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ORIGINAL ARTICLE

Who Uses Direct-to-Consumer Brain Stimulation Products, and Why? A Study of Home Users of tDCS Devices

Anna Wexler[1]

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Abstract
Despite the attention garnered by the home (or "do-it-yourself") use of tDCS (transcranial direct current stimulation), little is known about the population of actual users. The present study aimed to provide a comprehensive examination of those who purchase tDCS devices: who they are, how they learn about tDCS, and why and how they stimulate. A link to an online survey was sent to those who had purchased a tDCS device from seven different companies selling tDCS devices to the public as of June 2016; data was analyzed from 339 participants, the majority of whom reported residing in North America. The typical respondent was a wealthy, highly educated, liberal, fortysomething male living in the USA who reported being an early adopter of technology. Nearly three quarters of respondents reported using tDCS for cognitive enhancement, one-quarter for restoration, and approximately 40% for treatment; many participants selected a combination of usage indications. Notably, approximately one third of participants utilize tDCS to self-treat depression. Most who use tDCS for treatment find the technology to be effective, whereas most who use it for non-treatment purposes (i.e., only enhancement and/or restoration) find it to be ineffective. Approximately 40% of those who purchase tDCS devices either quit using the device (mostly due to lack of efficacy) or have never used the device (mostly due to lack of guidance). Participants depart from established scientific protocol particularly with regard to frequency of stimulation, with 8.4% reporting self-administering 100+ sessions of tDCS. With regard to side effects, a small subset of users ($n = 10$) reported serious skin burns. This study provides an empirical foundation on which to base policy recommendations and offers a fact-based perspective on a bioethical debate that has too-often been one step removed from reality.

Keywords Transcranial direct current stimulation · tDCS · Do-it-yourself · Consumer neurotechnology · Direct-to-consumer neuroscience · Neuroethics

Introduction

In the last two decades, there has been a vigorous debate about the ethical, legal, and social implications of human enhancement technologies (Farah et al. 2004; Lucke et al. 2011; Parens 2014; Farah 2015; Brenninkmeijer and Zwart 2016). One particular area of discussion has centered on the home (or "do-it-yourself"; DIY) use of transcranial direct current stimulation (tDCS; Dubljević et al. 2014; Hildt 2014; Lapenta et al. 2014; Maslen et al. 2014; Fitz and Reiner 2015; Wexler 2017), a technique that provides low levels of electrical stimulation to the brain. Scientists, clinicians, and ethicists have warned about the potential dangers and unintended consequences associated with the home use of tDCS (Cabrera et al. 2013; Iuculano and Cohen Kadosh 2013; Sarkar et al. 2014; Brem et al. 2014; Steenbergen et al. 2016), which is an experimental research technique (e.g., it does not have FDA approval or clearance in the USA; Fregni et al. 2015; Wexler 2016a). In 2015, the International Federation of Clinical Neurophysiology published a position paper cautioning against the DIY use of tDCS (IFCN 2015); the following year, an open letter to the DIY tDCS community—outlining the risks of brain stimulation—was published in *Annals of Neurology* and signed by 39 researchers (Wurzman et al. 2016).

Despite the attention garnered by the home use of tDCS, little is known about the population of actual users. To date, only two studies on home tDCS users exist: Jwa (2015) conducted a content analyses of postings to the online tDCS

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✉ Anna Wexler
awex@upenn.edu

[1] Department of Medical Ethics & Health Policy, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA, USA

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subreddit forum (www.reddit.com/r/tdcs), a survey, and in-depth interviews; Wexler (2016b) presented a preliminary sketch of the practices of home users, based on interviews and reviews of the tDCS-related forums, websites, and blogs. However, these studies had a number of limitations. First, because they relied on Internet sources, the sampled population may have skewed both towards active users of tDCS (who may be more likely to visit the tDCS subreddit and related websites) and towards younger, technology-savvy users of tDCS. Thus, findings may not have been representative of the broader user population. Second, both studies were conducted in late 2013 and early 2014, soon after the first direct-to-consumer wearable tDCS devices were marketed to the general public. The population of users, as well as the devices they utilize, may have shifted significantly in recent years, due to both extensive media coverage of DIY tDCS in 2014 and 2015 (Batuman 2015; Miller 2014; Radiolab 2014) as well as the increase in companies selling tDCS devices directly to consumers—in some cases for cheaper than it costs to build one from scratch.

The present study aimed to provide an updated, comprehensive examination of those who purchase consumer tDCS devices: who they are, how and why they use brain stimulation at home, and what they believe about safety, regulation, and brain optimization. Rather than recruiting via online avenues, the present study involved partnering with seven of the ten companies actively selling direct-to-consumer tDCS devices to the public as of June 2016. The resulting sample was comprised of individuals who had actually purchased such devices—not just those who had visited online forums. The study consisted of a survey that included both open-ended and forced-choice responses, allowing for the capture of quantitative data for some questions and qualitative data for others.

This study addressed a number of specific questions. First, while previous studies have shown that home users utilize tDCS both for cognitive enhancement and treatment (Jwa 2015; Wexler 2016b), it is unclear which characteristics, if any, differentiate these two groups. Thus, this study aimed to understand if "enhancers" and "treaters" differ from each other in meaningful ways (e.g., on demographics, attitudes, usage practices, and other measures). Second, this study aimed to better understand those who quit using tDCS, a population that has not yet been examined. Third, this study sought to determine if there was a significant population of users who are not actively engaged with the tDCS subreddit, and if so, what characteristics might differentiate them from visitors to the subreddit. Fourth, this study sought to understand how home users of tDCS differed from the general population by comparing participant data (e.g., on sociodemographics and attitudes) to data from the US population, where possible. Fifth, this study aimed to provide the first descriptive account of those who utilize tDCS primarily on others.

This study adds to the existing literature on cognitive enhancement in a number of ways. Although previous studies have examined the demographics, motivations, and attitudes of those who utilize cognitive enhancement *drugs* (e.g., Eickenhorst et al. 2012; Ragan et al. 2013; Forlini et al. 2014; Ott and Biller-Andorno 2014; Vargo and Petróczi 2016; Riddell et al. 2017), there is little data to-date on similar measures for those who utilize brain stimulation *devices* marketed for cognitive enhancement. In addition, while many studies on the use of cognitive enhancement drugs have focused on local populations, often comprised of university students, the methodology employed here allowed for the examination of a unique sample that cut across a wide array of ages and geographical locations. As users of pharmacological cognitive enhancement often source their drugs informally or illicitly (Ott and Biller-Andorno 2014; Vargo and Petróczi 2016), a similar methodology would not likely be feasible in that context. Furthermore, this study is one of the few to compare sociodemographics and attitudes of users of cognitive enhancement products—particularly with regard to education, income, political views, and views on religion and science—to existing population data.

