The Rising Tide of tDCS in the Media and Academic Literature

Veljko Dubljević,[1,2,*] Victoria Saigle,[1] and Eric Racine[1,2,3,4,*]
[1]Neuroethics Research Unit, Institut de recherches cliniques de Montréal (IRCM), 110 Avenue des Pins Ouest, Montréal, QC H2W 1R7, Canada
[2]Department of Neurology and Neurosurgery, McGill University, 3801 University Street, Montréal, QC H3A 2B4, Canada
[3]Experimental Medicine & Biomedical Ethics Unit, McGill University, 1110 Avenue des Pins Ouest, Montréal, QC H3A 1A3, Canada
[4]Department of Medicine and Department of Social and Preventive Medicine, Université de Montréal, 2900, boul. Édouard-Montpetit, Montréal, QC H3T 1J4, Canada
*Correspondence: veljko.dubljevic@ircm.qc.ca (V.D.), eric.racine@ircm.qc.ca (E.R.)
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Academic and public interest in tDCS has been fueled by strong claims of therapeutic and enhancement effects. We report a rising tide of tDCS coverage in the media, while regulatory action is lacking and ethical issues need to be addressed.

Introduction

Neurostimulation has a long history of attracting academic and public attention. The Egyptians knew about the electric properties of catfish (Finger, 1994), but it is unclear if (and how) they experimented with them for clinical purposes. Both Plato and Aristotle described the ability of the torpedo fish to generate numbing effects via its electric discharge (Finger, 1994). Later writings from Scribonius Largus, Pliny the Elder, and Galen of Pergamum detail the use of live torpedo fish to treat headaches (Priori, 2003). The Romans went beyond scholarly interest by cultivating the fish for explicit therapeutic purposes, as evidenced by a frescoed store front that marketed their use to the public in Pompeii (Finger, 1994). Other therapeutic uses of brain stimulation were reported by Ibn-Sidah, an 11th century physician, who suggested using an electric catfish to treat epilepsy (Brunoni et al., 2012). With the advent of electrophysiology in the 1700s, direct current began to be used in clinical settings for the treatment of melancholia (Priori, 2003). These advances drew significant public interest and generated discussion about their philosophical and ethical implications (e.g., Shelley's *Frankenstein*).

Principles of Neurostimulation

Early interventions involving electrical stimulation of the brain used direct current (DC) (as opposed to alternating current [AC] or magnetic fields, which were both introduced toward the end of 19th century). Ancient therapeutic practices as bizarre as applying a live torpedo fish to the scalp to cure headaches could thus qualify as a crude form of transcranial direct current stimulation (tDCS): they were transcranial (as opposed to intracranial), they used DC, and the desired effect was brain stimulation. Modern-day tDCS devices use weak electrical current (0.5–2 mA, such as that provided by a 9 V battery) and at least two electrodes placed on the scalp to facilitate or inhibit spontaneous neuronal activity. Although this effect is poorly understood, it is theorized that tDCS may induce long-term potentiation (LTP), a process thought to contribute to learning (Stagg and Nitsche, 2011). The effects of tDCS seem to be most pronounced when combined with a training paradigm (Hamilton et al., 2011).

It is known that tDCS acts by polarizing the resting membrane potential, the effects of which can last for up to 1 hr (Priori, 2003). Given that tDCS causes a constant electric field that displaces all electrically charged molecules and that most neurotransmitters and receptors in the brain have electrical properties, tDCS might induce prolonged neurochemical changes that are as of yet unknown (see Brunoni et al., 2012). The mechanisms of action of tDCS could involve different synaptic and nonsynaptic effects on neurons, nonneuronal cells (e.g., glia), and tissues within the brain (Brunoni et al., 2012). The long-lasting effects of tDCS may also depend on protein synthesis, since anodal stimulation appears to increase intraneuronal levels of calcium as well as the expression of genes responsible for neurotransmitter receptors (see Stagg and Nitsche, 2011).

Neurostimulation in the Modern Age

In modern times, the persistent challenge of treating complex conditions such as epilepsy, chronic pain, and headaches has served as a catalyst for the development of neurostimulation techniques. The success of electroconvulsive therapy (ECT) as a treatment for psychiatric disorders in the mid-1900s largely pushed techniques using weak electric current out of popular use for several decades (Priori, 2003). However, the public's strongly negative opinion of ECT contributed to the desertion of this technique despite its therapeutic efficacy in the treatment of depression (Lauber et al., 2005). Investigations into weak direct currents returned briefly in the 1960s but were once again abandoned with the rising use of psychopharmaceuticals to treat mental illness (Priori, 2003).

