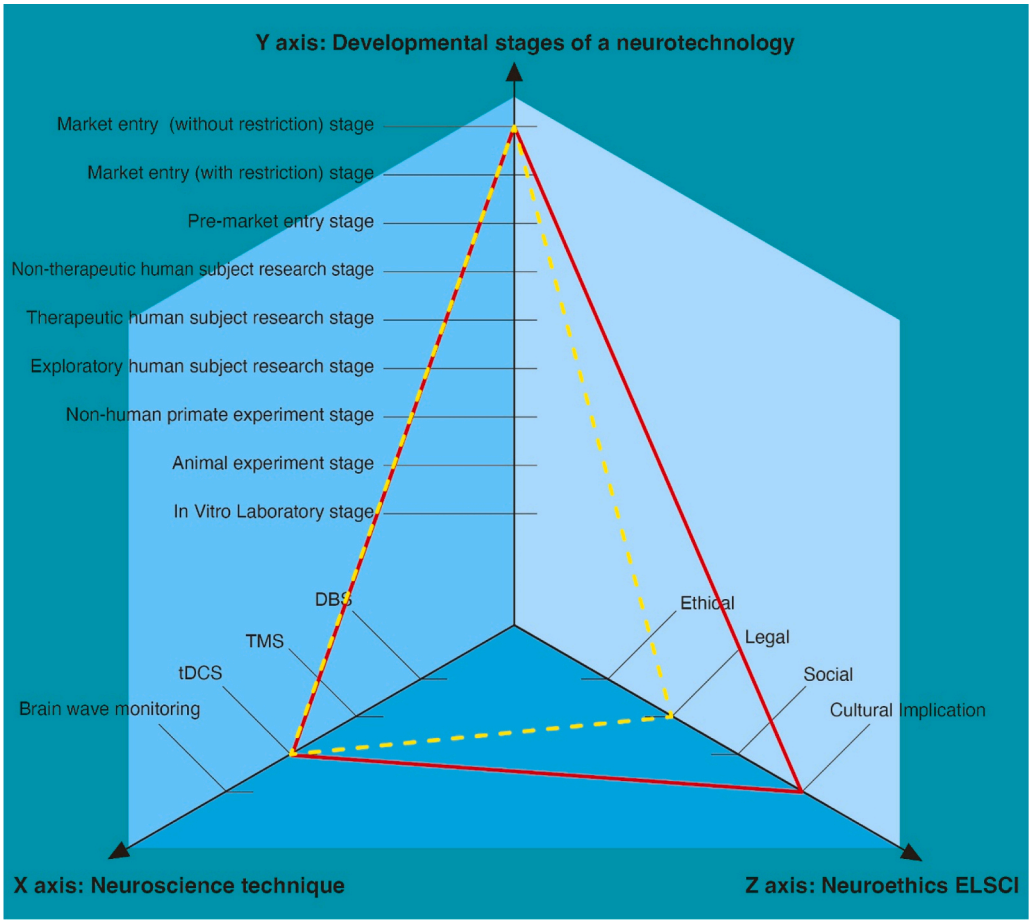


Fig. 2. An illustration of the XYZ Matrix Approach. The X axis represents a specific target neurotechnology, tDCS. The Y axis indicates the maturity of tDCS, market entry without restriction stage. The Z axis represents the four areas of the investigation, including ethical, legal, social, and cultural implications of a target technology, tDCS.

Welfare and are sold exclusively for research purposes. Similar to the situation in South Korea, cases of purchasing tDCS devices through direct sales platforms such as Amazon and using them for enhancement purposes have become noticeable. This trend, known as "brain zapping," has raised alarms about the casual use of neuromodulation technologies. NHK, a Japanese broadcaster, aired a program on Close-Up Gendai titled "Quick Recovery and Power-Up!? The Attention on Slight Electric Currents." (2019) The program highlighted the use of tDCS for enhancement in sports, raising concerns such as "widespread use without regulation is becoming an issue" and "its effects should be carefully assessed." Following this report, the Japanese Society of Clinical Neurophysiology issued a warning regarding the use of tDCS (Japanese Society of Clinical Neurophysiology, 2019a).