Methods

Recruitment

Of the ten companies selling tDCS devices directly to consumers as of June 2016, seven agreed to participate in the study on the condition of anonymity. Five of these companies were based in the USA, though all shipped devices internationally. In June 2016, an email was sent to companies' customer lists with a unique link to the online survey (five companies emailed their customers directly; customers of two companies were emailed directly by the author via Qualtrics online survey software). A follow-up reminder email was sent to the email lists of five of the seven companies after approximately 3 weeks (two companies did not comply with requests to send out a reminder email). The text of both the initial email and the reminder email were kept consistent across companies. The survey remained open for each unique link for approximately 30 days. Following completion of the survey, all participant data was anonymized and divided into subsets based on the unique links assigned to each company. Anonymized data from each unique link was shared only with that specific company; in other words, each company saw anonymized data only from respondents who clicked through their unique link.

Survey Instrument

The survey instrument (Appendix 1) was designed based on previous work studying home users of brain stimulation. Comments on the initial draft of the survey were solicited from members of the DIY brain stimulation community,

consumer tDCS manufacturers, sociologists, ethicists, and neuroscientists. The survey instrument underwent pilot testing prior to launch to ensure that all questions were clear and that navigation through the survey functioned as expected. The survey contained questions about participants' tDCS device(s), usage practices, beliefs, attitudes, and sociodemographics; the number of questions displayed for any one respondent was contingent upon participants' particular involvement with tDCS. For example, participants who reported using tDCS both on themselves and others saw the greatest number of questions (80), whereas participants who reported purchasing a device for use on oneself, but never using it, saw the fewest number of questions (40). The survey contained a mix of closed and open-ended responses for conventional content analysis.

Analysis

Closed-ended questions were analyzed using SPSS v24 (SPSS Inc., Chicago, IL). Descriptive statistics were used to characterize the composition and properties of the sample, and simple inferential statistics (Pearson chi-square) and effect sizes (Cramer's V), as well as independent sample *t* tests, were used to explore significant differences between subgroups. For each open-ended question, two individuals (the author and another coder) began by separately analyzing a subset of responses (generally ~100), developing categorical themes or codes iteratively (Chi 1997; Braun and Clarke 2006). Next, following discussion of the central concepts and research questions, both coders agreed upon a final set of thematic categories with sets of indicator codes. With final coding themes in place, each coder proceeded to code the entire data set separately. Each theme was treated as a binary variable, and each open-ended response received a "1" if the theme was present or "0" if it was absent. Once all comments were coded, the frequency with which any theme emerged in the comments was compared across contrastive conditions. Initial inter-coder reliability (Lombard et al. 2002) was calculated across the ten open-ended questions coded (Cohen's Kappa was 0.97); after review, agreement was 100%.

Results

Response Rate and Exclusion Criteria

Response Rate

The recruitment email message (Appendix A) was sent to a total of 10,393 email addresses across seven companies; as 232 emails bounced, the message was successfully delivered to 10,161 email addresses. This number does not necessarily reflect the number of unique individuals who received the recruitment email; it is possible that (a) participants purchased devices from two companies in the survey and therefore received an email from each company and/or (b) a single participant used multiple email addresses to purchase a device within the same company. Although companies were instructed to send emails only to those who had purchased a tDCS device, one company's mailing list did not differentiate between those who purchased accessories versus devices, and another company sent emails to everyone who had opted in to its mailing list. Together, these two companies' email lists made up approximately 7% of all email addresses.

To ensure as well-controlled a sample as possible, no recruitment links were posted to social media, the tDCS subreddit or other tDCS-related websites. During the month that the survey was open, the tDCS subreddit, Twitter, and tDCS-related blogs and websites were closely monitored for mentions of the survey. Aside from a home user who posted a survey link to Twitter, the survey appears to have remained limited to the seven companies' customer lists.

In total, 349 respondents completed the survey in its entirety, for an aggregate response rate of 3.9%. Response rates for individual companies ranged from 1.1 to 5.7%, with a median of 5%.

Exclusion Criteria

Eight participants were excluded because they did not report owning a consumer tDCS device. Another two participants were excluded because they had typed random letters for all the open-ended responses. Thus, in total, data from 339 participants was analyzed.

As an additional check on the data, all responses were reviewed to ensure that those coming from each company's unique link reported purchasing a device from that specific company. In total, 96.5% ($n = 327$) of respondents "matched" in terms of unique company link and reported device, while 3.5% ($n = 12$) were "mismatches." The "mismatches" may have occurred for a number of reasons: (a) participants who purchased devices and accessories from more than one company may have received multiple survey links, and may have clicked through the link from the company from which they purchased an accessory, not a device; (b) participants may have clicked on the survey link through the Twitter posting mentioned above, or were forwarded the survey link by another individual; and (c) participants may have erred in reporting on their purchased device. However, after ensuring that each of the 12 "mismatches" owned at least one consumer tDCS device, these participants were included in the analyses.

Demographics and Participant Characteristics

Sociodemographics

Detailed sociodemographic data is reported in Table 1. The mean age of participants was 45.3 (SD = 13.9; see also age histogram in Fig. 1), which was surprising given that previous studies have portrayed typical home users of tDCS as being in their 20s or 30s (Jwa 2015; Wexler 2016b). Respondents were split relatively evenly across generations, with approximately one-third each being Millenials, Gen Xers, and Baby Boomers. Although the majority of participants were male (83.5%), there was a much higher proportion of females (15.3%) than the 4% previously reported by Jwa (2015). Most participants (73.5%) reported residing in North America (Fig. 2). Across the 32 countries represented in the sample, the three most-common were the USA (68.7%), Australia (5.3%), and Canada (4.7%). Roughly a quarter of all US-based respondents reside in California, with the next most-represented states being Massachusetts, New York, and Texas.

Table 1 Sociodemographics ($N = 339$)

		n (%)	Range
Gender	Male	238 (83.5%)	
	Female	52 (15.3%)	
	Prefer not to answer	4 (1.2%)	
Age, mean (SD)	45.3 (13.9)		20–87
Age, by generation*	Millenial (ages 18–35)	99 (29.2%)	
	Generation X (36 to 51)	113 (33.3%)	
	Baby boomer (52 to 70)	106 (31.3%)	
	Silent generation (71+)	10 (2.9%)	
Race	White	286 (84.4%)	
	Asian	32 (9.4%)	
	Hispanic	19 (5.6%)	
	Other	22 (6.5%)	
Marital status	Never married	96 (28.3%)	
	Married	151 (44.5%)	
	Living with a partner	35 (10.3%)	
	Separated	13 (3.8%)	
	Divorced	40 (11.8%)	
	Widowed	4 (1.2%)	
Parental status	No children	194 (57.2%)	
	Has at least one child	145 (42.8%)	
Employment	Employed full-time	231 (68.1%)	
	Employed part-time	27 (8.0%)	
	Unemployed	17 (5.0%)	
	Retired	36 (10.6%)	
	Student	19 (5.6%)	
	Disabled	6 (1.8%)	

*Generation categories defined according to Pew (2016d)

Comparison to US Population: Education, Income, Political Views, and Religious Preferences

As US residents comprised more than two-thirds of the sample, population data from the USA was selected for comparative purposes. Similar results were obtained when comparing data from the general US population to either all participant data ($N = 339$) or to the subset of US residents only ($n = 233$); comparisons using data from all participants are reported here and statistics for both are reported in Table 2.