Over the past several decades, neurostimulation techniques have gradually gained favor in the public eye. A surge of interest in invasive (e.g., deep brain stimulation [DBS]) and noninvasive forms of neurostimulation (e.g., transcranial magnetic stimulation [TMS] and transcranial direct current stimulation [tDCS]) has propelled research that examines the therapeutic potential of these techniques. Currently, tDCS is primarily used as an investigative and therapeutic tool

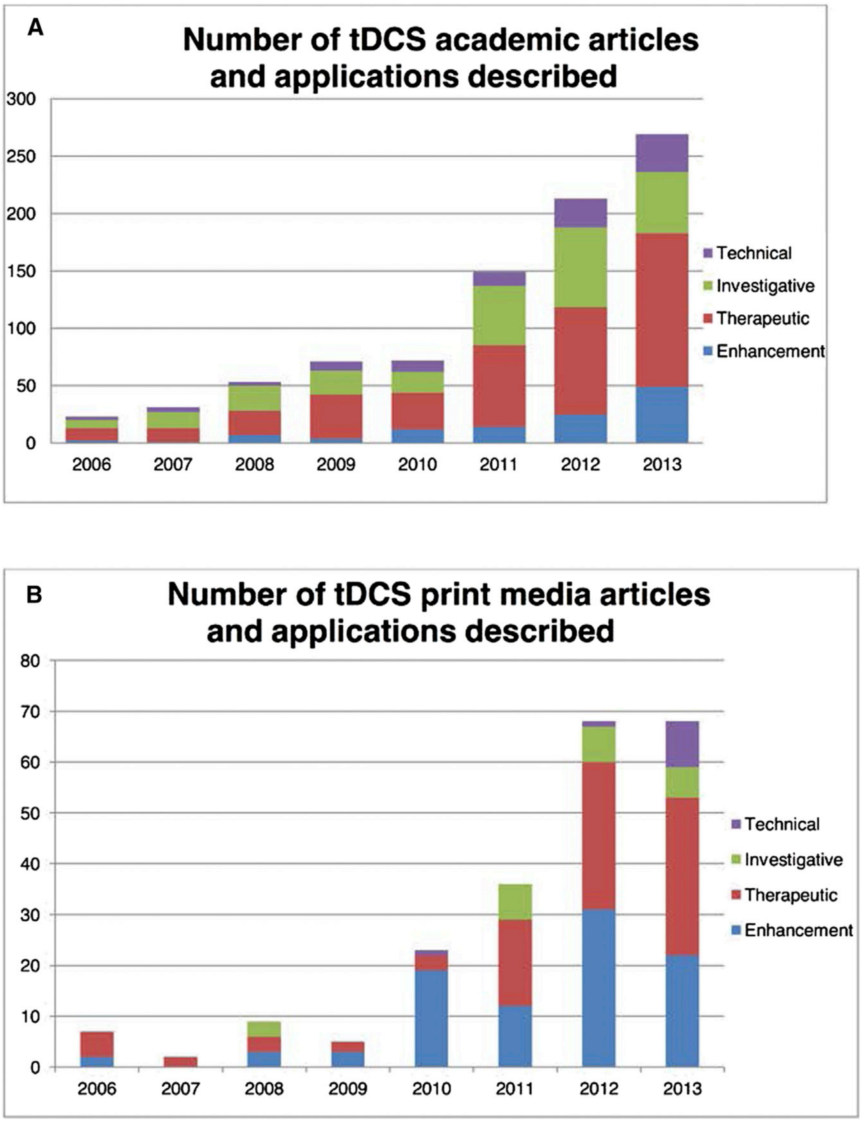

Figure 1. The Increasing Number of Articles on tDCS and Applications Described
The data for 2013 reflect articles published from January 1st to October 1st.

in the context of pain, neurorehabilitation after stroke, and depression (Stagg and Nitsche, 2011). However, tDCS has garnered considerable attention due to its capacity to enhance neurological function (Hamilton et al., 2011). Recently, the technique has caused excitement in the lay public and academia as a ‘‘portable, painless, inexpensive and safe’’ therapeutic and enhancement device (Cohen Kadosh et al., 2012). Yet, despite these claims, the safety and efficacy of tDCS have only been demonstrated in controlled laboratory settings and, without supervision, the use of tDCS for enhancement might cause serious adverse effects such as temporary respiratory paralysis (Brunoni et al., 2012). Thus, the effects of tDCS are hard to predict.

