



Received: 14 April 2017
Accepted: 22 July 2017
First Published: 28 July 2017

*Corresponding author: Kwangho Park,
Troy University, 610 Elm St. Apt 7, Troy,
AL 36081, USA
E-mail: kp15e@my.fsu.edu

Reviewing editor:
Vassil Girginov, Brunel University, UK

Additional information is available at
the end of the article

SPORT, LEISURE & TOURISM | RESEARCH ARTICLE

Neuro-doping: The rise of another loophole to get around anti-doping policies

Kwangho Park^{1*}

Abstract: The purpose of this study is to provide an overview of the emerging neuro-doping technology and its ability to enhance athletic performance, and to examine the physical and ethical risks associated with the technology. This study also suggests that sports governing bodies charged with anti-doping regulation begin to consider prohibiting the application of electrical stimulus to the brain as a means of physical manipulation aimed at enhancing performance.

Subjects: Law; Sociology of Media; Politics & International Relations; Sports and Leisure; Social Sciences; Health Communication

Keywords: neuro doping; anti-doping policy; transcranial direct-current stimulation; world anti-doping agency

1. Introduction

At present, the World Anti-Doping Agency (WADA), an international anti-doping policy decision-making institution, has banned various means of doping, including drugs, blood, and even gene doping (Davis, 2013). However, an emerging technology that involves electronic stimulus of the brain, and has been dubbed “neuro-doping” (Maney, 2016), is being used as a substitute for existing doping methods that are listed on the WADA’s prohibited list. This method of doping uses Transcranial Direct-Current Stimulation (tDCS), which is a non-invasive, painless brain stimulation treatment or technique that delivers an electrical stimulus to a particular part of the brain (Johns Hopkins Medicine, 2016).

ABOUT THE AUTHOR

Kwangho Park is a doctoral student in the academic field of sport management. He is, at present, working on several studies having to do with the utilization of Virtual Reality (VR) in a sport environment and the use of VR in advertising. This current research is intended to prevent the exploitation of a loophole (related to neuro-doping), which would enable athletes to get around the World Anti-Doping Agency’s anti-doping policy. If this loophole remains, and if it is exploited, it may effectively serve to undermine the integrity of the sports environment. This study can help policy-makers who are a part of anti-doping agencies to better understand the emergence of neuro-doping, and it can assist them in implementing policy that bans this newly emerging means of doping.

PUBLIC INTEREST STATEMENT

There are some athletes who aim to improve their levels of performance quickly so as to take advantage of their rankings or positions within their respective sports. This is why doping has evolved at a fairly constant rate. For this reason, The World Anti-Doping Association (WADA) has worked to prevent doping from ruining the “spirit-of-sports.” However, in 2016, a new doping technology, “neuro-doping,” arose. This technique uses Transcranial Direct-Current Stimulation (tDCS), which is a non-invasive brain stimulation technique that delivers an electrical stimulus to a particular part of the brain, is a potential tool for clinical treatment and may serve as a means of performance enhancement in the context of sports competition. However, tDCS is still in its experimental stage, and may result in safety problems that are as yet unknown; in addition, there are a number of ethical concerns regarding technique.

According to many studies related to the field of neuro-science (Chi & Snyder, 2011; Davis, 2013; Iuculano & Kadosh, 2013; Guardian, 2015), this technique could help increase attention span, enhance memory, and improve cognitive ability, and it could also improve sports performance through a change in brain activity affecting various aspects of mental performance such as “motor learning, enhanced muscular strength or reduced fatigue, or even changes to mental state or concentration” (Davis, 2013, p. 649). However, the effects of this technique are similar to the effects of brain-boosting drugs such as modafinil, methylphenidate, and dextroamphetamine. Those drugs are used illegally and off-label in order to chemically improve athletic performance (Rodenberg & Holden, 2016), and they can affect the moment that determines victory or defeat within top-tier competitions. Consequently, this technique, tDCS, is controversial and is the source of many questions “about the fairness of brain-based performance enhancement” (Maney, 2016) and the ability of such a technique to undermine the integrity of sport competition, which is one of WADA’s core values (WADA, 2017c).

The purpose of this study is to provide an overview of the emerging neuro-doping technology and its ability to enhance athletic performance, and to examine the physical and ethical risks associated with the technology. This study also suggests that sports governing bodies charged with anti-doping regulation begin to consider prohibiting the application of electrical stimulus to the brain as a means of physical manipulation aimed at enhancing performance.