Compared to the US population, participants' had a higher educational attainment: most (77.9%) had a college degree or higher, compared to 44.5% of the general US population, and 36.3% had a master's or doctoral-level degree, compared to just 12.0% percent of the general US population (U.S. Census Bureau 2016, p. 2, Table 1). Given that educational attainment has been shown to be positively correlated with income level (see, e.g., Boshara et al. 2015), it was not surprising that participants reported higher levels of income compared to the US population. Figure 3 shows the distribution of income among the subset of US residents as compared to the US general population (U.S. Census Bureau 2017).

Most participants (70.5%) reported being politically liberal; this proportion is nearly three times that of the general US population who self-identify as liberal (24%; Saad 2015). In addition, consumers of tDCS devices are far less engaged with religion than the US population, as measured by frequency of attending religious services: the majority of participants (77.9%) never or rarely attend religious services, compared to 36% of the US population (Pew Research Center 2015b, p. 152).

Comparison to US Population: Early Adoption of Technology and Engagement with Science

Compared to the US population, consumers of tDCS devices are earlier adopters of technology: most participants (63.7%) report being "the first" or "among the first" to try a new technology product relative to their peers (Table 2), while a recent study found that just 15% of Americans report trying a new technology before others (Pew Research Center 2016a, p. 2). Consumers of tDCS devices are also far more interested in science than the US population: most (82.3%) report reading articles about science frequently or very frequently (Table 2), while a recent survey found that just 37% of Americans enjoy keeping up with science news "a lot" (Pew Research Center 2015a, p. 82 Q3).

Use of Other Brain Enhancement/Electrical Stimulation Techniques

tDCS is not the only technique that participants utilize to improve their brain function: nearly half have used dietary

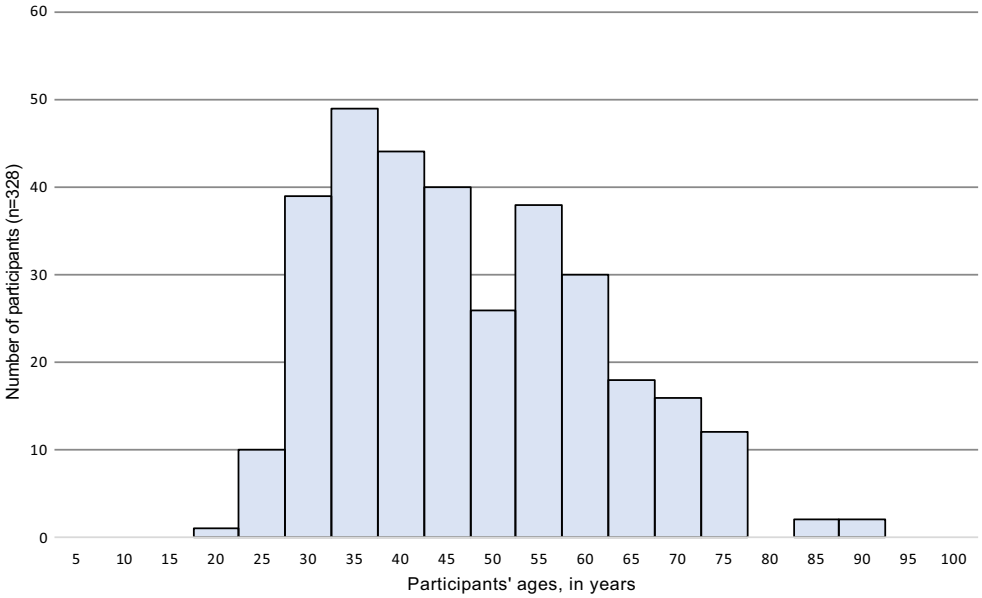

Fig. 1 Histogram of participants' ages ($n = 328$), in years. (Eleven participants did not provide age data)

supplements or non-prescription drugs to improve cognition; and more than a third each reported using (a) brain-training games, (b) binaural beats, or (c) self-tracking tools to optimize productivity (Table 3a**)**. Just 7.7% of participants have used direct-to-consumer electroencephalography (EEG) devices, which purportedly measure and display a user's electrical brainwave activity and are generally marketed for "wellness" purposes (see, e.g., Emotiv Insight, https://www.emotiv.com/insight/ and Muse, http://www.choosemuse.com/). Thus, although EEG- and tDCS-based devices represent the major direct-to-consumer, wearable neurotechnology products marketed for self-improvement, there may be little overlap among their users.

Learning About tDCS

Participants were asked to describe, in their own words, how they first heard about tDCS. Very few participants (7.1%) learned about tDCS from within their own social networks (i.e., from another person); most heard about it from the Internet (43.1%), podcast/radio (33.0%), or news/magazine outlets (13%); some first heard about tDCS from a television show or documentary (5.3%), or a scientific journal (5.0%). Notably, approximately 1 in 8 participants (13.3%) came to tDCS after hearing about it from a single Radiolab podcast episode (Radiolab 2014).

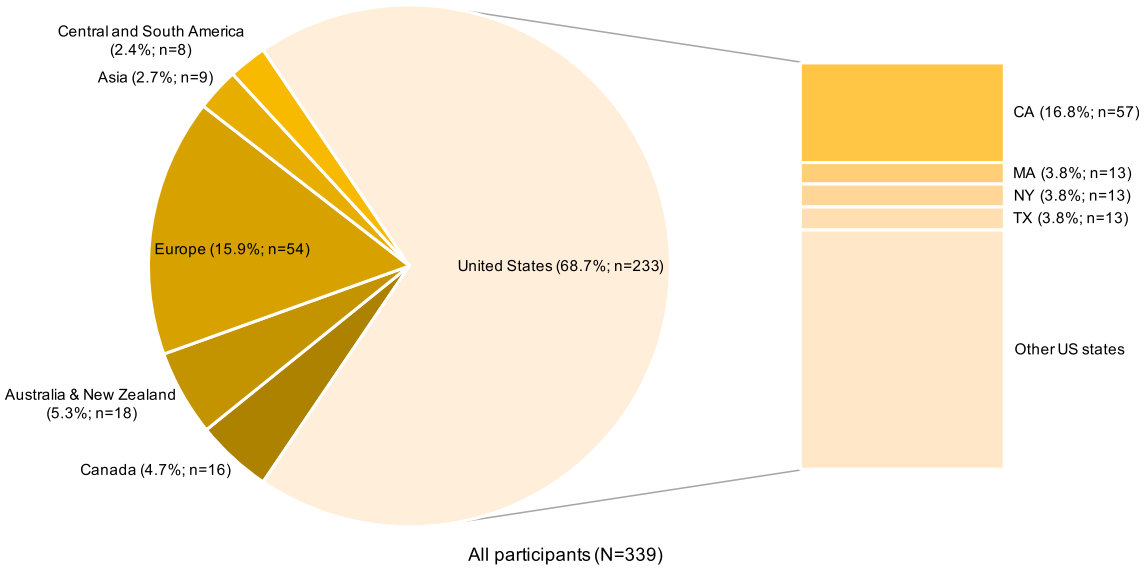

Fig. 2 Participants' ($n = 338$) geographical locations. (One participant did not provide geographical location data)