Media coverage of stimulation techniques is now often enthusiastic about the benefits these techniques could yield. For example, media discussions about DBS have been optimistic, with little explicit discussion concerning ethical issues, therapeutic limitations, or side effects that could result from the widespread use of DBS (Racine et al., 2007). Given the nature of tDCS and the lack of oversight governing its use, academic and print media discourse could shape the public’s risk-benefit perceptions, impact the uptake of this technology, and, consequently, lead to negative implications for ethical and regulatory oversight. Indeed, such positive portrayals in the media have been shown to indirectly affect patient understanding and consent for DBS (Bell et al., 2010).

Portrayal of tDCS in the Media

To better assess publically available information and discussions about tDCS, we analyzed academic and print media coverage of this technique. We performed academic literature searches on PubMed using the keywords ‘‘transcranial direct current stimulation’’ OR ‘‘transcranial electrical stimulation’’ OR ‘‘direct current brain polarization’’ and established the relevance of academic papers by analyzing the abstracts. Exclusion criteria included papers without an abstract in English or available full text, detailing techniques other than tDCS, reporting the use of tDCS during surgery or under anesthesia, and unpublished proofs (results: 1,237 retrieved articles; 948 relevant papers). One additional relevant paper that was repeatedly referred to in the literature but not captured in our searches was also included.

We used a similar strategy to search the Factiva database for relevant print media articles (306 retrieved articles; 218 relevant articles). The print media analysis included English language articles that provide information about tDCS to the general public. Exclusion criteria included sources targeting medical professionals, irrelevant article types (e.g., obituaries), and duplicates. Additionally, 18 online-only articles were excluded.

Articles were coded systematically by two independent coders. The coding structure included the identification of (1) the year of publication, (2) type of source (print media or academic), (3) type of tDCS application described (therapeutic, enhancement, technical, or investigative), and (4) overall tone (optimistic, critical, or neutral/balanced). For both academic and print media literature, therapeutic applications referred to the use of tDCS within a patient population to improve their condition, while technical descriptions referred to general information about the technique. Both the

Table 1. Illustrative Examples of Headlines in Print Media Reports on Therapeutic and Enhancement Use of tDCS

Therapeutic Application	Enhancement Application
"Mild jolt for beating blues" (*Hobart Mercury*, February 16, 2006)	"Electrify your mind" (*New Scientist*, April 15, 2006)
"Psychiatry's shocking new tools" (*IEEE Spectrum*, March 1, 2006)	"Little brain zap, big memory boost" (*New Scientist*, August 2010)
"Brain stimulation improves memory in Alzheimer's" (*Reuters News*, August 22, 2008)	"A tiny zap to improve memory" (*The Philadelphia Inquirer*, October 23, 2010)
"Therapies replace electroshock" (*Montreal Gazette*, October 9, 2010)	"Zapping brain boosts math skills" (*Investor's Business Daily*, November 8, 2010)
"Tiny brain shocks may help schizophrenia patients" (*The Conversation*, July 28, 2011)	"Got a problem – put your electrical thinking cap on" (*Guardian Unlimited*, February 2, 2011)
"Electricity zap to brain aids stroke recovery" (*Daily Mail*, September 16, 2011)	"A zap to brain to bring out the genius in you" (*The Press Trust of India*, February 3, 2011)
"Getting a head start" (*The Engineer*, January 23, 2012)	"Electric shock improves academic performance" (*Indo-Asian News Service*, January 26, 2012)
"Brainwave is a breakthrough" (*St George & Sutherland Shire Leader*, March 6, 2012)	"Zen and the art of genius" (*New Scientist*, February 4, 2012)
"Electric zap stops migraines" (*Investor's Business Daily*, May 2, 2012)	"Jump-start your brain" (*Boston Magazine*, June 1, 2012)
"Zap your way out of depression" (*Timaru Herald*, February 14, 2013)	"Spark of Genius" (*Sunday Tribune*, April 7, 2013)

investigative and enhancement descriptions detailed the use of tDCS in healthy populations; enhancement reflects tDCS used specifically to improve some aspect of performance, while investigative refers to all other types of tDCS studies (e.g., on moral judgment).