2. Transcranial direct-current stimulation

tDCS is a non-invasive brain stimulation technique that controls cortical activity via tonic stimulation (Davis, 2014; Hunter, Coffman, Trumbo, & Clark, 2013; Nitsche & Paulus, 2011). According to Uncini et al. (2017), Davis (2013), and Nitsche et al. (2008), the principle goal of tDCS is to modulate the excitability of an area of the brain’s cortex using two electrodes (i.e. anode and cathode) to pass a weak electric current of 1–2 mA from a cathode (negative electrode) to an anode (positive electrode) for a period of 3–20 min. Nitsche and Paulus (2000) explained the effect of both cathodal and anodal stimulation by noting that “cerebral excitability was diminished by cathodal stimulation, which hyperpolarizes neurons, and anodal stimulation caused neuronal depolarization, leading to an increase in excitability” (p. 633).

Several researchers have found that tDCS is effective in treating a variety of neurological and psychiatric disorders such as depression, stroke, Parkinson’s disease, and chronic pain (Arul-Anandam & Loo, 2009; Benninger et al., 2010; Fagerlund, Bystad, & Aslaksen, 2013; Loo et al., 2012; Mariano, van’t Wout, Garnaat, Rasmussen, & Greenberg, 2016; Marquez, van Vliet, McElduff, Lagopoulos, & Parsons, 2015; Nowak, Bösl, Podubekà, & Carey, 2010). Moreover, and more pertinent to the current study, this technique possesses a number of features that result in performance enhancement; this will be discussed in greater detail in the next section. A number of researchers and experts in the field of neuroscience, however, have reported that since tDCS is still in its experimental stage, the US Food and Drug Administration (FDA) has not approved the technique as a treatment for any medical indication (Kuersten & Hamilton, 2016; Wexler, 2016). This means that tDCS needs more evidence for practical applications as well as established appropriate stimulation parameters before it can be considered a viable clinical and physical enhancement technique. Despite this, and the fact that “no country has regulated the use of tDCS in clinical practice as an on-label treatment” (Tortella et al., 2015, p. 96), tDCS is still being used illegally as an off-label treatment for the aforementioned disorders.

3. The future of doping: Using tDCS for sports

According to Reardon (2016), the US Ski and Snowboard Association (USSA), and a company that makes a product for improving athletic ability among elite athletes using neuro-technology, are testing whether electronic stimulus to the brain could upgrade national ski-jumpers’ capabilities during performance through a new device worn as a headset. This test concluded that tDCS improves the athletes’ jumping force and their coordination when compared to the force and coordination of the control group (Reardon, 2016).

Further, a number of researchers have concluded that tDCS may potentially serve to enhance performance in sports with varying efficacies, which may appeal to elite athletes. According to Angius, Hopker, Marcora, and Mauger (2015), tDCS reduces exercise-induced pain and improves pedaling time to exhaustion. Similarly, tDCS improved competitive cyclists' maximal exercise performances (Okano et al., 2013). Cogiமானian, Marceglia, Ardolino, Barbieri, and Priori (2007) also demonstrate the ability of tDCS to improve isometric force endurance and decrease pathological conditions and muscle fatigue. With regard to muscle strength, Angius, Pageaux, Hopker, Marcora, and Mauger (2016) and Tanaka et al. (2011) conclude that tDCS could enhance the force of knee extension. Moreover, there is evidence that tDCS can improve certain functions of the brain. It is likely that tDCS allows for quick acquisition and retention of skills in under three months' time (Reis et al., 2009), enhances response time to various sensory reception (Pascual-Leone et al., 1992), and eases tremor suppression (Axford, Lakany, & Conway, 2011). In addition, there is indication that tDCS may give athletes the advantage of more efficient training (Davis, 2013). These functions of the technique may, directly and indirectly, help improve athletes' performance in sports competitions.

It is common for athletes to try performance-enhancing substances that are not banned per the WADA prohibited-substances list (Stewart, Outram, & Smith, 2013). Further, athletes often care little about punitive deterrence, "especially when the motivation for substance use comes from the pursuit of superior performance" (Smith & Stewart, 2015). If tDCS has a complete stimulation parameter, then it might become a new and complete doping technique. And, as a result, athletes who hope to develop their performance in a short time would gravitate toward tDCS as a means of complete doping because they could use it without experiencing the risky side effects associated with physical or chemical doping, and they could use it without violating the regulations implemented by the sport anti-doping governing bodies, WADA or the US Anti-Doping Agency (USADA). However, tDCS has become associated with a number of problems of both a physical and ethical nature, and this might negatively affect the anti-doping agency.