Table 2 Comparisons to US general population data

		All participants ($N = 339$) n(%)	US residents only ($n = 233$) n(%)	General US population %
				U.S. Census Bureau (2017)
Education	High school or less	19 (5.6%)	7 (3.0%)	39.7%
	Some college or university	56 (16.5%)	44 (18.9%)	26.8%
	College/university degree	141 (41.6%)	95 (40.8%)	20.8%
	Master's degree	68 (20.1%)	43 (18.5%)	9.3%
	Doctorate/professional degree	55 (16.2%)	44 (18.9%)	3.4%
				U.S. Census Bureau (2016)
Income	Less than $25,000	41 (12.1%)	22 (9.4%)	22.1%
	$25,000–49,999	51 (15.0%)	35 (15.0%)	22.7%
	$50,000–74,999	53 (15.6%)	27 (11.6%)	16.7%
	$75,000–99,999	46 (13.6%)	30 (12.9%)	12.1%
	$100,000–149,999	59 (17.4%)	42 (18.0%)	14.1%
	$150,000–199,999	39 (11.5%)	32 (13.7%)	6.2%
	$200,000 +	50 (14.7%)	45 (19.3%)	6.1%
				Saad (2015)
Politics	Liberal	239 (70.5%)	158 (67.8%)	24.0%
	Moderate	59 (17.4%)	40 (17.2%)	34.0%
	Conservative	41 (12.1%)	35 (15.0%)	38.0%
		Political affiliation (US-based participants only, $n = 233$)		Pew Research Center (2016c)
		Democrat	165 (70.8%)	48.0%
		Republican	45 (19.3%)	44.0%
		Other/no preference	23 (9.9%)	8.0%
				Pew Research Center (2015b)
Religion (frequency of attending religious services)	Weekly or more	29 (8.6%)	23 (9.9%)	30.0%
	Monthly/yearly	46 (13.6%)	36 (15.5%)	33.0%
	Never or seldom	264 (77.9%)	174 (74.7%)	36.0%
				Pew Research Center (2016a)
Adoption of technology	Early adopters	217 (63.7%)	145 (62.2%)	*
	In the middle	98 (28.7%)	69 (29.6%)	
	Late adopters	24 (7.0%)	19 (8.2%)	
				Pew Research Center (2015a)
Frequency of reading scientific articles	Frequently/very frequently	279 (82.3%)	185 (79.4%)	*
	Occasionally	53 (15.6%)	43 (18.5%)	
	Rarely or Never	7 (2.1%)	5 (2.1%)	

*Only select data points comparable; see main text

Most participants learned about which stimulation parameters to utilize (i.e., how to apply stimulation) from the Internet (52.9%). Others learned from the device manufacturer (20.8%), as some companies provide information on their websites (or include instructions with the device) regarding usage. The remainder learned about stimulation parameters from trial and error (14.6%), scientific journals (14.6%), or tDCS placement websites (e.g., http://tdcsplacements.com/; 8.1%). A small percentage (9.1%) mentioned that their device had a pre-set placement configuration and they did not need to learn about stimulation parameters.

tDCS Device(s)

On average, participants paid $177 for their tDCS device, with a median of $139. Though prices paid ranged from $0 (presumably for a home-built or gifted device) to $6000 (for the highest-end device), the middle 90% of participants (i.e., excluding the top and bottom 5%) paid between $25 and $325 for their device. Most participants (79.9%) reported owning only one device and purchasing it directly from the manufacturer (90.7%; Table 4). At the time of the survey, participants reported owning a tDCS device for a mean length of

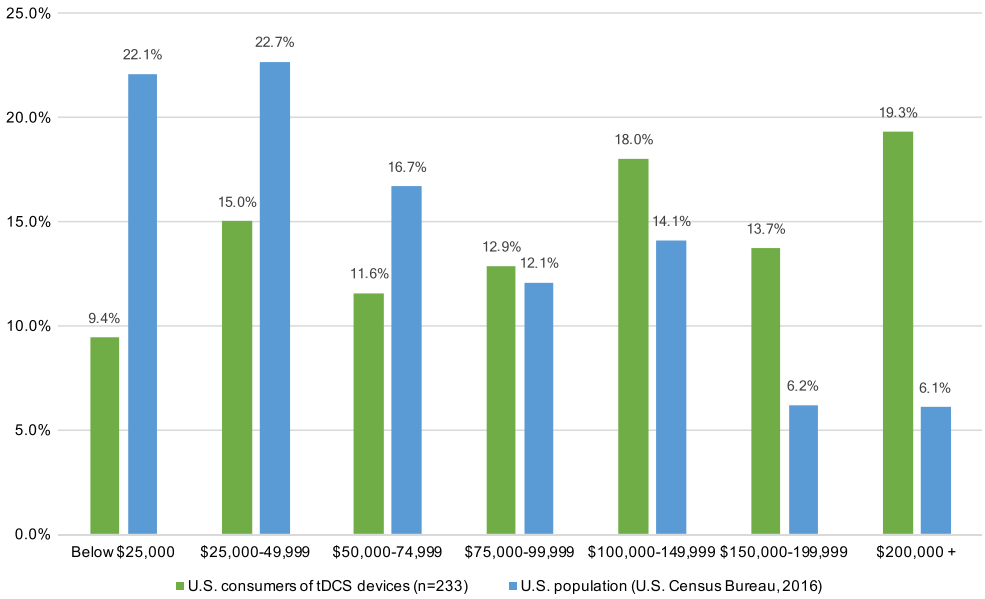

Fig. 3 Annual household income, US consumers of tDCS devices ($n = 233$) compared to US population (US Census Bureau 2016b)

16.9 months (Table 4). Participants reported owning a total of 421 neurostimulation devices from 18 different companies. This figure includes manufacturers selling devices that are not expressly marketed for tDCS (e.g., iontophoresis devices, research-grade devices, and Thync edition one), as well as several companies no longer actively selling tDCS devices as of spring 2016. Notably, 66.0% of all reported devices came from a single manufacturer (Table 4).

Primary Intended Use: Self vs. Other

Primary Intended Use: Self vs. Others

The vast majority of respondents (96.5%, $n = 327$) reported purchasing a device to use primarily on themselves, whereas 3.5% ($n = 12$) purchased a device with the primary intention of administering stimulation to others.

Below, results are briefly reported from participants who purchased tDCS devices primarily for use on others; the "Purpose of use" section through the "Perceived effects of tDCS stimulation" report results only from those who intended to use tDCS primarily on themselves.

Participants Who Use tDCS Primarily on Others

Among those who purchased a tDCS device to use primarily on others ($n = 12$; 9 males), in all but one case, the intended subject(s) of stimulation included a family member, most commonly a child ($n = 6$) or spouse ($n = 4$). Most individuals ($n = 11$) were using tDCS on others to treat disease or mitigate disease-related symptoms, such as those related to depression ($n = 4$), traumatic brain injury ($n = 2$), chronic pain ($n = 1$), migraine headaches ($n = 1$), epilepsy ($n = 1$), incontinence due to multiple sclerosis ($n = 1$), and memory loss due to primary progressive aphasia ($n = 1$). Five individuals reported using tDCS to affect cognition—memory, focus, attention—in some way, although the line between treatment and enhancement was not always clear (e.g., two participants used tDCS in an attempt to improve a family member's concentration levels: one reported that a diagnosis of ADD had been given, whereas the other only noted that the child had low grades).

