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HOME USE OF tDCS
From "Do-It-Yourself" to "Direct-to-Consumer"

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Introduction

In recent years, the technique known as transcranial direct current stimulation (tDCS) has come into prominence. tDCS can be distinguished from deep brain stimulation in that it is noninvasive, and it differs from electroconvulsive therapy in that it requires a much lower level of current. The prototypical tDCS device contains a current-generating component (often powered by a 9V battery), wires that carry the current, and electrodes that act as a conductive interface between the wires and the scalp. When the electrical circuit is complete, the device is thought to deliver current to a small area of the brain beneath the electrodes. Interest in the use of this technique on the human brain sharply increased following publication of a paper showing that passing a weak electrical current (0.2 to 1 milliamps) through the motor cortex caused human subjects to perform significantly better on motor tasks (Nitsche and Paulus, 2000).

In the decade and a half since this keystone paper was published, approximately 1,000 peer-reviewed articles about tDCS have emerged, many of which suggest that tDCS may have beneficial effects in both clinical settings (for review, see Kuo et al., 2014) and non-clinical ones (for review, see Coffman et al., 2014). For example, studies have claimed that tDCS may be effective for a variety of conditions and psychiatric disorders, such as depression (Shiozawa et al., 2014) and chronic pain (Knotkova et al., 2013). In healthy individuals, research has suggested that tDCS can "enhance cognition" in a variety of domains, such as creative problem solving (Chi and Snyder, 2012), working memory (Fregni et al., 2005), object detection (Falcone et al., 2012), sustained attention (Nelson et al., 2014), and motor learning (Reis et al., 2009). One notable feature of tDCS is that its efficacy for cognitive enhancement seems to be more salient with concurrent training on a cognitive task. The fact that tDCS has been shown to be effective *without* concurrent training—for example, in cases of depression and chronic pain—has led some to speculate that in clinical populations, tDCS may be modulating brain networks involved in the placebo response (Schambra et al., 2014). It should be noted, however, that several meta-analyses have been published that question the validity of the reported effects of tDCS for cognitive enhancement (Horvath et al., 2015a; Horvath et al., 2015b).

Currently, tDCS is not approved by regulatory authorities in either the United States or Europe as a medical treatment for any indication. In the United States, researchers (but not

the general public) may obtain medical-grade tDCS devices for investigational use from either Soterix or Neuroconn, the two U.S. companies whose devices have an "investigational device exemption" from the Food and Drug Administration (FDA; Fregni et al., 2014). Nonetheless, the simplicity of tDCS devices has led to a phenomenon wherein individuals stimulate their own brains with tDCS[1] outside of research or medical settings, primarily for self-improvement purposes (Jwa, 2015; Wexler, 2015a). The movement has been referred to as do-it-yourself (DIY) tDCS because it began with individuals constructing tDCS devices themselves. In the past few years, the availability of ready-made, direct-to-consumer devices has grown, and there are currently at least nine consumer tDCS devices—which are not regulated as either medical or investigational devices—on the market, ranging in price from $49 to $299. As a result, the border between DIY and direct-to-consumer tDCS has become muddled. We therefore use the term "home users" to encompass the full range of individuals who use tDCS devices outside of professional research and medical settings.

For more on cognitive enhancement, see Chapter 8.

Unsurprisingly, the emergence of home use of tDCS has not been well received by ethicists, scientists, and the medical community (Hamilton et al., 2011; Cohen Kadosh et al., 2012; Levy and Savulescu, 2014; Fitz and Reiner, 2013, 2014; Editorial *Nature*, 2013; Dubljević et al., 2014; Davis and Koningsbruggen, 2013). Although no serious adverse events have been reported among the 10,000 subjects studied to date (Fregni et al., 2014), at least one study has found that tDCS can simultaneously enhance one cognitive function while impairing another (Iuculano and Cohen Kadosh, 2013). A letter in *Nature* implored, "Unorthodox technologies and applications must not be allowed to distort the long-term validation of tDCS" (Bikson et al., 2013). Thus, there exist at least two groups—researchers and home users—who utilize a single technology in very different ways. Whereas researchers apply tDCS to subjects within the controlled realm of the laboratory in the context of experimental studies, home users apply tDCS to themselves, mostly in private settings, for cognitive enhancement or self-treatment (Wexler, 2015a).