4. tDCS and increasing safety problems

As previously mentioned, tDCS is still in its experimental stage, and the extent of its effects remains unknown. In the field of neuroscience, there has been considerable theoretical evidence attained from laymen (e.g. healthy participants, patients); however, not much evidence has been obtained from elite athletes or sports participants who display high athletic performance (Banissy & Muggleton, 2013). Despite this, the company mentioned above, which makes a product that can improve performance using neuro-technology, is already marketing and selling its new device to elite athletic teams and organizations for their performance enhancement, and the company is basing its marketing on results secured via its own experiments regarding the effect of tDCS on the exercise performance ability of national-level elite athletes (e.g. ski jumpers, NFL players). The company's test results, however, may be lacking in credibility because there may exist a conflict of interest since the company stands to profit from promoting its brand and selling its product quickly before potential and as-yet unknown tDCS-related risks become known. This is worth exploring because the technique of electrically stimulating the brain still does not formally guarantee full safety for athletes in a sports context, and there is the possibility of side effects related to the application of tDCS.

Sellers et al. (2015) examined whether tDCS would affect a standardized intelligence quotient (IQ) test, and the researchers found that the technique had a significant detrimental impact on IQ scores. Moreover, tDCS may result in a number of possible serious risks. Nitsche et al. (2008), a group of well-known neurologists, claimed that electronic brain stimulation is indeed associated with various potential health risks such as (1) tissue damage as a result of pulsed electrical stimulation; (2) the creation of electrochemically generated toxins; (3) the generation of electrode dissolution product; (4) skin damage via electronic current density; (4) brain damage via deposition of charge and electrolysis, and modification of amino acids and proteins; (5) damage to vulnerable parts of the brain (e.g. skull defect, foramina, open fontanelles, fissures in infants); (6) trivial side effects (e.g. skin itching, headache, fatigue, nausea, and dizziness); (7) neurologic diseases (e.g. epilepsy, acute eczema, epileptic seizures); and (8) other unintended or adverse effects. Further, the authors emphasized

that “because relatively strong tDCS protocols might be used in clinical studies, safety measures should be added to exclude deleterious effects of tDCS, which might be related to disease-specific damage of brain tissue, if the stimulation protocol is significantly stronger than what has been previously tested” (Nitsche et al., 2008, p. 220).

This suggests that there are several potential risks associated with tDCS, and it may not be a completely safe way to improve athletic performance, despite the claim that neuro-doping techniques would “of course provide further potential avenues for improved performance” (Banissy & Muggleton, 2013). Moreover, the use of electronic brain stimulation techniques for performance enhancement remains at the center of many unresolved ethical issues within the sports world (Banissy & Muggleton, 2013; Davis, 2013; Edwards et al., 2017).

5. tDCS and ethical issues

In order to learn their opinions regarding the ethics of tDCS, Riggall et al. (2015) surveyed nearly 260 researchers who have studied tDCS. Most study participants responded to the survey questions such that it was evident that their focus was on the potential enhancement effects associated with tDCS rather than on other preoccupations (e.g. research, clinical application). This is not surprising, given that tools and techniques applied as means of enhancement are often increasingly viewed by those in the field of neurology as ethically questionable and potentially unsafe.

With regard to enhancement, several studies have indicated that tDCS may improve creative thinking, insight, and memory (Chi & Snyder, 2011; Davis, 2013). Today, people consider games such as chess, go, e-sports (i.e. electronic sports, professional gaming) as a form of sport. Such games require players to concentrate, possess strong memory, and demonstrate creativity (Boot, Kramer, Simons, Fabiani, & Gratton, 2008) in order to win competitions. In addition, sports such as archery and shooting, which are part of the Olympic Games, require players to remain very steady while aiming for a bullseye or other target (Tang, Zhang, Huang, Young, & Hwang, 2008). tDCS may also serve to help reduce tremors, which often result from nerves or stimulation associated with the competitive environment, in players so that they are able to maintain steadiness (Axford et al., 2011) during or right before competitions. If some players use tDCS in effort to secure victory for themselves, would their opponents feel that the wins were justified? It is likely that many opponents would resort to suing the players who were doped via electrical stimulation to the brain.

The efficacies of tDCS mentioned above are similar to those of a few other popular drugs; these include amphetamines, which increase memory and concentration (Brunoni et al., 2012), and beta-blockers, which reduce tremors (Zhang et al., 2016). Both of these drugs are included in the list of prohibited substances published by WADA (2017a). Further, the use of this neuro-doping technique may result in a social problem, as only athletes of means would likely benefit from the technique (Rodenberg & Hampton, 2013). Given the costs of tDCS devices, which start at \$200 per device for gamers and \$500 per device for athletes (Halo Neuroscience, 2016; Hildt, 2014), this is worth considering, as there are surely individual athletes and teams that may be unable to purchase these devices.