Among those who have used tDCS on others, the number of sessions administered ranged from 5 to 100 with a mean of 28; electrical current levels utilized ranged from .5 to 2 milliamps (mA) with a mean of 1.59 mA; and the typical length of stimulation session in minutes ranged from 10 to 40 with a mean of 23.64. Most ($n = 7$) have used tDCS at least once on themselves, but only some ($n = 3$) reported still actively self-administering stimulation.

Half of those who have used tDCS on others ($n = 6$) found the technique to be successful; some ($n = 3$) were not sure and a few ($n = 2$) felt it was unsuccessful. When asked if tDCS caused any unwanted effects in those to whom it was administered, most ($n = 7$) said it did not, though some ($n = 3$) reported skin sensations (tingling/itching) and one reported a phosphene (flash of light in the visual field). Six participants reported that they currently administer tDCS to others once a month or more, some ($n = 2$) use it in fits and spurts, and others ($n = 3$) no longer use tDCS, mostly ($n = 2$) due to lack of efficacy.

Purpose of Use

As noted above, the analyses in this section (as well as the "Frequency of tDCS use" section through the "Perceived effects of tDCS stimulation" section) focus only on those individuals who reported using tDCS primarily on themselves ($n = 327$). Among these participants, the reasons for

Table 3 Use of other brain enhancement/electrical stimulation techniques. Panel A, left: responses for all participants. Panel B, right: responses for those who visited the tDCS subreddit (VR) compared to those who had never visited (NR) and X^2 significance

A. All participants ($N = 339$)		B. Visited tDCS subreddit (VR; $n = 179$) vs. never visited (NV; $n = 160$)		
	n (%)	VR	NV	X^2
Dietary supplements or non-prescription drugs to improve cognition	164 (48.4%)	99 (55.3%)	65 (40.6%)	**
Brain-training games (e.g., lumosity or CogniFit)	132 (38.9%)	79 (44.1%)	53 (33.1%)	*
Binaural beats	125 (36.9%)	75 (41.9%)	50 (31.3%)	*
Self-tracking tools to help optimize some aspect of my life (e.g., sleep or productivity)	116 (34.2%)	72 (40.2%)	44 (27.5%)	*
Prescription drugs to improve cognition	90 (26.5%)	57 (31.8%)	33 (20.6%)	*
Other	40 (11.8%)	20 (11.1%)	20 (12.5%)	
Transcutaneous electrical nerve stimulation (TENS)	39 (11.5%)	24 (13.4%)	15 (9.4%)	
Self-tracking tools to help cope with a disease/condition	37 (10.9%)	26 (14.5%)	11 (6.9%)	*
Transcranial alternating current (tACS)	32 (9.4%)	22 (12.3%)	10 (6.3%)	†
Consumer electroencephalography device (EEG)	26 (7.7%)	20 (11.2%)	6 (3.8%)	**
tRNS (transcranial random noise stimulation)	20 (5.9%)	14 (7.8%)	6 (3.8%)	†
Audio visual entrainment (AVE) therapy	19 (5.6%)	13 (7.3%)	6 (3.8%)	
Cranial electrotherapy stimulation (CES)	12 (3.5%)	9 (5.0%)	3 (1.9%)	
Transcutaneous vagus nerve stimulation (tVNS)	6 (1.8%)	6 (3.4%)	0 (0.0%)	‡

†$p <= .10$; *$p <= .05$; **$p <= .01$; two-tailed test. ‡ = Fisher's exact test, $p < .05$

purchasing consumer tDCS devices were assessed in two ways: first via an open-ended response and later with forced-response questions that were shown to those who reported using tDCS at least once on themselves ($n = 308$).

Open-Ended Response

Without any category prompts, participants were asked to report in their own words why they purchased a tDCS device. Open-ended responses were coded thematically; responses could be coded for more than one theme. Approximately two-thirds of participants mentioned cognitive enhancement reasons and one-third mentioned therapeutic reasons. Notably, one-quarter mentioned curiosity, novelty, and/or self-experimentation, suggesting that enhancement and treatment are not the only reasons why individuals purchase consumer tDCS devices. For clarity, detailed statistics are reported only for the forced response questions, which queried participants specifically about each usage indication (see below).

Forced-Response Questions: Utilization for Treatment, Restoration, and/or Enhancement

All participants who reported using tDCS at least once on themselves ($n = 308$, see "Frequency of tDCS use" section) were asked to indicate (yes/no) whether they had ever self-administered tDCS "to treat a medical/psychological disease or condition" (i.e., treatment), "to restore diminished cognitive abilities (for example, to counteract the effects of aging" (i.e., restoration), or "to improve your own cognitive abilities" (i.e., enhancement). As shown in Fig. 4a, approximately three-quarters (76.9%) of all those who used tDCS at least once reported using tDCS for enhancement, a little under a half (42.5%) for treatment, and roughly one-quarter (26.3%) for restoration. The percentages reported here are slightly higher than those reported in the previous question for two reasons: first, participants were specifically asked if they had used tDCS for each of these particular indications, as opposed to a general question about why they purchased a tDCS device; second, the denominator is smaller, as this question was shown only to those who had actually used tDCS at least once on themselves ($n = 308$). Both across open-ended responses and forced-response questions approximately the same proportion (2:1) was found for enhancement vs. treatment; this is roughly the same proportion as reported by Jwa (2015). Similar to Jwa (2015), there was significant overlap in terms of usage indications; as shown in Fig. 4b, only 56.8% of participants selected a single indication (i.e., only treatment, only enhancement, or only restoration).

Detailed Usage Indications for Treaters, Enhancers, and Restorers

Among those who have used tDCS for treatment ($n = 131$), approximately three quarters (74.0%) reported utilizing tDCS for depression; anxiety (42.0%) and ADD/ADHD (26.7%) represent the second- and third-most common usage indications (Table 5). Among both enhancers and restorers, the two most common indications were improving focus/concentration and

Table 4 tDCS device characteristics

	n	%	Mean	Median
Number of consumer tDCS devices owned by participants	*N = 339*			
One	271	79.9%		
Two	57	16.8%		
Three	8	2.3%		
Four	3	0.9%		
Price of tDCS device			$177	$139
Length of time owned device (in months)			16.9	14
Point of sale	*n* = 421 (devices)			
Company/manufacturer	382	90.7%		
eBay	6	1.4%		
Amazon	4	1.0%		
Other	29	6.9%		
Distribution of tDCS devices across 18 different companies	*n* = 421 (devices)			
Company A	278	66%		
Company B	40	9.5%		
Company C	21	5%		
Company D	19	4.5%		
Home-built	15	3.6%		
Company E	7	1.7%		
Company F	6	1.4%		
Company G	6	1.4%		
Companies H-R	29	6.9%		
Most common likes*	*N = 339*			
Ease of use	115	33.9%		
Design of the device	108	31.9%		
Portability	65	19.2%		
Cost	50	14.7%		
Most common dislikes*	*N = 339*			
Poor design/quality	108	31.9%		
Electrodes	93	27.4%		
Side effects	46	13.6%		
Lack of directions	46	13.6%		
Lack of efficacy	39	11.5%		

*Participants were asked to describe, in their own words, what they liked and disliked about their device; responses were coded thematically. For participants who owned multiple devices, one device was selected at random and participants were asked them to respond to the likes/dislikes question for that device only

memory (Table 5). Interestingly, the order of these two indications was flipped for each group: memory was the most common target of restorers, whereas focus/concentration was the most common target of enhancers.