Practices and Motivations of Home Users

Quantifying the demographics and prevalence of the home use of tDCS is no simple feat, as the most active forum where home users communicate—a Reddit.com forum (known as a "subreddit") dedicated to tDCS—is pseudonymous. Two recent studies, however, provide initial information about the practices and motivations of home users. One study consisted of content analyses of the postings to the subreddit, in-depth interviews, and an online questionnaire (Jwa, 2015), while the second study presented a preliminary sketch of the practices of home users, based on interviews and reviews of the subreddit, websites, blogs, and videos related to the home use of tDCS (Wexler, 2015a). Both studies found that home users were overwhelmingly male, with age ranging from late teens to 60s; 71% of survey respondents were in their 20s and 30s (Jwa, 2015). Both reports found the phenomenon to be global, although the majority of users seem to be concentrated in the United States and Canada. It should be noted, however, that both studies were limited in that they focused on the population of users that communicate online. Interestingly, a recent survey of researchers engaged in studying tDCS suggests that these

professionals do not, for the most part, engage in the equivalent of home use of tDCS: by and large they do not use tDCS on themselves (Shirota et al., 2014).

How prevalent is the home use of tDCS? As of July 2015, there were approximately 7,500 "subscribers" to the tDCS subreddit, though "subscribing" only means that new posts to the forum will be displayed on an individual's Reddit.com homepage. Conversely, individuals may be home users without subscribing to the tDCS subreddit. Furthermore, as the subreddit was created in April 2011, many current subscribers may no longer be actively using tDCS. Thus, while the forum received 6,000 page hits per month on average in 2013 (Jwa, 2015), this number does not necessarily reflect active users. Perhaps the most revealing figure is the number of posts to the forum: by the end of 2013, the forum was averaging several original posts per day, with many more comments appended to each post (Jwa, 2015; Wexler, 2015a). Outside of the subreddit, it is possible to turn to other measures, such as the tens of thousands of views on YouTube videos related to the home use of tDCS. However, these figures and others represent aggregate numbers over time and do not differentiate between a bona fide home user and those merely curious about the technology.

In the survey of home users, 59% of respondents reported using tDCS for cognitive enhancement, for purposes such as improving attention, learning, working and long-term memory, and perception (Jwa, 2015). Eleven percent of individuals reported self-stimulating for treatment (most commonly for depression but also for attention deficit hyperactivity disorder, pain, obsessive compulsive disorder, and stroke), and 24% reported using tDCS for both purposes. On the subreddit, individuals have written about self-treating for anxiety disorder, seasonal affective disorder, and generalized anxiety disorder (Wexler, 2015a).

Some home users believe that tDCS may someday be used instead of drugs or even administered for suicide prevention. They seem to utilize tDCS almost exclusively on themselves (and very occasionally on significant others or close friends) but not on unknown subjects. In contrast to related movements, such as DIY biology and quantified self (wherein individuals meticulously track data about themselves, such as sleeping and eating habits), tDCS home users have not (yet) held large-scale meetings or public gatherings, though local meetings in "hackerspaces" have been reported. Thus, the home use of tDCS for some is simultaneously a private act, as stimulation is most often done in the seclusion of one's home, and public, as an individual's subreddit posts are openly visible.

Much of the conversation on the subreddit (and on websites and blogs) focuses on the construction or acquisition of a tDCS device (Jwa, 2015; Wexler, 2015a). Thirty-nine percent of survey respondents reported building a stimulation device (Jwa, 2015), and home users regularly post descriptions and diagrams of their self-built devices. There are frequent discussions about fuses, voltages, electrodes, resistors, diodes, transistors, and regulators on the subreddit (Wexler, 2015a). Despite the popularity of building a device in true DIY fashion, 48% of survey respondents reported purchasing a device (9% reported that they had both constructed and purchased a device). Of the devices that individuals purchased, most users reported purchasing the Foc.us headset, but others purchased a variety of device "kits" as well as iontophoresis devices, which can be repurposed for tDCS (Jwa, 2015). On the subreddit and other sites, users who purchase devices share reviews and discuss safety issues (Wexler, 2015a).