Taken together, tDCS’ various means of enhancement, its unknown or unanticipated safety problems, and the fact that tDCS is still in its experimental stage will likely continue to be a source of many ethical controversies. As such, policymakers at anti-doping institutions must be proactive in modifying or reinforcing regulations that guide athletes, athlete support personnel, and law enforcers in terms of the validity of such electronic brain stimulation techniques. Further, these policymakers must act quickly.

6. WADA and loopholes that allow athletes to get around their anti-doping policy

The World Anti-Doping Association (WADA) is an international independent anti-doping agency that was established on 10 November 1999, under the International Olympic Committee (IOC), in order to fight against doping (WADA, 2017b). In accordance with its core value—integrity—the

organization serves to “develop policies, procedures, and practices that reflect justice, equity, and integrity” (WADA, 2017c). To protect its core value from the effects of doping, WADA has consistently banned many substances or techniques which meet two of the following three criteria: (1) drugs or tools that likely enhance performance to secure a winning edge; (2) drugs or tools that place athletes’ health at risk; (3) any substances or techniques that ruin the “spirit-of-sport” (WADA, 2017c). However, even though some of the substances or techniques meet two or three criteria, WADA does not always ban them immediately, and this can allow for more loopholes.

Moreover, with rapid and ever-changing technological advances, WADA, as well as other anti-doping agencies, has encountered an imbalance between existing policies against doping and emerging doping techniques because of an increase in loopholes in anti-doping policies (Rodenberg & Hampton, 2013). For these reasons, athletes or athletic support personnel are more likely to adeptly exploit loopholes in the anti-doping policies. Such corruption related to doping is serious because it causes a disruption in integrity and fair play (McLaren, 2008), which in turn undermines the values associated with sports.

There are a number of examples of loopholes that permit athletes to get around anti-doping policies. Rodenberg and Hampton (2013) pointed out that surgical doping, which is body manipulation via surgery that serves as a means of athletic performance enhancement, effectively allows athletes to get around WADA code. However, WADA still has not begun including a category related to surgical doping in the code. Further, gene-doping, a form of doping that emerged in the early 2000s, was at one point undetectable (Fore, 2010). Gene-doping took such a long time (from 2002 to 2009) to “establish procedures and state-of-the-art testing methods for identifying athletes who might misuse such technology” (IOC, 2001), but, in 2009, the WADA finally began including gene-doping on its list of prohibited techniques (Fore, 2010). Lastly, in the case of meldonium, the regulatory anti-doping agencies added the drug to their list of prohibited performance enhancers in 2016 even though athletes had been taking the drug for medical reasons for more than a decade (Clarey, 2016).

This suggests that a fair number of athletes had already been using many unknown substances or techniques to improve their levels of performance, thereby taking advantage of anti-doping policy loopholes. While WADA has eventually implemented new rules to address the use of some of these substances and techniques, this has often happened only after athletes and their means of performance enhancement have already undermined the integrity of sport. WADA and other anti-doping agencies must work more quickly to include more of these emerging substances and techniques on their lists of prohibited means of enhancement to minimize the destruction of the core value. If they do not work quickly now, neuro-doping, which has effectively just emerged, will also undermine the integrity of athletic competition.

7. An assessment of anti-doping policies to be applied to the area of neuro-doping

The agency has not yet begun to include a category that would encompass neuro-doping, despite the fact that it is on the radars of sport context stakeholders. As such, the WADA code, for example, and its list of prohibited substances and techniques should be reviewed, and the agency should consider adding to the list, under the category of prohibited physical manipulation techniques, techniques involving electronic brain stimulation. In the agency’s 2017 list of prohibited substances and techniques, the collection of prohibited substances and techniques are accumulative and expansive. However, neuro or brain doping has not been listed among the collection, which includes only the following methods of manipulation: (1) blood and blood component; (2) chemical and physical style; (3) gene doping, considered as a potential doping method.