3.1.2. Accessibility and costs

tDCS devices are currently available for purchase through various online retailers, making them easily accessible to consumers. The low current levels used (typically 1–2 mA) make tDCS appear less intimidating than stronger electroconvulsive therapies, while its relatively low cost increases its appeal. Fully manufactured devices can cost up to $400, though many prefabricated options are available for under $100. These devices are often designed as portable headbands, enhancing ease of use. The presence of numerous tDCS device companies in the market is likely due to the relatively low technical barriers to entry—these devices can be built with undergraduate-level engineering skills. In addition to commercially available products, tDCS is also accessible in do-it-yourself (DIY) form. DIY tDCS typically refers to home-built devices powered by dry cell batteries, assembled using instructions shared on online forums (e.g., Reddit tDCS, https://www.reddit.com/r/tDCS/ (Accessed June 25, 2025)) and platforms like YouTube.

3.1.3. Effects

The use of low currents (1–2 mA) initially led some to suspect that the current would flow along the scalp rather than penetrating the brain. However, this suspicion was dispelled when Marom Bikson at the City University of New York used MRI imaging to demonstrate that transcranial direct current stimulation (tDCS) does indeed cause current to flow inside the head. (Datta et al., 2008). Numerous published studies confirmed this effect. For example, in 2013, a team of researchers from the University of Oxford observed improvements in math computation skills after stimulating the frontal lobe of participants with random noise electricity (Snowball et al., 2013). The results indicated that most people in the experimental group showed enhanced computational skills after the treatment, with effects lasting up to six months.

Additionally, a 2004 study by Lisa Marshall at the University of Lübeck reported that 20 min of electrical stimulation to the frontal lobe improved and maintained memory performance for periods ranging from two to three hours to as long as one week (Marshall et al., 2004). Marshall's research on sleep also revealed that electrical stimulation of the frontal lobe, which is crucial for memory consolidation, increased activity during sleep. Other studies have shown that electrical stimulation can affect decision-making, improve impulse control, enhance intuition, and boost both working memory and episodic memory.

The effects of tDCS are typically assessed by comparing an active stimulation session with a sham (control) session. In most cases, sham tDCS involves delivering a brief period of active stimulation at the beginning of the session (e.g., 10 s at 0.1 mA (Huey et al., 2007), 120 s at 1 mA (Axelrod et al., 2015)), followed by no stimulation for the remainder of the session, matching the total duration of the active condition (Fonteneau et al., 2019). It is generally assumed that sham stimulation controls for any effects not directly attributable to cortical stimulation (Fonteneau et al., 2019).

3.2. Ethical analysis

3.2.1. Safety

While tDCS is perceived to be relatively safe due to the low intensity of the current applied to the scalp, research has indicated that prolonged brain stimulation can pose several health risks. The most common side effects of tDCS are skin-related issues, such as burning or itching sensations under the electrodes (Brunoni et al., 2011). However, according to Nitsche et al.(2008), electrical brain stimulation can also cause ① tissue damage, ② electrochemically generated toxins, ③ generation of electrode dissolution products ④ skin damage through electron current density, ⑤ deposition of charge and electrolysis, modification of proteins and amino acids in brain tissue, ⑥ damage to vulnerable parts of the brain (e.g., skull defect, foramina, open fontanels, fissures in infants), and ⑦ neurological disorders (e.g., epilepsy, acute eczema, epileptic seizures) Additionally, Sellers et al. (2015) investigated whether tDCS affects standardized intelligence quotient (IQ) tests and found that the technique actually lowered IQ scores. These findings suggest that tDCS may not be entirely safe. Nevertheless, companies selling tDCS may exaggerate its effects and downplay potential side effects to promote their products and increase the sales of the products before the full range of risks associated with tDCS is understood. For example, a transcranial electrical stimulator marketed in South Korea as a comb was featured in a video advertisement suggesting the effects of scalp stimulation without providing substantial information (Lifestyle mart, https://lifestylemart.kr/product/감정케어-마음치료기/1404/(Accessed June 25, 2025)).