The overall conclusion is that when building or acquiring a device, the knowledge that home users draw upon is separate, for the most part, from that of the scientific community (Wexler, 2015a). However, when *using* the device, home users draw heavily upon scientific publications, particularly when considering whether a specific orientation of electrodes exists for their specific disorder or enhancement goal. Scientific review articles appear to be particularly appealing to home users insofar as they provide broad overviews of the medical conditions that have been

successfully treated with tDCS as well as the cognitive functions that have been enhanced by it. Home users also make use of other resources geared toward professionals, such as a video tutorial on electrode positioning created by several tDCS researchers. Sometimes home users even produce derivative scientific work. For example, one home user compiled a document containing more than 400 abstracts about tDCS, and another, frustrated that information about montage placements was scattered across the internet, created a website (tdcsplacements.com) that featured stimulation diagrams in a clean, easy-to-browse format. Thus, home users transform existing scientific knowledge and diagrams into user-friendly indexes and guides geared toward their needs (Wexler, 2015a).

Both Jwa (2015) and Wexler (2015a) found that home users largely adhere to the current levels (1–2 milliamps) used in scientific tDCS studies but appear to experiment to a limited degree with duration and frequency of use. While many reported employing the duration most commonly used in scientific tDCS studies (20 minutes), some individuals reported stimulating for longer durations. While there is also no set scientific standard with regard to session frequency, most studies utilize several sessions of tDCS spread across days or weeks. The majority (61%) of survey respondents reported using tDCS for 6 months or less, but 21% reported using tDCS for "6 months–1 year," and the remainder (16%) reported using tDCS for more than 1 year (Jwa, 2015). An important caveat is that the survey question did not appear to differentiate between frequent and occasional users (i.e., those who reported using tDCS for 1 year could have used tDCS daily or just several times across that same time period).

When attempting to measure the effects of tDCS in the face of "*n*-of-1" experimental constraints, some users, particularly those interested in self-treating a mental disorder, rely on a subjective feeling of improvement (Wexler, 2015a). Other home users, particularly those interested in cognitive enhancement, take a more empirical approach to the enterprise and attempt to quantify their performance on cognitive tests (Wexler, 2015a). One of the most popular strategies is to track scores on open-source versions of dual n-back tests, performance measures often used in scientific studies that assess working memory (Jwa, 2015). Some attempt to control for potential confounding factors, such as the practice effect, but few individuals control for the placebo effect (Wexler, 2015a), even though it is an oft-discussed topic on the subreddit. Whether based upon empirical results or subjective impressions, home users do not universally report that tDCS achieves the aims they were hoping for. When assessing the perceived effects of tDCS, respondents reported success more often than failure, yet the single most common response was the midpoint on a scale whose anchors indicated "extremely successful" and "totally unsuccessful" (Jwa, 2015). Nonetheless, 92% of respondents reported that they would continue using tDCS (Jwa, 2015).

From Do-It-Yourself to Direct-to-Consumer

Although there are isolated mentions of DIY brain stimulation that date back to 2007, the home use of tDCS truly came into being in mid-2011, when a Yahoo group and the tDCS subreddit were formed (Wexler, 2015b). By early 2012, there were a number of blogs and sites dedicated to the home use of tDCS. Interestingly, the rise of the movement tracks the increase in scientific journal publications about tDCS: in 2011, the number of tDCS peer-reviewed articles doubled (to more than 130), and in 2012 there was the greatest quantitative increase in mentions of tDCS in the popular press. It is likely that the home-use movement built upon related movements that were well established by 2010, such as DIY biology (Delfanti, 2013; Meyer, 2013) and quantified self (Swan, 2013).

During the early days of DIY tDCS, most individuals built their devices from scratch, with the help of diagrams posted online and electronics assistance from other DIYers. In the spring of

2012, two undergraduates from the University of Michigan constructed a prototype of a tDCS device and set up a website on which they promised to sell it for $99 (GoFlow, 2012). The story went viral, with the initiative enthusiastically described with headlines such as "Buy a DIY Brain Supercharger for $100" (Vance, 2012) and "Transcranial direct current stimulation works, and you can try it at home" (Mims, 2012). Ultimately plans for the headset were abandoned, and the mailing list was quietly sold to another firm in the process of building a consumer tDCS device (Wexler, 2015b).