At present, the anti-doping agency remains without a technology to detect whether athletes have made use of tDCS for performance enhancement. According to Davis (2013), there is a technique that exists—Magnetic Resonance Spectroscopy (MRS), which is a technique that can detect alterations of concentrations of related metabolites and neurotransmitters—that may possess the ability to detect neuro-doping. However, the testing device costs range from \$20,000 to beyond \$100,000

(Edgar, 2011), which makes it cost prohibitive, as it would cost roughly 10% of WADA's annual doping testing fee, which is about \$1 million per year (Maennig, 2014). Further, a high risk of false-positives make this potential method of detecting neuro-doping problematic (Davis, 2013). Further, WADA, USADA, and anti-doping agencies in other countries (e.g. United Kingdom, Norway) have available to them the latest effective method of detecting various means of doping, the "athlete biological passport," which is "an electronic record of test results of the lingering effects of banned substances in the body, rather than the substances themselves" (Gilbert, 2010, p. 18); however, this method is unable to detect tDCS.

Thus, "there is no known way to reliably detect whether or not a person has recently experienced brain stimulation" (Davis, 2013, p. 650). All of this makes tDCS look to athletes—who want to get around the anti-doping policy—like perhaps the ideal source of performance enhancement.

8. Conclusion

As loopholes enable athletes to get around WADA's anti-doping policy, the "spirit-of-sports" continued to be undermined. To minimize this, it would be prudent for WADA to begin to act in a timelier manner, yet the agency seems to experience difficulty in forecasting new doping techniques. Although tDCS is more likely to violate all three criteria (i.e. performance enhancement, safety, and ethics) necessary for it to be placed among the list of prohibited substance and techniques, WADA has yet to initiate an investigation regarding how tDCS affects the sports environment. If WADA hesitates to act to control this emerging doping technology, then this method may become increasingly appealing to and a complete performance enhancer for athletes, as it is, relatively speaking, less risky than other means of doping and could be more portable (Davis, 2013).

For these reasons, before WADA establishes a policy against neuro-doping, several experts in the field of neurology who want to market tDCS devices commercially or who have already begun marketing the devices to elite athletes and pro-gamers have been preparing to receive approval from the Food and Drug Administration (FDA) (Maney, 2016). If this neuro-doping technique is officially approved as a means of performance enhancement for elite athletes, then it would serve to undermine the values set forth by organizations such as WADA and the International Olympic Committee, both of which aim for fairness and equity.

Because tDCS is still in its experimental stage (Kuersten & Hamilton, 2016; Wexler, 2016), research is incomplete with regard to the unexpected critical side effects one may experience from either regular use or abuse of electronic brain stimulation. Thus, by arousing the agencies' attention and gathering an abundance of evidence via research, the agencies charged with composing anti-doping policies must be required to further extend the range of restrictive rules such that they apply to newly emerging doping practices (Miah, 2006), and develop a new doping test that will effectively detect the application of neuro-doping as soon as possible so as to maintain fairness in sports and soundness among athletes' bodies.

Consequently, because new enhancement techniques constitute cheating, as they break existing or unwritten rules and are unfair, new official rules aimed at preventing the use of these new techniques must be established (Schermer, 2008). If these actions are not taken, then additional loopholes will be found, and more means of doping will be developed.

Funding

The authors received no direct funding for this research.

Author details

Kwangho Park¹

E-mail: kp15e@my.fsu.edu

ORCID ID: <http://orcid.org/0000-0002-6021-6837>

¹ Troy University, 610 Elm St. Apt 7, Troy, AL 36081, USA.

Citation information

Cite this article as: Neuro-doping: The rise of another loophole to get around anti-doping policies, Kwangho Park, *Cogent Social Sciences* (2017), 3: 1360462.

References

- Angius, L., Hopker, J. G., Marcora, S. M., & Mauger, A. R. (2015). The effect of transcranial direct current stimulation of the motor cortex on exercise-induced pain. *European Journal of Applied Physiology*, 115, 2311–2319. <https://doi.org/10.1007/s00421-015-3212-y>