Treaters, enhancers, and restorers differ from each other in several ways. Those who selected "restoration" had a significantly higher mean age (48.6 years; SD = 14.4) than those who did not [42.5 years; SD = 12.8; $t(296) = 0.001$, $p <= .001$], and those who selected "treatment" also had a significantly higher mean age (46.2 years; SD = 13.5) than those who did not [42.6 years; SD = 13.3; $t(296) = 0.24$, $p <= .05$]. Additionally, those who selected "enhancement" had a significantly lower mean age (43.0 years; SD = 13.2) than those who did not [47.0 years; SD = 14.0; $t(296) = 0.047$, $p <= .05$].

As depicted in Fig. 4b, there was significant overlap among treaters, enhancers, and restorers, with many participants

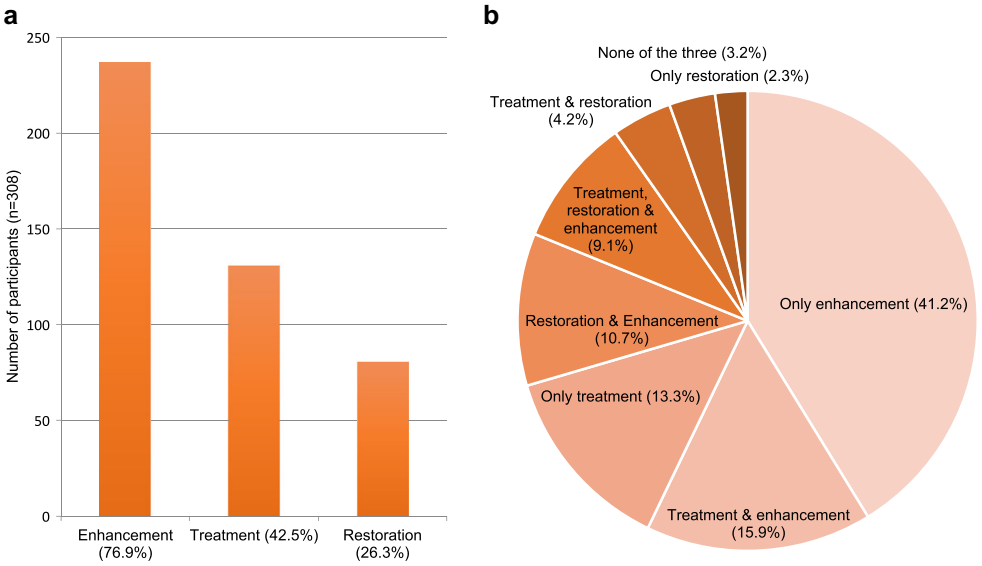

Fig. 4 **a** Primary purpose of tDCS, as indicated by yes/no forced responses; participants could select "yes" to all three indications. **b** Percentages of participants falling within each combination of usage indications (treatment, restoration, enhancement). Question was shown to all those who purchased tDCS primarily for use on themselves and had used tDCS at least once ($n = 308$)

selecting more than one usage indication. However, as restorers were similar to enhancers in that they were aiming to affect a cognitive function (as opposed to treating a disease), all those who had selected using tDCS for treatment ("treaters"; $n = 131$) were grouped together and compared to a separate set of individuals who had selected only enhancement, only restoration, or enhancement and restoration ("non-treaters"; $n = 167$). The effect of "purpose of use" (i.e., treaters vs. non-treaters) was then compared across categorical and continuous variables.

Most notably, there was a significant relationship between gender and usage purpose, with males significantly more likely to be non-treaters and females more likely to be treaters (Fig. 5a**)**. Among female treaters ($n = 33$), most ($n = 27$) reported using tDCS to self-treat depression. There was also a significant relationship between usage purpose and perceived success of tDCS, with treaters more likely than non-treaters to rate tDCS as successful, and vice versa Fig. 5b. This effect was robust and apparent across other indirect measures of success: non-treaters had a significantly higher mean agreement level than treaters on a variety of statements, such that they expected to get more out of tDCS than they actually did, and that tDCS is merely a novelty item (Table 6b). Furthermore, those who cited "lack of efficacy" as a reason for quitting tDCS were significantly more likely to be non-treaters than treaters [$X^2(1, N = 298) = 4.45$, $p = .035$; Cramer's V = .117]. Not surprisingly, treaters—who found tDCS to be more successful—were more likely than non-treaters to be current users of tDCS [$X^2(1, N = 298) = 4.24$, $p = .04$; Cramer's V = .122].

Treaters also had a higher mean agreement level (than non-treaters) with the statement that mainstream medicine is out of touch with the needs of patients (Table 6b). However, there were no significant differences between treaters and non-treaters when it came to how they value alternative medicine (Table 6b). Thus, while treaters may be frustrated with modern medicine, they are not necessarily more likely than enhancers/restorers to turn to alternative medicine; this finding can be expected given that the present sample is comprised of individuals who have a strong affinity towards science. Additionally, as shown in Table 6b, non-treaters had a higher mean agreement level with the statement that the brain can be "hacked" to improve performance. In other words, while treaters may be turning to tDCS because of a disease or disorder, non-treaters are turning to tDCS to improve their cognition—either for enhancement or restoration—and are therefore more likely to conceptualize the brain as an organ that can be optimized for performance.

Frequency of tDCS Use

Usage Distribution

The distribution of current users, former users, and those who never used tDCS is shown in Fig. 6 for participants who purchased tDCS for use on themselves ($n = 327$). The 59.3% ($n = 194$) who reported being current users were further subdivided based on their frequency of use, with the largest group using tDCS only in "fits and spurts" (Fig. 6). Approximately half of all current users of tDCS ($n = 92$) report that their frequency of use has remained constant since they began using tDCS. Those who reported that their frequency of use has changed were asked to describe their previous patterns of usage; while responses were not coded thematically, the overall trend was towards decreasing usage (e.g., participants reported using tDCS less now than they did in the past). Thus, even among current users, tDCS is a technique that participants use less over time, not more.