Around the same time, other consumer tDCS devices appeared on the market: Hong Kong–based TCT Technologies began selling a US$379 device, and several other websites offered more affordable tDCS device "kits."[2] The kits were geared to those who had knowledge of tDCS but lacked the necessary skills to build their own device from scratch. Some home users began purchasing and repurposing iontophoresis devices (typically used for drug delivery through a current), which legally require a prescription but in practice are widely available online.[3]

The Foc.us device, released in the summer of 2013, was arguably the first true direct-to-consumer tDCS device. With its sleek, ready-to-wear headset design, it looked more like a proper consumer product than a cobbled-together DIY device. The company's website, advertising campaign (featuring photos of an attractive woman wearing the device), and promised smartphone integration made it clear that the product was a step up from the kits sold by small-scale vendors. Though the Foc.us device was ostensibly marketed to gamers, its release thrust the direct-to-consumer tDCS movement into the spotlight, changing the tenor of public perception of tDCS (Cabrera and Reiner, 2015) and bringing the debate over regulation of cognitive enhancement devices to public attention (Murphy, 2013; Statt, 2013). Among the home-use community, the Foc.us device seemed to cause a major demographic shift (Jwa, 2015), as it opened up tDCS to those who neither had the technical savvy to build their own device or were not compelled to purchase device "kits" or repurpose iontophoresis devices.

Since 2014, Foc.us has released a second generation of products, and it currently has a headset specially designed for exercise. In 2014, two Silicon Valley start-ups announced that they were entering the consumer brain stimulation device market. In May 2014, Halo Neuroscience announced that it had received $1.5 million in venture capital funding and was developing "wearable technology that boosts brain function" (Halo Neuroscience Press Release, 2014). As a well-financed Silicon Valley company, it populated its board of directors with well-known names such as Reed Hundt, former chairman of the Federal Communications Commission (Halo Neuroscience, n.d.). In October 2014, Thync raised the bar further, announcing that it had raised $13 million in venture capital funding (Stone, 2014), and in June 2015, the company released a device that is controlled via smartphone and provides a form of noninvasive brain stimulation for mood-alteration purposes (either a "calm vibe" or an "energy vibe"). Thync reports that it has tested thousands of subjects, both on its own and in collaboration with tDCS researchers, and recently published a subset of its results in a peer-reviewed journal (Tyler et al., 2015). The existence of well-funded, highly connected companies with an eye on the consumer device market for noninvasive electrical brain stimulation suggests that what began as DIY brain stimulation is likely to be superseded by direct-to-consumer brain stimulation.

Regulation of Consumer Noninvasive Brain Stimulation Devices

In both the United States and Europe, products *intended* for use in the treatment or diagnosis of disease or other medical conditions are considered medical devices (Wexler, 2015b, Maslen et al., 2014). Historically, regulators have relied upon the content of the product's advertising

and labeling to determine intended use. At the present time, some consumer noninvasive brain stimulation device manufacturers clearly state that their device has applications for the treatment of diseases, whereas for others, it is unclear whether the manufacturers make "implied" medical claims (Wexler, 2015b). Other consumer noninvasive brain stimulation devices are marketed for cognitive enhancement purposes only, and at least one device makes no claims at all. Interestingly, the most recent entrant in the field, the device marketed by Thync, is being marketed as a "lifestyle product" and, according to the company, on this basis has been exempted from medical device regulatory requirements by the FDA because its intended use is related to recreational purposes (Thync, n.d.).

The FDA has no official position on tDCS devices (FDA, 2012), nor has it formally taken action against any manufacturer, but that is not to say that there has been no attention to such matters. In 2013, a biomedical engineer from the FDA notified the California Department of Public Health (CDPH) that a California based-firm, TDCS Device Kit Inc., appeared to be unlawfully selling a device that made implied medical claims (Wexler, 2015b). In May 2013, the CDPH sent a notice of violation to the company for violating California's Sherman Food, Drug, and Cosmetic Law, as it is illegal to sell medical devices that have not been approved by the FDA (Wexler, 2015b). A later press release from the CDPH noted that the company was voluntarily issuing a recall of its devices (California Department of Public Health, 2013). Although the CDPH took action after receiving an email from the FDA biomedical engineer, it should be noted that the FDA engineer's email is not considered representative of the FDA's formal position. Thus, while the FDA officially has no formal position on tDCS devices, it is hardly unaware of the situation, as evidenced both by the FDA engineer's actions and even more so by comments made by the chief of the neurostimulation devices branch at a recent Institute of Medicine workshop (Institute of Medicine, 2015). This view is further reinforced by the fact that the FDA recently held a public workshop on noninvasive brain stimulation medical devices (FDA, n.d.), which it defined as "medical devices that are intended to improve, affect, or otherwise modify the cognitive function of a normal individual (i.e., without a treatment objective)."