The Rising Tide of tDCS in the Media and Academic Literature

The amount of information on tDCS available to the public has increased dramatically in recent years in both academic literature and print media articles (Figure 1).

Even though modern uses of tDCS have been reported in peer-reviewed academic literature since 1964, the earliest print media article on this topic we found was published in 2006. This publication date coincides with a substantial increase in volume of academic literature on tDCS and the appearance of several academic papers reporting the therapeutic and enhancement effects of tDCS.

There was a considerable mismatch between the focus in academic and print media articles. The academic articles focused primarily on therapeutic uses of tDCS (n = 428; 45%), followed by investigative uses (n = 297; 31%). Enhancement use was the dominant topic in only 120 articles (13%) and was followed closely in number by technical aspects (n = 104; 11%). In print media articles, discussions surrounding potential enhancement uses of tDCS were the primary focus of 92 (42%), with an equal number (n = 92; 42%) focusing on therapeutic applications of tDCS. These were followed by descriptions of investigative uses (n = 23; 11%) and technical aspects (n = 11; 5%).

The majority of print media headlines were enthusiastic and described tDCS as an "amazing new technique" and only highlighted the potential benefits of tDCS (Table 1). We encountered strong and potentially misleading statements about the real-world effects and applicability of tDCS (e.g., "schoolchildren who struggle to grasp mathematics could benefit from having their brains roused with electricity" [*The Guardian*, April 11, 2010]). In the entire sample of relevant articles, only eight (3.5%) advised caution or mentioned the possibility of adverse effects (Figure 2). The fact that the mechanisms of action of tDCS are unknown and that long-term changes could also include adverse effects were almost never mentioned.

Academic articles, while also enthusiastic, usually involved more balanced discussions. The academic literature also mentioned safety issues, the need for technical improvements, and potential adverse effects from the use of tDCS more frequently than in the print media, where these conversations were largely lacking.

Print media articles sensationalized the capabilities of tDCS (e.g., "tDCS … could improve anything from focus and motor control to moral reasoning. It's simple. It's relatively cheap" [*Sunday Tribune*, July 4, 2013]). In the print media, findings about tDCS were also combined with misconceptions (e.g., "It is a known fact that humans only use 10% of their brain. … with the advancements in technology a person can boost this capacity. By attaching a 9 V battery to the scalp…" [*TopNews*, October 3, 2013]). Therefore, not only was the content reported by the two media types different, but the way in which they reported the information was as well.

Implications of the Rising Tide of tDCS and the Way Forward

Given the rapid evolution of tDCS in the public domain and in academia, tackling its social, ethical, and policy implications requires a multifaceted response. We explore three areas of action.

Increasing Neuroscientific Literacy

The enthusiastic depiction of neuroscientific and neurotechnological advances can generate deep public misunderstandings about the scientific and clinical aspects of these findings (e.g., Racine et al., 2007, 2010). By not measuring (and hence not reporting) the potential detrimental effects of tDCS, experiments reported in academic papers could also bolster the perception that tDCS induces cognitive enhancement. However, it is unclear if such an effect provokes collateral inhibition of other cognitive functions (Iuculano and Cohen Kadosh, 2013). The