- Angius, L., Pageaux, B., Hopker, J., Marcora, S. M., & Mauger, A. R. (2016). Transcranial direct current stimulation improves isometric time to exhaustion of the knee extensors. *Neuroscience*, 339, 363–375. <https://doi.org/10.1016/j.neuroscience.2016.10.028>
- Arul-Anandam, A. P., & Loo, C. (2009). Transcranial direct current stimulation: A new tool for the treatment of depression? *Journal of Affective Disorders*, 117, 137–145. <https://doi.org/10.1016/j.jad.2009.01.016>
- Axford, P., Lakany, H., & Conway, B. (2011). *The effects of transcranial stimulation on enhanced physiological tremor: A pilot study*. Retrieved June 30, 2016 from https://www.robots.ox.ac.uk/~davidc/pubs/pgbiomed_proc2011.pdf#page=43/
- Banissy, M. J., & Muggleton, N. G. (2013). Transcranial direct current stimulation in sports training: Potential approaches. *Frontiers in Human Neuroscience*, 7, 129. doi:10.3389/fnhum.2013.00129
- Benninger, D. H., Lomarev, M., Lopez, G., Wassermann, E. M., Li, X., Considine, E., & Hallett, M. (2010). Transcranial direct current stimulation for the treatment of Parkinson's disease. *Journal of Neurology, Neurosurgery & Psychiatry*, 81, 1105–1111. <https://doi.org/10.1136/jnnp.2009.202556>
- Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta psychologica*, 123, 387398.
- Brunoni, A. R., Nitsche, M. A., Bolognini, N., Bikson, M., Wagner, T., Merabet, L., ... Edwards, F. (2012). Clinical research with transcranial direct current stimulation (tDCS): Challenges and future directions. *Brain Stimulation*, 5, 175–195. doi:10.1016/j.brs.2011.03.002
- Chi, R. P., & Snyder, A. W. (2011). Facilitate insight by non-invasive brain stimulation. *PLoS One*, 6, e16655. <https://doi.org/10.1371/journal.pone.0016655>
- Clarey, C. (2016, June 10). Maria Sharapova bungled her doping case, but her appeal has a chance. *New York Times*. Retrieved June 30, 2016 from https://www.nytimes.com/2016/06/12/sports/tennis/mariasharapova-suspension-meldonium.html?_r=0
- Cogiamanian, F., Marceglia, S., Ardolino, G., Barbieri, S., & Priori, A. (2007). Improved isometric force endurance after transcranial direct current stimulation over the human motor cortical areas. *European Journal of Neuroscience*, 26, 242–249. <https://doi.org/10.1111/j.1460-9568.2007.05633.x>
- Davis, N. J. (2013). Neurodoping: Brain stimulation as a performance-enhancing measure. *Sports Medicine*, 43, 649–653. <https://doi.org/10.1007/s40279-013-0027-z>
- Davis, N. J. (2014). Transcranial stimulation of the developing brain: A plea for extreme caution. *Frontiers in Human Neuroscience*, 8, 600. doi:10.3389/fnhum.2014.00600
- Edgar, M. (2011). Physical methods and techniques: NMR spectroscopy. *Annual Reports Section B (Organic Chemistry)*, 107, 308–327. <https://doi.org/10.1039/c1oc90006d>
- Edwards, D. J., Cortes, M., Wortman-Jutt, S., Putrino, D., Bikson, M., Thickbroom, G., & Pascual-Leone, A. (2017). Transcranial direct current stimulation and sports performance. *Frontiers in Human Neuroscience*, 11, 94. doi:10.3389/fnhum.2017.00243
- Fagerlund, A. J., Bystad, M. K., & Aslaksen, P. M. (2013). Transcranial direct current stimulation for chronic pain. *Tidsskrift for Den norske legeforening*, 133, 2266–2269. <https://doi.org/10.4045/tidsskr.13.0003>
- Fore, J. (2010). Moving beyond gene doping: Preparing for genetic modification in sport. *Virginia Journal of Law & Technology*, 15, 76.
- Gilbert, S. (2010). The biological passport. *Hastings Center Report*, 40, 18–19.