Because of the patchwork of marketing strategies and the dearth of enforcement action, it has been suggested that there is a "regulatory gap" for consumer cognitive-enhancement devices (Dubljević et al., 2014). Some have proposed extending medical device legislation, at least in the European Union, to cover such devices (Maslen et al., 2013). Others have considered the appropriate "level" of regulation that might be applied to such devices (Dubljević, 2014). However, the lack of enforcement action should not be conflated with the lack of regulation (Wexler, 2015b), as there exists a comprehensive regulatory framework for both medical devices and consumer products. Indeed, the Federal Trade Commission (FTC) has recently taken enforcement action against a computer game manufacturer (FTC, 2015a) and a dietary supplement manufacturer (FTC, 2015b) that made unsubstantiated claims related to cognitive enhancement, and there is no reason to suspect that it will not act in similar fashion with tDCS device manufacturers. Some scholars have pointed out that focusing on regulatory enforcement might be impractical or infeasible (Jwa, 2015; Wexler, 2015b) and instead have supported the "open engagement" approach to the DIY community first proposed by Fitz and Reiner (2013), which favors communication and education, as opposed to strict regulation that might instead serve to increase underground use of home-made devices.

The Ethical Landscape of the Home Use of tDCS

The ethical landscape of the home use of tDCS is in many ways similar to the well-developed literature on the use of pharmacological agents for cognitive enhancement (Farah et al., 2004;

Greely et al., 2008; Fitz et al., 2014). The cardinal concerns of safety, peer pressure, distributive justice, and authenticity all apply (Hamilton et al., 2011; Cohen Kadosh et al., 2012; Levy and Savulescu, 2014; Fitz and Reiner, 2013), but with home use as the primary focus, some differences are worthy of mention.

Safety

The primary issue that has been debated to date relates to the question of whether tDCS is "safe." While no serious adverse events have been reported, short-term side effects such as headache, tingling, discomfort, and skin redness are common (Bikson et al., 2009), and home users report experiencing some of these same effects (Jwa, 2015). A different perspective on safety is the worry that in addition to these mild and relatively obvious side effects, there may be occult effects on cognitive function itself (Fitz and Reiner, 2013). Indeed, evidence exists demonstrating that the gains achieved by using tDCS to enhance one cognitive function may impair another cognitive function (Iuculano and Cohen Kadosh, 2013). Alternatively, the effects of tDCS may depend on individual traits, enhancing for some and impairing for others. For example, one study found that tDCS enhanced reaction time on arithmetic tests for those with high mathematics anxiety but impaired reaction time for those with low mathematics anxiety (Sarkar et al., 2014). There is every reason to suspect that home users are subject to these same phenomena.

The good news is that home users seem to have taken an active role in monitoring and discussing safety. In line with the general ethos of other DIY movements—experiment, report, and share—safety warnings are regularly shared in comments to online postings (Jwa, 2015). Indeed, despite worries about tDCS home users damaging themselves (see, e.g., Maslen et al., 2014a), for the most part, home users appear to be more thoughtful than reckless and regularly concerned about their own safety (Jwa, 2015; Wexler, 2015a). The moderator of the Reddit forum, for example, solicited reviews and safety reports from users of the Foc.us device after it first came out, in what seems to be the only attempt to quantify the safety of a consumer tDCS device (PSA: Potential Safety Issues with the Foc.us, 2014).

A final set of safety considerations relates to the use of tDCS in children. It has been suggested that tDCS may be of particular utility in overcoming developmental disorders, as these are among the most disabling of maladies (Krause and Cohen Kadosh, 2013). In response, several commentators have urged caution (Reiner, 2013; Davis, 2014), and others have suggested that in particular when used for enhancement (as opposed to therapy), tDCS use should be delayed until adolescents have sufficient autonomy that they are able to make the decision for themselves (Maslen et al., 2014b).

The three remaining cardinal concerns—authenticity, peer pressure, and distributive justice—have garnered less attention than worries over safety. We briefly review these issues in what follows.