3.2.1.1. Lack of side effect data on long-term use. Currently, there are very few longitudinal observational studies examining whether negative outcomes, such as brain damage, occur in people who use the device for an extended period of times. Even if negative outcomes are observed, it would be difficult to prove whether they are caused by tDCS or not. Although device companies, such as Soterix Medical (2020), have been granted an investigational device exemption by the FDA and have conducted large-scale depression-related clinical trials in the U.S., it is still challenging to find reliable studies of a similar scale for enhancement purposes outside of a clinical context. Currently, several companies in Korea sell transcranial electrical stimulators in the form of wearable devices, such as the "XXX Sole". These devices are marketed for mood stabilization, migraine or insomnia relief, and other purposes, but there is still very little information available on their safety and effectiveness. Even the most well-known company, Y brain, lacks sufficient evidence on the safety and effectiveness of its products. For example, its 2022 clinical trial, which reported the efficacy of its device on depression, was conducted with only 65 patients (An, 2022).

3.2.1.2. Concerns about consumer assembly use. Another concern regarding tDCS is the use of DIY products. In South Korea and Japan, medical devices must be licensed as medical devices to be used for treatment in hospitals. Generally, before these devices enter the consumer market, their intensity is reduced or adjusted so they can be safely used by the general public. Product Liability Act is a law that defines the responsibility of manufacturers to ensure product safety for commercially available goods. Its purpose is to protect consumers from harm caused by defective products by holding manufacturers legally liable for any damage to life, body, or property. Similar laws are in force both in South Korea and Japan (South Korea: Product Liability Act, Act No. 14764, Apr. 18, 2017; Japan: Product Liability Act, Act No. 85 of July 1, 1994). In contrast, tDCS was initially released as a DIY product that could be purchased and assembled before it was licensed as a medical device (Jwa, 2015). This was a strategy to reduce people's fear of strong electroconvulsive therapy by promoting the "low current of 1 mA" used

in tDCS. However, when the quality of the finished product is outside the control of the company or regulatory oversight, safety issues can arise. These issues become particularly concerning if consumers do not use the product at a consistent current intensity or use it for purposes other than those indicated. To date, this has not been a significant issue, likely because most DIY users pay close attention to safety (Jwa, 2015; Wexler, 2018). Nonetheless, there is still a risk that some individuals may modify the device to produce higher stimulation or attempt to bypass the time limit. It is also difficult to predict what side effects might occur if the anode and cathode positions are reversed or if different regions of the brain are stimulated.

3.2.2. Effectiveness

Some studies have produced inconsistent results, with working memory improving or deteriorating regardless of current flow or stimulus location (Berryhill et al., 2014), and others have failed to replicate or extend the effects of tDCS on response inhibition. In 2015, Hovarth and colleagues reported that existing studies on healthy volunteers showed little to no reliable neurophysiologic effects of tDCS (Horvath et al., 2015a). In another 2015 paper, Hovarth and colleagues analyzed 53 research papers that reported effects of a single transcranial electrical stimulation on executive function, language, memory, and other domains, and found a surprising lack of statistically significant results in all four outcome measures (Horvath et al., 2015b.). Papers have been published refuting Horvath et al.'s analysis (Antal et al., 2015; Price et al., 2015) and rebuttals to these criticisms have also been published (Horvath, 2015), indicating that the controversy is ongoing. A fundamental reason for the discrepancies between these findings is a lack of understanding of the underlying mechanisms of how tDCS works in the brain (Giordano et al., 2017). For example, the dose-response relationship of transcranial DC stimulation is still not well understood, making it unclear which level of current strength would have the greatest effect. Moreover, even if the current reaches the brain through the skull, differences in the electrical conductivity of cerebral spinal fluid (CSF), gray matter, and white matter could cause significant deviation of current from the intended cortical path between the electrodes (Jwa et al., 2023a). Multi-modal experiments, such as concurrent tDCS-fMRI, are increasingly used to investigate stimulation-induced changes in brain function. However, these approaches face both technical and theoretical challenges that contribute to inconsistent and variable findings, raising concerns about the replicability and interpretability of results (Ekhtiari et al., 2022). In light of these issues, it can be argued that tDCS has reached a point where the initial hype has begun to diminish, surpassing the peak of inflated expectations for its effectiveness (Gartner, gartner.com (Accessed June 25, 2025)). Initial hype refers to the excessive expectations placed on new technology upon its emergence. This hype often transitions into disappointment regarding the technology's effectiveness in the next phase. However, this process can also be seen as a step toward more measured and realistic societal acceptance of new technology. In fact, among the Amazon review comments, alongside reviews claiming the effectiveness of the product, there are also comments expressing disappointment due to the lack of the expected results. Also although in a North American survey of tDCS users, approximately 40 % reported that the devices were effective for their intended use (Jwa, 2015; Wexler, 2018), a significant proportion of users were either unsure of the effectiveness of tDCS or found it to be ineffective, with approximately one-third of users reporting discontinuing use due to ineffectiveness (Wexler, 2020). Given the current lack of scientifically proven effectiveness, many consumers may struggle to verify the validity of the claims made about these devices and could be easily influenced by marketing hype. Variability in tDCS effects across individuals may stem from inter-individual differences in current flow direction—even with standard electrode montages—due to anatomical variations in brain struc1ture (Evans et al., 2022). Therefore, further research is necessary to better understand the precise neurophysiological mechanisms of this technology and to develop more optimized experimental designs and protocols.