- Guardian. (2015, May 6). Warning: Transcranial direct current stimulation can do your head in. *The Guardian*. Retrieved July 07, 2016 from <https://www.theguardian.com/science/shortcuts/2015/may/06/warningtranscranial-direct-current-stimulation-bad-for-iq/>
- Halo Neuroscience. (2016). Buy Halo sport. Author. Retrieved July 07, 2016 from <https://www.haloneuro.com/gethalo-sport/>
- Hildt, E. (2014). The next stage of neuroenhancement? Transcranial direct current stimulation. *The Neuroethics Blog*. Retrieved July 07, 2016 from <https://www.theneuroethicsblog.com/2014/03/the-next-stage-ofneuroenhancement.html/>
- Hunter, M. A., Coffman, B. A., Trumbo, M. C., & Clark, V. P. (2013). Tracking the neuroplastic changes associated with transcranial direct current stimulation: A push for multimodal imaging. *Frontiers in Human Neuroscience*, 7, 495. <https://doi.org/10.3389/fnhum.2013.00495>
- IOC. (2001). *IOC gene therapy working group – Conclusion*. Author. Retrieved July 07, 2016 from <https://www.olympic.org/content/news/media-resources/manual-news/1999/2009/2001/06/06/ioc-gene-therapy-working-group—conclusions/>
- Iuculano, T., & Kadosh, R. C. (2013). The mental cost of cognitive enhancement. *The Journal of Neuroscience*, 33, 4482–4486. <https://doi.org/10.1523/JNEUROSCI.4927-12.2013>
- Johns Hopkins Medicine. (2016). Transcranial Direct Current Stimulation. Johns Hopkins Medicine. Retrieved July 03, 2016 from https://www.hopkinsmedicine.org/psychiatry/specialty_areas/brain_stimulation/tDCS.html
- Kuersten, A., & Hamilton, R. H. (2016). Minding the 'gaps' in the federal regulation of transcranial direct current stimulation devices. *Journal of Law and the Biosciences*, 3, 309–317. <https://doi.org/10.1093/jlb/lsw015>
- Loo, C. K., Alonzo, A., Martin, D., Mitchell, P. B., Galvez, V., & Sachdev, P. (2012). Transcranial direct current stimulation for depression: 3-Week, randomised, sham-controlled trial. *The British Journal of Psychiatry*, 200, 52–59. <https://doi.org/10.1192/bjp.bp.111.097634>
- Maennig, W. (2014). Inefficiency of the anti-doping system: Cost reduction proposals. *Substance Use & Misuse*, 49, 1201–1205. <https://doi.org/10.3109/10826084.2014.912065>
- Maney, K. (2016, February 10). Halo claims to make you jump higher, think faster, remember longer. *Newsweek*. Retrieved July 03, 2016 from <https://www.newsweek.com/halo-neuroscience-brain-stimulation424829>
- Mariano, T. Y., van't Wout, M., Garnaat, S. L., Rasmussen, S. A., & Greenberg, B. D. (2016). Transcranial direct current stimulation (tDCS) targeting left dorsolateral prefrontal cortex modulates task-induced acute pain in healthy volunteers. *Pain Medicine*, 17, 737–745.
- Marquez, J., van Vliet, P., McElduff, P., Lagopoulos, J., & Parsons, M. (2015). Transcranial direct current stimulation (tDCS): Does it have merit in stroke rehabilitation? A systematic review. *International Journal of Stroke*, 10, 306–316. <https://doi.org/10.1111/ijvs.12169>
- McLaren, R. H. (2008). Corruption: Its impact on fair play. *Marquette Sports Law Review*, 19, 15. Retrieved July 03, 2016 from <https://scholarship.law.marquette.edu/sportslaw/vol19/iss1/3/>
- Miah, A. (2006). Rethinking enhancement in sport. *Annals of the New York Academy of Sciences*, 1093, 301–320. <https://doi.org/10.1196/annals.1382.020>
- Nitsche, M. A., & Paulus, W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *The Journal of Physiology*, 527, 633–639. doi:10.1111/j.1469-7793.2000.t011-1-00633.x