Those Who Never Used tDCS

Those who purchased a consumer tDCS device but never used it (5.8%; $n = 19$) were asked to describe, in their own words,

Table 5 Detailed usage indications for treaters, enhancers, and restorers

	n	%
Treatment	*n = 131*	
Depression	97	74.0
Anxiety	55	42.0
ADD/ADHD	35	26.7
Chronic pain	12	9.2
Bipolar disorder	7	5.3
Migraine	7	5.3
Tinnitus	6	4.6
Addiction	5	3.8
Enhancement	*n = 237*	
Focus/concentration	100	42.2
Memory	61	25.7
Learning	57	24.1
General enhancement	56	23.6
Mood/emotion	26	11.0
Physical abilities	25	10.5
Speed/reaction time	23	9.7
Creativity	14	5.9
Restoration	*n = 81*	
Memory	31	38.3
Focus/concentration	21	25.9
General enhancement	19	23.5
Problem solving	12	14.8
Mood/emotion	9	11.1
Other	8	9.9
Learning	7	8.6
Speed/reaction time	4	4.9
Physical abilities	4	4.9

Participants who answered affirmatively to having used tDCS for either treatment, enhancement, or restoration were asked to provide follow-up information, by selecting from a list of diseases/conditions (for treatment) or elaborating via free-form text (for restoration/enhancement); the latter responses were coded thematically

why they had not tried stimulation. The most common reasons provided were concerns regarding the safety of the procedure and lack of information provided by the manufacturer, particularly with regard to electrode placement. All of these participants reported that they were open to using tDCS, if there was additional evidence to validate the efficacy and safety of technique, and/or if more information was provided by the manufacturer regarding electrode placement.

Those Who Quit Using tDCS (Former Users)

Approximately one-third of participants (34.9%; $n = 114$) reported being former users of tDCS; they were asked to describe, in their words, why they stopped using stimulation. The most common reason provided was lack of efficacy, although participants also cited side effects, lack of information about stimulation protocols, and concerns about potential long-term effects, among other reasons (Table 7). When asked if they would use tDCS again (and if so, to describe why), 93% reported being open to using tDCS again, if there was additional evidence regarding efficacy or additional guidance from the manufacturer (Table 7).

That lack of efficacy is the main reason for quitting tDCS was supported by further statistical analysis on the differences between current and former users. Current users were much more likely than former users to rate tDCS as successful (and former users more likely to rate tDCS as unsuccessful), as shown in Fig. 7. In addition, current users had a significantly higher mean disagreement level than former users with related attitudes measures shown in Table 6, such that they expected to get more out of tDCS then they actually did [mean current users = 2.8 (SD = 1.1), mean former users = 1.8 (SD = 1.0), $t(306) = 0.000$, $p < =.001$], and that tDCS devices are merely novelty items [mean current users = 3.7 (SD = 1.0), mean former users = 2.9(SD = 1.0), $t(306) = 0.000$, $p < =.001$]. Former users hold a more negative and skeptical view of tDCS, as they had a significantly higher mean agreement level with the statement that tDCS should not be used without professional guidance [mean current users = 3.7 (SD = 1.0), mean former users = 3.3 (SD = 1.1), $t(306) = 0.001$, $p < =.001$], and a significantly higher mean disagreement level with the statement that tDCS is a relatively safe technique [mean current users = 1.8 (SD = .8), mean former users = 2.4(SD = 1.0), $t(198) = 0.000$, $p < =.001$]. As noted earlier in the discussion of treaters vs. non-treaters, current users are more likely than former users to use tDCS for treatment than non-treatment (i.e., only enhancement and/or restoration).

Stimulation Parameters and Protocols

Results reported in this section reflect responses from those who purchased tDCS devices for use primarily on themselves and reported using tDCS at least once ($n = 308$). Most participants reported utilizing 2.0 milliamps (mA) of current or less, similar to the levels of current utilized in scientific studies (Lefaucheur et al. 2017; Mancuso et al. 2016). Although some users reported current levels higher than 2.0 mA, all of these users reported either not understanding the question—it was an open-ended response—or only owning devices that do not provide more than 2.0 mA of current. Participants also roughly adhere to the typical length of stimulation sessions used in scientific studies (~ 15–30 min), with the most common reported length being 20 min (Fig. 8).

Notably, participants departed from established scientific tDCS protocols when it came to frequency of stimulation (i.e., total number of sessions administered). Scientific studies of tDCS in healthy populations often administer a single session of stimulation (Horvath et al. 2015); those that examine the effects of tDCS in clinical populations (i.e., to treat depression)

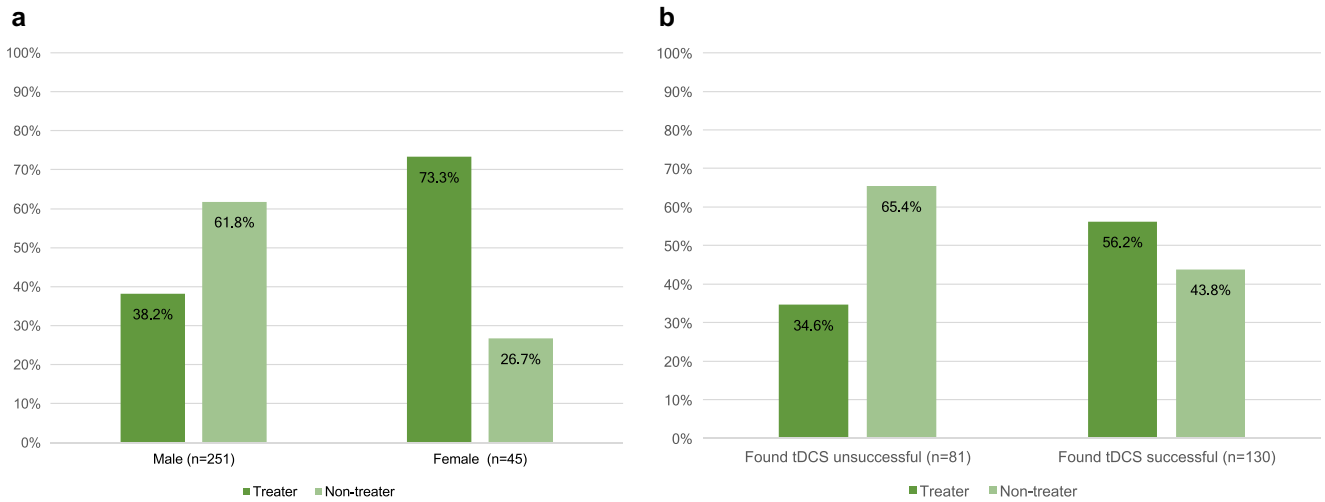

Fig. 5 **a** Treaters vs. non-treaters (i.e., those who selected only enhance and/or restore), by gender [$X^2(1, N = 296) = 19.11, p < .001$; Cramer's V = .254]. **b** Treaters vs. non-treaters, by ratings of success of tDCS [$X^2(1, N = 211) = 9.32, p = .002$; Cramer's V = .210]

generally administer on the order of 5–15 sessions (Lefaucheur et al. 2017). Among those who had used tDCS at least once on themselves, more than 40% of participants had self-administered over 21 sessions of tDCS, and among them, 8.4% were "super-users" who had self-administered 100 or more sessions (Fig. 9).