3.2.3. Fairness

Humans have long competed to achieve higher status, wealth, and fame. The hallmark of these competitions is that there will always be a winner and a loser – the winner takes high status, great wealth, and fame, so many people aspire to win. Competitions typically have certain fair rules that are enforced among competitors. If participants follow these rules, the competition is fair. However, if someone intentionally breaks the rules to gain an advantage, this behavior is called cheating (Green, 2004) (Korean: trickery + cheating, In Japanese, the word "cheat" is used as "chi-to," adopting the English term with a Japanese accent.). Should using tDCS in a competition be considered cheating?

Cheating with tDCS can occur in sports, for example, using tDCS to enhance one's performance just before a sporting event is often referred to as "neuro-doping" or "brain doping". The prerequisites for cheating are: 1) gaining an unfair advantage in competition and 2) intentionally breaking the rules (Green, 2004). If an athlete secretly uses tDCS without disclosing it, they implicitly recognize that their behavior may be unfair. Since other athletes may not even know the extent of tDCS' s effects, let alone use it themselves, it can be argued that an athlete using tDCS in secret may be cheating.

However, in almost all sports, there are no guidelines or regulations on the use of tDCS. What would happen if sports organizations did want to regulate the use of tDCS? They would have two options. The first option is to allow all athletes to use tDCS, much like allowing the consumption of caffeine. The rationale for this argument comes from the fact that various technologies are already used legitimately in competition. For example, many athletes use customized running shoes for specific sports or use hyperbaric oxygen therapy to improve their cardiopulmonary function. However, organizations like the World Anti-Doping Agency have banned many of these performance-enhancing methods, labeling them as doping. Steroids, for instance, are banned not only because they artificially enhance performance, but also due to their negative impact on athletes' health and lives. Yet, some enhancements are banned even if they aren't harmful. For example, technical full-body swimsuits have been banned in swimming competitions because they can significantly improve performance.

The second option is to ban the use of tDCS in swimming competitions, just as performance swimsuits are banned. Typically, enhancements are banned if they compromise safety or significantly improve performance. Unlike steroids, tDCS has not been shown to severely harm health, and the extent to which it benefits performance is still uncertain. Therefore, safety and effectiveness may not be reasonable grounds for banning tDCS in competitive sports. Despite this, many people intuitively feel that using tDCS is unfair, often referring to it as neuro-doping or brain doping (Petersen et al., 2021). Regardless of its safety and effectiveness, they consider the use of tDCS is cheating. The U.S. President's Council on Bioethics points out that sports competitions are not only about competing against other athletes, but also about competing against oneself (The President's Council on Bioethics, 2003). In sports, breaking a record is highly valued because it signifies a victory against oneself, regardless of whether one wins against others. However, using tDCS may be considered cheating because it can artificially enhance performance, regardless of natural talent or effort. Sports are not just about competing with others to achieve high status, fame, and fortune; they also showcase one's talents and hard work. The purpose of sports is to demonstrate more sophisticated and superior physical abilities than in previous competitions. If the sole purpose of using tDCS is to gain an advantage over others, then its use contradicts the ethos of sports, which values integrity and the demonstration of true excellence. Behavior consistent with the ethos of a sport is an implicit rule that all athletes are expected to follow, even if not explicitly stated. In this respect, using tDCS in competitive sports is morally problematic.