Authenticity

The debate over authenticity of achievement following cognitive enhancement has a long history. The essence of the debate is that using enhancements represents shortcuts to success and is therefore morally suspect (Schermer, 2008). A key argument has been that the absence of hard work debases achievement, a form of pharmacological Calvinism for the modern era (Klerman, 1972; Parens, 2013). Because enhancing through tDCS generally requires not just stimulation but also training on a task, some have argued that the introduction of tDCS as a cognitive

enhancer effectively reduces the authenticity concern (Cohen Kadosh et al., 2012). Closer inspection reveals that this argument falls flat when one realizes that just as with tDCS, pharmacological cognitive enhancers are not magic bullets, and when they are used for such objectives, studying (or other forms of training) is still required. Moreover, in the context of home use of tDCS for enhancement purposes, the argument may not matter in any case: empirical data demonstrate that while the public is fully cognizant of the key features of the authenticity concern, diminished authenticity does not fully translate into diminished worthiness (Fitz et al., 2014).

Peer Pressure

The use of tDCS is not yet sufficiently widespread for *bona fide* peer pressure to have taken hold. But in a world in which we are buffeted by articles extolling the need to raise the perfect child, to have the perfect body, to be the best that we can be (and better), the societal pressure to enhance our brains is nearly palpable. Even a brief perusal of the current crop of advertising for home use of tDCS devices reveals this to be the essence of the marketing strategy. Thus the advertisements promise that these devices will make you calm or energized, improve your gaming or your workout regimen, all with an undercurrent that it is you, the consumer, who is responsible for managing your well-being. And while a modicum of responsibility for our actions is healthy and perhaps even welcome, at some point it can transform into what Saskia Nagel has characterized as the burden of self-determination (Nagel, 2010)—the notion that we are subject to societal pressure to adhere to unrealistic standards of achievement.

Distributive Justice

Because the cost of the devices—whether built by DIYers or purchased for home use—is relatively modest (the upper bounds being comparable to an inexpensive smartphone), not only are concerns about distributive justice mitigated, but there is an opportunity to use the devices to benefit the less well off in society. The only ongoing cost is the minimal energy required to power the device and the replacement of worn-out electrodes. Moreover, the same device can be used by different users, further driving down cost. As a result, it has been suggested that the affordability of tDCS for home use may favor its adoption in small medicine initiatives in developing countries (Fitz and Reiner, 2013).

As tDCS moves from its DIY roots to a maturing direct-to-consumer mode, new questions arise. The most important of these is whether new safety concerns will emerge if the technology achieves widespread adoption. As with pharmaceuticals, postmarketing surveillance is the key, irrespective of whether devices are being sold within or outside of the jurisdiction of the FDA. Given that tDCS products marketed for recreational purposes may be exempt from medical device regulation, it is unclear who will shoulder the burden of postmarket surveillance (i.e., other regulatory authorities, device manufacturers, or third parties). Other questions that arise from the transition to direct-to-consumer devices include the responsibility of manufacturers to represent their product accurately to the public and to ensure that consumers have clear guidelines as to how to use the device as safely as possible.

Looking Ahead

When DIY tDCS first burst upon the scene, many commentators opined that we might be on the cusp of an explosion in the use of this technology by home users (Hamilton et al., 2011;

Fitz and Reiner, 2013). While the technology has been embraced by some, the evidence that has accrued to date does not demonstrate widespread uptake (Jwa, 2015). Overall, it seems that the worries about an onrushing wave of DIY tDCS use—and calls for regulation—may have been overstated (Fitz and Reiner, 2013; N*ature* Editorial, 2013; Maslen et al., 2014). Indeed, one analysis of the home user community concluded that "the DIY use of tDCS is not currently widespread, that it does not seem to pose an imminent risk or danger to the public, and there seems to be only a remote possibility of a dramatic increase of DIY use of tDCS in the near future" (Jwa, 2015, 25).

There are several possible explanations for why the home use of tDCS has not undergone broad adoption by the general population. Perhaps only a small subset of individuals is sufficiently motivated to experiment with electrical brain stimulation devices that have not undergone review by regulatory authorities. As with any novel technology, home users may represent a group of "early adopters," and it is possible that there has not been enough time (or technological refinement) for tDCS to gain mainstream acceptance. Indeed, one study of the comments on online articles related to tDCS found that although public misunderstanding of the technology has diminished in the years following the release of the Foc.us device, there is still a significant degree of confusion surrounding tDCS (Cabrera and Reiner, 2015). In line with such thinking, people may be skeptical of either the efficacy or safety involved in home use of tDCS. It is also worth observing that while DIY movements themselves do not generally spread to the mainstream public, the commercialization of DIY techniques into consumer-friendly devices often results in greater public uptake. For example, though the quantified self movement began in mid-2008 (Swan, 2009), the commercialization of self-tracking tools (such as Fitbit and other wearable devices) has brought these technologies to the general population.