- Nitsche, M. A., Cohen, L. G., Wassermann, E. M., Priori, A., Lang, N., Antal, A., ... Pascual-Leone, A. (2008). Transcranial direct current stimulation: State of the art 2008. *Brain Stimulation*, 1, 206–223. doi:10.1016/j.brs.2008.06.004
- Nitsche, M. A., & Paulus, W. (2011). Transcranial direct current stimulation – update 2011. *Restorative Neurology and Neuroscience*, 29, 463–492. doi:10.3233/RNN-2011-0618
- Nowak, D. A., Bösl, K., Podubecká, J., & Carey, J. R. (2010). Noninvasive brain stimulation and motor recovery after stroke. *Restorative Neurology and Neuroscience*, 28, 531–544. doi:10.3233/RNN-2010-0552
- Okano, A. H., Fontes, E. B., Montenegro, R. A., de Farinatti, P. T. V., Cyrino, E. S., Li, L. M., ... Noakes, T. D. (2013). Brain stimulation modulates the autonomic nervous system, rating of perceived exertion and performance during maximal exercise. *British Journal of Sports Medicine*, 49, 1213–1218. doi:10.1136/bjsports-2012-091658
- Pascual-Leone, A., Valls-Solé, J., Wassermann, E. M., Brasil-Neto, J., Cohen, L. G., & Hallett, M. (1992). Effects of focal transcranial magnetic stimulation on simple reaction time to acoustic, visual and somatosensory stimuli. *Brain*, 115, 1045–1059. <https://doi.org/10.1093/brain/115.4.1045>
- Reardon, S. (2016). “Brain doping” may improve athletes’ performance. *Nature*, 531, 283–284. doi:10.1038/nature.2016.19534
- Reis, J., Schambra, H. M., Cohen, L. G., Buch, E. R., Fritsch, B., Zarahn, E., ... Krakauer, J. W. (2009). Noninvasive cortical stimulation enhances motor skill acquisition over multiple days through an effect on consolidation. *Proceedings of the National Academy of Sciences of the United States of America*, 106, 1590–1595. <https://doi.org/10.1073/pnas.0805413106>
- Riggall, K., Forlini, C., Carter, A., Hall, W., Weier, M., Partridge, B., & Meinzer, M. (2015). Researchers’ perspectives on scientific and ethical issues with transcranial direct current stimulation: An international survey. *Scientific Reports*, 5, 68. <https://doi.org/10.1038/srep10618>
- Rodenberg, R. M., & Hampton, H. L. (2013). Surgical doping: A policy loophole? *International Journal of Sport Policy and Politics*, 5, 145–149. <https://doi.org/10.1080/19406940.2012.656683>
- Rodenberg, R. M., & Holden, J. T. (2016). Cognition enhancing drugs (“nootropics”): Time to include coaches and team executives in doping tests? *British Journal of Sports Medicine*. doi:10.1136/bjsports-2015-095474
- Schermer, M. (2008). On the argument that enhancement is cheating. *Journal of Medical Ethics*, 34, 85–88. <https://doi.org/10.1136/jme.2006.019646>
- Sellers, K. K., Mellin, J. M., Lustenberger, C. M., Boyle, M. R., Lee, W. H., Peterchev, A. V., & Fröhlich, F. (2015). Transcranial direct current stimulation of frontal cortex decreases performance on the WAIS-IV intelligence test. *Behavioural Brain Research*, 290, 32–44. <https://doi.org/10.1016/j.bbr.2015.04.031>
- Smith, A. C., & Stewart, B. (2015). Why the war on drugs in sport will never be won. *Harm Reduction Journal*, 12, 559. doi:10.1186/s12954-015-0087-5
- Stewart, B., Outram, S., & Smith, A. C. (2013). Doing supplements to improve performance in club cycling: A life-course analysis. *Scandinavian Journal of Medicine & Science in Sports*, 23, e361–e372. doi:10.1111/sms.12090
- Tanaka, S., Takeda, K., Otaka, Y., Kita, K., Osu, R., Honda, M., ... Watanabe, K. (2011). Single session of transcranial direct current stimulation transiently increases knee extensor force in patients with hemiparetic stroke. *Neurorehabilitation and Neural Repair*, 25, 565–569. <https://doi.org/10.1177/1545968311402091>
- Tang, W. T., Zhang, W. Y., Huang, C. C., Young, M. S., & Hwang, I. S. (2008). Postural tremor and control of the upper limb in air pistol shooters. *Journal of Sports Sciences*, 26, 1579–1587. <https://doi.org/10.1080/02640410802287063>
- Tortella, G., Casati, R., Aparicio, L. V. M., Mantovani, A., Senço, N., D’Urso, G., ... Brunoni, A. R. (2015). Transcranial direct current stimulation in psychiatric disorders. *World Journal of Psychiatry*, 5, 88–102. <https://doi.org/10.5498/wjpv.5.i1.88>
- Uncini, A., Zappasodi, F., Musumeci, G., Navarra, R., Caulo, M., & Di Lazzaro, V. (2017). P287 Effect of closely repeated cathodal transcranial direct current stimulations. *Clinical Neurophysiology*, 128, e150. <https://doi.org/10.1016/j.clinph.2016.10.395>
- Wexler, A. (2016). A pragmatic analysis of the regulation of consumer transcranial direct current stimulation (TDCS) devices in the United States. *Journal of Law and the Biosciences*, 2, 669–696.
- World Anti-Doping Agency. (2017a). *Prohibited list*. Author. Retrieved June 06, 2017 from <https://www.wada-ama.org/en/what-we-do/the-prohibited-list>
- World Anti-Doping Agency. (2017b). *The agency’s history*. Author. Retrieved June 06, 2017 from <https://www.wada-ama.org/en/who-we-are>
- World Anti-Doping Agency. (2017c). *Our core value*. Author. Retrieved June 06, 2017 from <https://www.wada-ama.org/en/who-we-are>
- Zhang, J., Liu, R., Zhou, M., Shang, L., Yang, M., Xia, Z., & Zhu, C. (2016). Beta blockers for essential tremor. *Cochrane Database of Systematic Reviews*. doi:10.1002/14651858.cd008083.pub2



© 2017 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license.

You are free to:

Share — copy and redistribute the material in any medium or format

Adapt — remix, transform, and build upon the material for any purpose, even commercially.

The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:

Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made.

You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

No additional restrictions

You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