E-sports may also represent a context in which the "cheating" meme is likely to emerge. As in traditional sports, the use of tDCS in e-sports

could enhance attention, reaction time, or decision-making, potentially improving performance. However, because doping remains relatively underdiscussed and less regulated in e-sports compared to traditional sports (Richardson, 2024), the use of tDCS to gain a competitive edge raises additional concerns about fairness and oversight.

tDCS can be used not only in sports but also in other areas of life, given that it is readily available on the market without a prescription. The question arises: is it cheating to use tDCS to excel in a test or perform well at work? Goodman (2010) proposed two variables that can determine whether enhancement with drugs constitutes cheating. These variables can also be applied to the use of tDCS.

First, whether the activity being enhanced is a zero-sum or non-zero-sum game plays a role in determining if tDCS use is considered cheating. In a zero-sum game, there is a clear winner and a loser, with wealth, status, fame, and power distributed based on the outcome. In such cases, any outside intervention that might affect the result could be seen as cheating. For example, using tDCS to improve computational skills just before a math test would be considered cheating, as the test is a relative assessment compared to others. Conversely, if the activity being enhanced is a non-zero-sum game where the outcome does not exclude others from benefiting, using tDCS might not be considered cheating. For instance, using tDCS to solve a math problem not related to the test does not create a competitive disadvantage for other students, thus not qualifying as cheating.

The second variable is whether the use of tDCS is acceptable based on whether greater value is derived from the outcome or the process itself (Goodman, 2010). For example, if a scientist uses tDCS to enhance their research and produces results that benefit humanity, the enhancement might be considered acceptable, even within a competitive research environment. This is because the benefit to humanity outweighs the disadvantage experienced by other scientists in the competition. In contrast, some activities are valued not just for their outcomes but for the process itself. For example, a mountaineer might choose to climb a mountain on foot rather than take a jet, valuing the experience of climbing over the outcome of reaching the summit (Cole-Tuner, 1998). Therefore, if using tDCS undermines the value derived from the process, then the use of tDCS can be problematic. This is because once you stop getting great value from the task or activity itself, the point of doing the task or activity itself is lost. Consider a hypothetical scenario where a person plays Go, and tDCS enables them to perform at a high level without cognitive efforts. Even if the result of using tDCS is good (whether the opponent is an AI or a human), it is unlikely that he is playing for the true value of Go. Here the player is not consciously learning the value of Go by thinking deeply about what moves to make in a particular situation and what strategies and tactics to deploy depending on the opponent, but is simply playing mechanically for the sake of winning or the rewards that come with winning - wealth, fame, status, etc. If tDCS reinforces this approach, then the person may not need to play Go, because there are many other activities where winning is more rewarding. If he still wants to play, he will have to choose to learn the true values of Go without using tDCS.

3.3. Legal analysis

The guidelines for evaluating brain electrical stimulation devices issued by the Korean Ministry of Food and Drug Safety (MFDS) in 2015 focus solely on therapeutic use in clinical settings. These guidelines do not address the issue of tDCS being marketed and used for various non-clinical purposes. Few years later, Subcommittee on Brain Stimulation which has belonged to the Japanese Society of Clinical Neurophysiology issued the “Guidelines on the Safety of Low-Intensity Transcranial Electrical Stimulation (tES)” (2019b). Similar to South Korea, these guidelines focus on the use of tES in research. However, they also include a section titled “Self-Treatment and Amateur Therapy,” which states: “There have been reports of cognitive decline associated with the use of commercially available tDCS devices, indicating that the effectiveness of these devices has not been sufficiently scientifically verified. The International Federation of Clinical Neurophysiology has issued a caution against the use of such devices and protocols unless both their effectiveness and safety have been demonstrated, and their use is not recommended” (Guidelines on the Safety of Low-Intensity Transcranial Electrical Stimulation(tES), 2021).

The use of tDCS for non-clinical applications raises safety and fairness concerns, as previously discussed, indicating a need for updated guidelines to address these issues. For instance, companies marketing tDCS for performance enhancement may base their claims on experimental results conducted internally involving elite athletes. These results may be unreliable, as companies often aim to promote their products and achieve quick sales before potential risks are widely recognized by the public.