Indeed, the advent of consumer tDCS devices marketed via the direct-to-consumer route—a phenomenon that is just gaining steam—may alter the trajectory of uptake of tDCS. However, how vigorously consumers embrace this technology remains to be seen. Two recent studies have examined the efficacy of consumer devices: the first found that subjects who received stimulation with a Foc.us device performed significantly worse on an accuracy component of a working-memory task than subjects who received sham stimulation (Steenbergen et al., 2015). The second study, which was conducted by Thync on its own device, found that subjects who received stimulation reported reduced levels of stress and anxiety as compared to those who received sham stimulation, and their physiological measures of stress (such as heart rate variability and galvanic skin response) were also significantly lower (Tyler et al., 2015). It should be noted, however, that whether or not the technology works from a scientific perspective may be less relevant than how consumers *perceive* the efficacy of consumer-grade tDCS. Indeed, as described earlier, some individuals view a subjective sense of self-improvement as evidence of the device's effectiveness (Wexler, 2015a).

One notable feature of tDCS is that its efficacy for cognitive enhancement—at home or in the laboratory—seems to depend on concurrent training on a cognitive task. That is, tDCS for cognitive enhancement is not a "magic pill" but rather requires the individual to "train" on cognitive tasks while undergoing stimulation. Thus it is possible that the additional effort required to "train" may limit its uptake by the general public. There are instances, however, when training is not required: for example, tDCS used to treat depression has been shown to be effective without concurrent training (Brunoni et al., 2013). Thus, while the training effort may present a barrier for uptake in certain circumstances, it may not present a barrier in others.

In the preceding paragraphs, we have alluded to the modest gains that have been achieved with tDCS to date, but there is no reason to suspect that this state of affairs will hold in the

future. There is considerable interest in modifying the technology in a variety of ways—with alternating-current waveforms, combining it with EEG monitoring to provide current at just the right moment, and more (Voss et al., 2014; Chaieb et al., 2011; Lustenberger et al., 2015)—and some of these new techniques may result in more substantial gains than have been achieved to date.

In many ways, we are at a crossroads in the home use of tDCS. Although two studies on consumer tDCS devices have been published to date, only one (Steenbergen et al., 2015) was conducted by a third party without a conflict of interest. We recommend that efforts on the part of academics to study both the short- and long-term effects of consumer tDCS devices on cognitive function be increased; indeed, neuroscientists and neuroethicists may have an important role to play in monitoring the consumer neurotechnology industry. In tandem, we suggest the continuation of sociological studies on home users so that a comprehensive picture—both of the cognitive effects of the devices themselves and of their real-world usage practices—may be obtained.

The most important determinant of the future consumer tDCS market will likely be decisions from regulatory authorities. Even if the FDA elects not to enforce regulations against consumer tDCS devices, other regulatory agencies with jurisdiction over these products may take action. Indeed, the FTC's recent complaint against Lumos Labs (the makers of the brain-training program Lumosity) for making unsubstantiated cognitive-enhancement claims (FTC, 2016) has signaled that it is paying close attention to direct-to-consumer cognitive-enhancement products. A strict approach on the part of regulatory authorities may result in a gradual decline of consumer tDCS devices, whereas a more lax one may lead to the proliferation of such devices. Still, whether the technology achieves widespread adoption or becomes a niche product, whether it finds its best use in clinical or nonclinical settings, and whether it produces robust effects are all questions that remain to be answered.

Notes

1 Although we use the term "tDCS" throughout this chapter, many of our comments apply to the entire range of electrical brain stimulation devices.
2 See TCT Technologies, www.trans-cranial.com/; note that the company is currently conducting business as TCT Research Limited. See also www.tdcs-kit.com, and www.tDCSdevicekit.com, accessed between December 2012 and April 2013, archived versions available at http://web.archive.org.
3 See, e.g., www.amazon.com/DSS-Chattanooga-Ionto/dp/B00FC2SRMY and www.isokineticsinc.com.

Further Reading

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