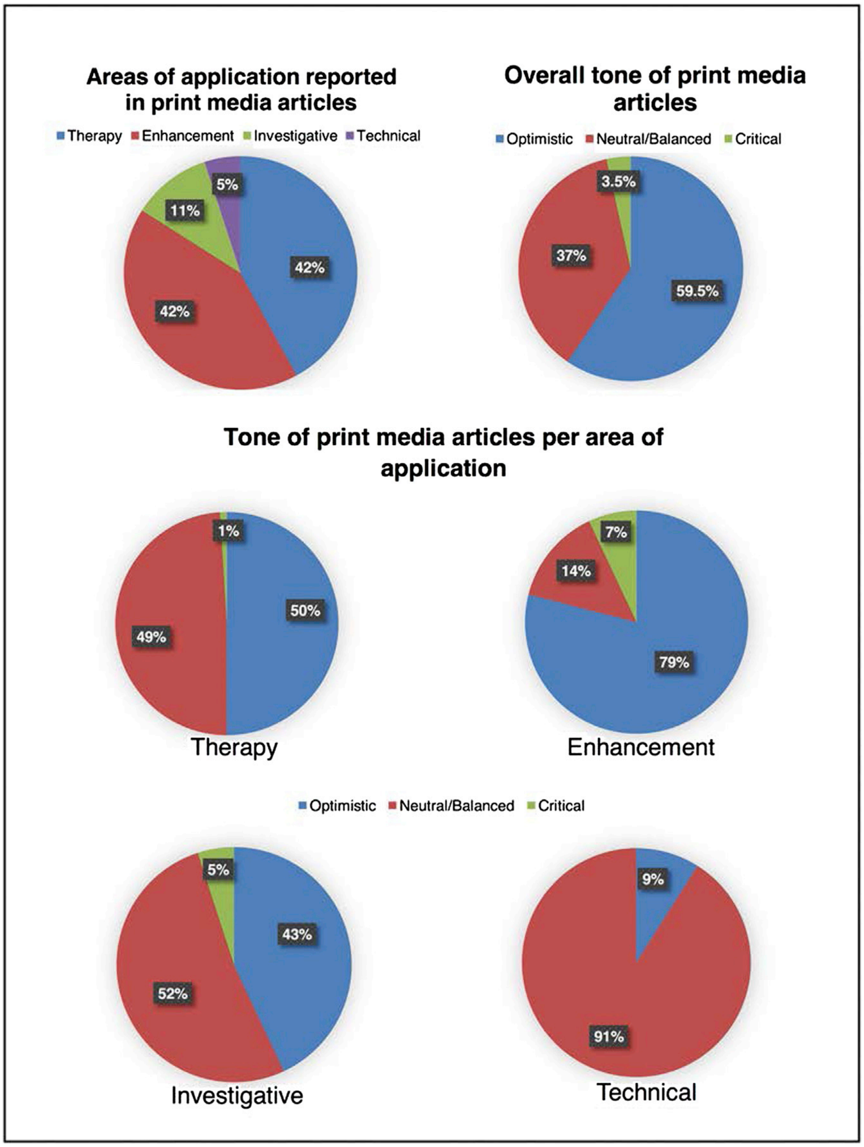

Figure 2. Areas of Application and Tone of tDCS Print Media Articles

belief that the biological mechanism acting behind tDCS is a simple and accessible concept to the layperson, in addition to the long-standing history of using noninvasive current in therapeutic contexts, may increase the public's enthusiasm for and comfort in using this device for enhancement. This, in turn, could lead to a swell in public interest and to the broad use of the technique.

To curtail misunderstandings about tDCS, professional societies and researchers, perhaps in collaboration with academic publishers, could help the public understand the mechanisms, limitations, and genuine therapeutic potential of tDCS. Governmental agencies, such as the NIH, could issue health warnings about tDCS to increase the public's scientific literacy. This information could clarify the mechanism of action of tDCS and potential safety concerns in layman's terms as well as clearly outline the current state of research. Beyond its usefulness for the public, clinicians, and others, this information would serve as a reference to media outlets wishing to discuss tDCS knowledgeably. Additionally, researchers, journalists, and other members of the media who frequently write about scientific topics could receive training concerning how to translate neuroscientific information to the public.

Monitoring and Regulating tDCS Devices

The wide availability of tDCS is a significant issue (Fitz and Reiner, 2013; Bikson et al., 2013; Maslen et al., 2014). While some companies have imposed self-restraint on the sale of this technology (Table 2), such self-regulation does not resolve the issue. Even if tDCS devices as *products* were only sold to physicians, a secondary market for tDCS as a therapeutic and enhancement *service* seems to be on the rise, making the issue of training requirements salient. The most concerning aspect is the virtually omnipresent availability of tDCS as a simple *do-it-yourself gadget*: several websites offer detailed instructions on how to build a tDCS device and where to place electrodes to achieve enhancement (Table 2).

The regulation of medical devices is a complex area where discrepancies between European, North American, and Asian markets create significant challenges by impacting the dissemination and use of these devices internationally. Currently, the regulatory regimes have important blind spots: devices may be designated as "safe" without any review of claims about their effectiveness. Furthermore, manipulating claims about effectiveness might lead to admission of devices by regulatory default (Guleyupoglu et al., 2013). The European Union "CE" (i.e., conformité européenne) mark can be obtained by mere compliance with production standards as long as no medical claims are made in the application. In the U.S., medical claims regarding a device that is "substantially equivalent" to a formerly "cleared" device allow this similar device to be marketed (FDA, 2014). Therefore, producers that claim that tDCS has medical uses are able to do so because similar devices that generate weak electrical currents have been used effectively for rehabilitation of muscle injuries.