The World Anti-Doping Agency (WADA) and the Korea Anti-Doping Agency(KADA) operate anti-doping programs designed to "protect the health of athletes and provide opportunities for athletes to pursue human excellence without the use of prohibited substances and prohibited methods"(KADA, 2022). These agencies prioritize athletes' health in sports. While the risks associated with tDCS are relatively small compared to drugs like steroids, they still exist, particularly with the uncertainty surrounding long-term use. In addition, sports such as archery and shooting require precise steadiness, and tDCS may help reduce cramps and nervous tension, aiding athletes in maintaining focus (Tang et al., 2008). However, if some athletes use tDCS to gain an unfair advantage, opponents might question the legitimacy of such victories. Many may consider the use of tDCS as a form of doping. Therefore, tDCS should be included in the list of banned substances by WADA, as it can serve as an alternative to traditional doping methods. Such concerns align closely with previous ethical analyses discussing whether organizations like WADA should explicitly regulate or prohibit the use of tDCS in competitive sports contexts (Pugh and Pugh, 2021).

Beyond sports, the use of tDCS in everyday healthcare should be regulated to prevent misleading advertising that exaggerates its effectiveness. In Korea, exaggeratedly labeling or advertising a product that is not a medical device but is misleadingly perceived to have similar performance, efficacy, or effectiveness as a medical device can be regulated under the Medical Devices Act (Paragraphs 1 and 2 of Article 26 of the Medical Devices Act). In addition, the Act on Fair Labeling and Advertising prohibits deceptive or misleading advertising and imposes penalties, including imprisonment or fines, for such practices (Articles 3 and 17). In Japan, regulations are also in place under the Act on Securing Quality, Efficacy and Safety of Products Including Pharmaceuticals and Medical Devices (Pharmaceuticals and Medical Devices Act). Article 68 stipulates that “No person shall advertise matters related to Article 14, Paragraph 1, or Article 23,” thereby prohibiting advertisements about the name, manufacturing methods, efficacy, effects, or performance of pharmaceuticals, medical devices, or regenerative medicine products prior to their approval.

4. Sociocultural analysis

In the cultural dimension, the non-clinical use of tDCS could lead to a prevailing social interest in improving brain health within the cultural climate. In the late 20th century, the United States saw a cultural shift towards enhancing brain health through meditation, diet, and exercise (Vidal et al., 2020). This period also embraced the notion that psychoactive drugs could chemically alter the brain to improve performance and foster personal transformation (Vidal et al., 2020). This cultural context helps explain the personal use of tDCS in North America. Some individuals believe they can achieve their goals or solve problems by using electrical stimulation to modify their brains, similar to how they might use psychotropic drugs for brain enhancement. Many see tDCS as a tool for self-improvement that can be used independently, without the need for external guidance. Studies on DIY or personal use of tDCS outside of clinical settings in North America reveal that these devices are

primarily used by younger individuals, aged 20–40, who are early adopters of new technologies and often engage with scientific literature, for various purposes, including simple therapeutic uses, cognitive enhancement, or curiosity (Jwa, 2015; Wexler, 2018). Since its inception in 2011, a US-based website dedicated to sharing information about tDCS devices has grown to over 18,000 members (Reddit tDCS, https://www.reddit.com/r/tDCS/ (Accessed June 25, 2025)).

In South Korea, tDCS is discussed in online communities focused on incurable diseases on major portal sites like DAUM (www.daum.net) and NAVER (www.naver.com) since the late 2010s. These discussions often involve inquiries about using tDCS to treat conditions such as tinnitus, fibromyalgia, depression, ADHD, tics, Parkinson's disease, and the aftermath of brain lesions like strokes. Though non-therapeutic uses of tDCS are still relatively rare, foreign media reports highlighting its potential benefits, such as improving memory among elderly population, alleviating insomnia, reversing fatigue, and enhancing performance, have sparked interest among online communities, with some expressing a willingness to try tDCS despite concerns about its cost. Given its lower side effects compared to other neuromodulation techniques and the possibility of DIY administration, tDCS might see increased use in Korea if its cost decreases.

However, it remains uncertain whether personal use of tDCS in Korea will evolve into independent online communities akin to those in North America. The cultural context of psychoactive drug use in North America and Korea provides some insight. In North America, individualism fosters a belief that people have the freedom to choose their actions independently, while also being fully responsible for their outcomes (Vidal et al., 2020). This perspective extends to the use of psychoactive drugs or tDCS, where individuals believe they can shape their personality and abilities without complete reliance on societal or external influences.

In South Korea, on the other hand, collectivism and risk aversion are significantly stronger compared to North America (Hofstede, 2011; Hofstede Insight, www.hofstede-insights.com/country/south-korea/(Accessed June 25, 2025)). Koreans often seek to maintain their economic status or social reputation by constantly evaluating their position within their affinity groups. They are keen to understand their relative status compared to others and strive to ensure their choices and behaviors are stable and secure. For instance, many Koreans aspire to secure stable and higher-paying jobs to avoid the risks of poverty and declining status, aiming to be perceived as superior. The path to achieving these goals is typically defined by meritocratic competition through education and exams (Kim, 2022). In South Korea, there is a strong belief that meritocratic competition is the fairest method for determining rewards and status, given the historical role of exams in selecting elites (Kim, 2022).

In this cultural context, it is essential to do whatever it takes to succeed in exams. Traditionally, Koreans have used nutrient-rich foods, dietary supplements, and herbal medicines to enhance performance during exam preparation. Recently, Western influences have led to an increase in the use of pharmaceutical enhancements. Reports indicate that individuals have used propranolol to reduce anxiety for job interviews or steroids to boost performance in physical fitness tests for police recruitment (Oh, 2022; Lee et al., 2013). This trend, seen in the West as well, tends to spread more rapidly in Korea due to its strong collectivist culture and "ppalli ppalli" (taste of haste) mentality.

In the same vein, tDCS might be used to improve test performance and gain a competitive edge. In South Korea, tDCS is primarily prescribed for conditions like depression and migraines, but its users also include adolescents dealing with anxiety and stress related to academic performance, as well as professionals seeking to excel in their careers (Min, 2022). Thus, tDCS can be seen as an appealing tool for enhancing performance in competitive contexts.

Japanese society, like South Korea, is characterized by collectivism and a strong emphasis on risk aversion. However, Japan appears to differ slightly in that, in recent years, fewer citizens seem to place significant importance on meritocratic competition. Meritocratic competition, such as preparing for difficult entrance exams to get into good middle schools or studying hard to enter prestigious universities, certainly exists in Japan. However, interest in such competition is often confined to certain social classes, creating a gap with other classes that are less interested in meritocratic competition. There is also a growing tendency to value individual lifestyles and enjoy life. In this context, the rationale for using tDCS may shift from "winning competitions" to entertainment purposes, such as "experiencing better sensations.

5. Discussions

Previous studies have critically analyzed the ethical issues surrounding non-invasive brain stimulation for enhancement purposes (Hamilton et al., 2011; Levy et al., 2014; Lavazza, 2017), but relatively a few have addressed issues specifically related to tDCS (Lavazza, 2017; Pustovrh, (2014) except Riggall et al. (2015)'s work that have noted significant ethical concerns about the use of tDCS and emphasized the need for enhanced dialogue between scientists and ethicists to address such issues effectively. The relative lack of tDCS-specific analysis would probably stem from the assumption that the ethical issues associated with brain stimulation technologies are broadly similar, regardless of the specific technology used, as long as it consistently enhances nervous system and behavior.

In contrast, this study focused on the unique technical characteristics of tDCS, such as its ease of access and use - including DIY products - and its portability, which distinguishes it from other non-invasive brain stimulation technologies. The study examines the specific ethical, legal, and sociocultural issues that arise when these characteristics intersect with the maturity of tDCS technology, particularly its unregulated market presence. For instance, tDCS devices marketed without mandatory clinical trials raise concerns about safety and effectiveness due to inadequate testing. Despite this, companies often promote their devices with incomplete or misleading information, which can lead to deceptive advertising claims.