Postmarket surveillance is another crucial aspect that falters in its current shape and form even for invasive implantable devices (e.g., DBS). There is currently no consensus on tDCS regulation, though several leading authors have proposed ways to manage devices

Table 2. Examples of the International Availability of tDCS

Country	Webpage	Advertised Application	Targeted Market	Disclaimer/Restrictions in Access
tDCS as a Product				
Germany	http://www.neuroconn.de/dc-stimulator_mc_en/	Investigative	Researchers	No training required
Hong Kong	http://www.trans-cranial.com/	Therapy, enhancement	Unspecified individual users	No training required; world-wide shipping
United States	http://tdcsdevicekit.com/index.php/wholesale-distributors	Therapy, enhancement	Wholesale distributors, unspecified individual users	No training required
Canada	http://www.mindalive.com/Products_OASIS_Pro.htm	Therapy, enhancement	Physicians	Physicians only
United Kingdom and United States	http://www.foc.us/	Enhancement (neurogaming)	Unspecified individual users	No training required; "The foc.us [device] … is not a medical device, and is not regulated by the FDA;" "The headset is not a toy, is not recommended for under 18s, epilepsy sufferers or people with implants."
tDCS as a Service				
United States	http://www.transcranialbrainstimulation.com/	Therapy	Psychiatric and neurological conditions	No disclaimers or restrictions
United Kingdom	http://www.york-biofeedback.co.uk/neurofeedback/tdcs.aspx	Therapy, enhancement	Decrease in symptoms, increase in cognition	Not used on minors
Canada	http://www.drmueller-healthpsychology.com/tDCS.html	Therapy	Depression and chronic pain	No disclaimers or restrictions
tDCS as a Do-It-Yourself Device				
			Presentation Form	
–	http://speakwisdom.wordpress.com/2012/12/09/can-a-simple-safe-tdcs-device-be-built-from-radio-shack-components/	Therapy, enhancement, investigative "tDCS … Swiss Army knife of 21st Century"	Step-by-step tutorial	
–	http://www.youtube.com/watch?v=hgFWEBwT6BE	Therapy, enhancement, investigative	Step-by-step tutorial	
–	http://www.youtube.com/watch?v=h1Y3cpB26lY	Therapy, enhancement, investigative	Commercial presentation quoting scientific studies	

Note: the list found in this table is representative, not exhaustive. All webpages accessed on March 7, 2014.

with enhancement effects by accommodating them within the current regulations for medical devices (Maslen et al., 2014). Most proposals posit that solutions should include the monitoring of adverse events stemming from tDCS in addition to paying closer attention to marketing and manufacturing standards. Simple policy actions could be to make mandatory disclaimers about the current evidence supporting tDCS. Training and licensing procedures should also be considered (Dubljević, 2012).

Supporting Responsive and Ethical Clinical Practice

At this time, raising clinicians' awareness about tDCS as an emerging and largely unregulated device is warranted. Previous clinical responses to other forms of unproven therapies are pillars to build from. In such cases, clinicians must balance the potential benefits of the device with their unknown risks, as well as other implications for users such as the exclusion from prospective clinical trials, financial costs, and clinical follow-up. Clarifying the role of clinicians with respect to enhancement uses of tDCS brings another level of complexity given that such uses raise distinct ethical and social issues that are not well covered by current clinical practice guidelines. The American Academy of Neurology has proposed that physicians have leeway in accepting or declining requests for cognitive enhancement drugs based on their expertise (Larriviere et al., 2009). Although it is encouraging to see a professional society address this issue, this proposal neither provides clear guidance to physicians about what they should do nor is it directly applicable to the distinct issues raised by cognitive enhancement devices.

The use of tDCS in pediatric populations also amplifies the ethical challenges of crafting responsible clinical practice due to the uncertainty of its long-term effects on developing brains. This could call for more protective approaches (as suggested in the context of pediatric use of enhancement drugs, see Graf et al., 2013). Physicians and other clinicians have—up until now—not been actively engaged in tackling ethical, clinical, and policy aspects of tDCS. However, their crucial role in the public eye as knowledgeable and informed advisors for medical decision making calls for their involvement in the clinical aspects of policy responses to tDCS.

In conclusion, the media have enthusiastically reported that tDCS could be used to enhance cognitive function. The current regulatory gap means that tDCS is readily available as a service, product, or even a homemade device, in many countries without any guidance being provided by policy makers. A response to the policy and regulatory aspects of tDCS is urgently needed.

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