Furthermore, if tDCS devices become widely available without thorough ethical and sociocultural review, their use for enhancement purposes in competitive environments could be seen as unfair. This concern is particularly relevant in highly competitive societies like South Korea and Japan, where tDCS might be used to gain an edge in academic and professional competitions. It can be said that competitive situations, such as university entrance exams, could also potentially become significant issues. However, current laws and regulations lack specific provisions to address these issues related to tDCS enhancement.

Additionally, some previous studies have focused more on the ethical and social impacts of tDCS rather than on the legal and cultural aspects (Pustovrh, 2014; Voarino et al., 2017). Others have reviewed only the technical and ethical aspects of tDCS and then argued what laws or policies should be established based on them. (Wexler, 2016; Maslen et al., 2015; Fregni et al., 2015; Fitz, Reiner, 2015). These approaches often overlook the broader implications of tDCS technology, which interact with legal, societal, and cultural factors. To address this issue, this study employs the Integration Workflow and XYZ matrix approach to comprehensively examine the technical, ethical, legal, social, and cultural aspects of tDCS, considering how each dimension influences and is influenced by the others. The authors collaborated across disciplines, using the Integration Workflow to explore the ripple effects of tDCS use in South Korean society from multiple perspectives. For example, fairness issues in ethics prompt legal considerations for guidelines, while sociocultural aspects reveal new concerns such as hype and reckless use in competitive settings. The results indicate that issues across different domains are closely interconnected.

For the purposes of this study, we narrowed down the scope of our analysis to the issues most critically relevant to tDCS. For example, we excluded the discussion on whether tDCS affects the user's autonomy or authenticity (Schermer, 2015; Shin et al., 2020), as tDCS does not lead to

or produce the perception of a new self that is completely distinct from the old self. While the discussion could be expanded to other types of neuromodulation technologies, including invasive techniques such as deep brain stimulation (DBS), which is known to be able to affect a person's personality and identity, we have attempted to limit the discussion to issues specific to tDCS. In addition, our analysis did not address issues that are not yet impending given the current state of art tDCS technology, but may become problematic in the future. For example, some studies have reported that tDCS affects concepts of distributive justice and fairness (Knoch et al., 2006; Knoch et al., 2008; Ruff et al., 2013; Strang et al., 2015). As research progresses, there may be possibilities for combining tDCS with other methods for moral enhancement to strengthen human morality. Another limitation of this study is that it is a qualitative case study and does not include quantitative analysis. More specifically, due to the scarcity of data on the safety of tDCS when used for enhancement purposes, we could not quantitatively assess the balance of harm and benefit. Moreover, some of the issues discussed remain speculative and require further testing through rigorous experimental models and social survey research.

6. Conclusion

Despite its limitations as a qualitative study, which does not fully account for future technological advancements, it offers valuable insights for scientists and policymakers by addressing some of the critical ethical, legal, social, and cultural issues given the current state of tDCS technology. First, although there is no evidence that the harms of tDCS are severe enough to warrant strict regulation of its use for enhancement purposes, scientists should continue to conduct relevant research to provide consumers with detailed and accurate information about the enhancing effects and side effects of tDCS. Second, policymakers should address not only safety concerns but also issues related to fairness, hype, and misuse in competitive contexts when developing policies for the non-medical use of tDCS. Third, there is an urgent need for collaboration between scientists and policymakers to implement the first and second recommendations. Finally, interdisciplinary research teams focused on neuroethics should facilitate and support this collaboration to ensure well-rounded and informed decision-making.

CRediT authorship contribution statement

Anita S. Jwa: Writing – review & editing, Writing – original draft, Data curation. **Sinu Choi:** Writing – original draft, Investigation, Data curation. **Young-Joon Ryu:** Writing – original draft, Supervision, Project administration, Funding acquisition, Conceptualization. **Eisuke Nakazawa:** Writing – review & editing, Writing – original draft. **Yoshiyuki Takimoto:** Writing – review & editing, Writing – original draft. **Juhee Eom:** Writing – original draft. **Soojin Kim:** Writing – original draft. **Jiwon Shim:** Writing – original draft.

Acknowledgements

This research was supported by the Bio & Medical Technology Development Program of the National Research Foundation (NRF) funded by the Korean government (MSIT) (NO. 2019M3E5D2A02064496). The authors are particularly grateful to science illustrator MH Kim for drawing the figures included in this paper.

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