Perceived Effects of tDCS Stimulation

Measuring the Effects of Stimulation

Participants ($n = 308$) were asked if they had attempted to measure or quantify the effects that tDCS had on them, and if so, to describe how they did so. The largest group of participants (47.7%; $n = 147$) reported that they did not attempt to measure the effects the stimulation. Others (19.5%; $n = 60$) reported relying on self-observation and self-reflection (i.e., how they felt). Another group utilized what was coded as "personal tests" (12.3%, $n = 38$), meaning that they created measures of validity for themselves. Examples of responses coded as personal tests include "I tried memorizing various lists of medical terms with and without tDCS, and compared my recall with and without tDCS" and "I pay attention to if my guitar playing sounds better and it's like I've made a breakthrough or leap to another level." Other individuals measured the effects of tDCS with existing cognitive games or tests (11.4%; $n = 35$) or tracked their progress in a log or journal (7.5%; $n = 23$).

Success of Stimulation

Participants were asked to rate the extent to which they felt tDCS was successful on a 1 to 5 scale (1 = totally unsuccessful; 5 = totally successful). As shown in Fig. 10, overall, more individuals found tDCS to be successful (42.5%) than unsuccessful (27.6%), though many participants (29.9%) were not sure. Among those who felt strongly about the effects of tDCS (i.e., a "1" or "5" response), a greater number found it totally unsuccessful than totally successful. Furthermore, among those who found tDCS to be successful, a far greater number reported tDCS being "somewhat" successful rather than "totally" successful. Indeed, as shown in Table 6, more than half of participants (53.7%) agreed that they expected to get more out of tDCS than they actually did.

Unwanted Side Effects

Participants were asked if they experienced any unwanted side effects from tDCS, and if so, to describe them; responses were coded thematically. The largest group of participants (38.0%) reported not experiencing unwanted effects from tDCS. Approximately one-third (35.4%) of all participants reported experiencing skin irritation (i.e., redness, tingling, itching). Less common side effects were headaches (10.1%), flashes of light in the visual field (known as "phosphenes"; 8.4%) dizziness (1.9%), and a metallic taste (1.5%). Side effects reported by less than five participants include sleepiness/fatigue ($n = 4$), difficulty finding words ($n = 4$), insomnia ($n = 3$), mania ($n = 3$), muscle twitching ($n = 3$), overstimulation ($n = 2$), and blurred vision ($n = 3$). Reports of mania and overstimulation are especially intriguing, as one recent review article (Matsumoto and Ugawa 2017) highlighted a number of reports of mania following tDCS stimulation in patients with depression; however, only two of the five participants who reported either mania or overstimulation in the present study reported using it for treatment (one for depression only, the other for depression and anxiety).

Notably, 16.9% of participants used the word "burn" (e.g., "skin burn" or "burning sensation") to describe an unwanted side effect. Mentions of burns were difficult to interpret, as participants used the term interchangeably to describe everything from heat sensations to varying degrees of skin redness. However, a small number of participants

Table 6 Attitude questions: panel A, left: responses for all participants. Panel B, right: responses for treaters vs. non-treaters (i.e., those who selected only restoration and/or enhancement indications)

	A. All ($N = 339$)					B. Treaters ($n = 131$)	Non-treaters ($n = 167$)	*t* test
	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)	mean (SD)	mean (SD)	
Expectations about tDCS and consumer tDCS as novelty items								
Direct-to-consumer tDCS devices are merely novelty items.	2.7%	20.6%	28.3%	*29.5%*	18.9%	3.7 (1.1)	3.2 (1.1)	***
I expected to get more from tDCS than I actually did.	24.8%	28.9%	*30.1%*	11.2%	5.0%	2.6 (1.2)	2.3 (1.1)	**
Opinions about safety								
The risks of using tDCS at home outweigh the benefits.	6.2%	11.8%	*27.7%*	*27.7%*	26.5%	3.6 (1.3)	3.5 (1.1)	
tDCS should not be used on children.	31.6%	22.4%	*39.5%*	3.5%	2.9%	2.4 (1.1)	2.1 (1.0)	*
tDCS is a relatively safe technique.	34.2%	*38.6%*	21.5%	4.7%	0.9%	1.8 (.9)	2.1 (.9)	**
Regulation and availability of tDCS to the general public								
tDCS should remain available to the public.	*65.5%*	25.1%	8.0%	1.2%	0.3%	1.3 (.7)	1.5 (.7)	*
Government regulations should control the technical features (e.g., current output) of directto-consumer devices.	10.0%	*25.7%*	25.1%	20.4%	18.9%	3.2 (1.2)	3.1 (1.3)	
tDCS should not be used without supervision/guidance from a trained professional.	4.4%	13.0%	*32.4%*	*32.4%*	17.7%	3.5 (1.0)	3.6 (1.0)	
Identification with DIY tDCS and thoughts on media coverage								
I identify with the DIY tDCS movement.	18.9%	29.5%	*32.4%*	10.9%	8.3%	2.4 (1.1)	2.7 (1.2)	*
The media blows the issue of do-it-yourself tDCS out of proportion.	15.3%	27.4%	*50.7%*	6.2%	0.3%	2.4 (0.9)	2.5 (0.8)	
Beliefs about brain optimization								
People do not use their brains to their fullest potential.	*39.2%*	36.3%	14.7%	5.9%	3.8%	2.1 (1.0)	2.0 (1.1)	
The brain is an organ that can be "hacked" to improve performance.	*38.9%*	37.8%	18.6%	4.4%	0.3%	2.0 (0.9)	1.8 (0.8)	*
Attitudes towards mainstream and alternative medicine								
Mainstream medicine is often out of touch with the needs of patients.	28.6%	*32.4%*	23.3%	8.6%	7.1%	2.1 (1.1)	2.5 (1.2)	***
I value alternative medicine practices.	26.3%	*32.7%*	20.6%	11.2%	9.1%	2.3 (1.1)	2.5 (1.3)	
I learned most of what I know about tDCS from my colleagues.	2.4%	5.0%	15.3%	20.6%	*56.6%*	4.2 (1.1)	4.2 (1.0)	
Neuroscience literacy								
Left-brained people are more rational and scientific, whereas right-brained people are more creative and artistic.	6.5%	19.5%	*47.2%*	11.5%	15.3%	3.0 (1.1)	3.3 (1.1)	*
Drugs and alcohol kill brain cells.	*37.5%*	32.2%	18.9%	6.5%	5.0%	2.2 (1.2)	2.1 (1.1)	
We use our brain 24 h a day.	*71.7%*	17.7%	6.2%	3.5%	0.9%	1.5 (0.9)	1.4 (0.8)	
Brain activity can be studied through the oxygen consumption of specific brain areas.	19.8%	28.3%	*48.4%*	2.4%	1.2%	2.3 (0.8)	2.4 (0.9)	
People only use a small percentage of their brains.	22.1%	17.4%	17.7%	14.2%	*28.6%*	3.0 (1.5)	3.3 (1.5)	

Italics indicate that the category contains the largest percentage of responses

*$p <= .05$; **$p <= .01$; ***$p <= .001$ (two-tailed test)

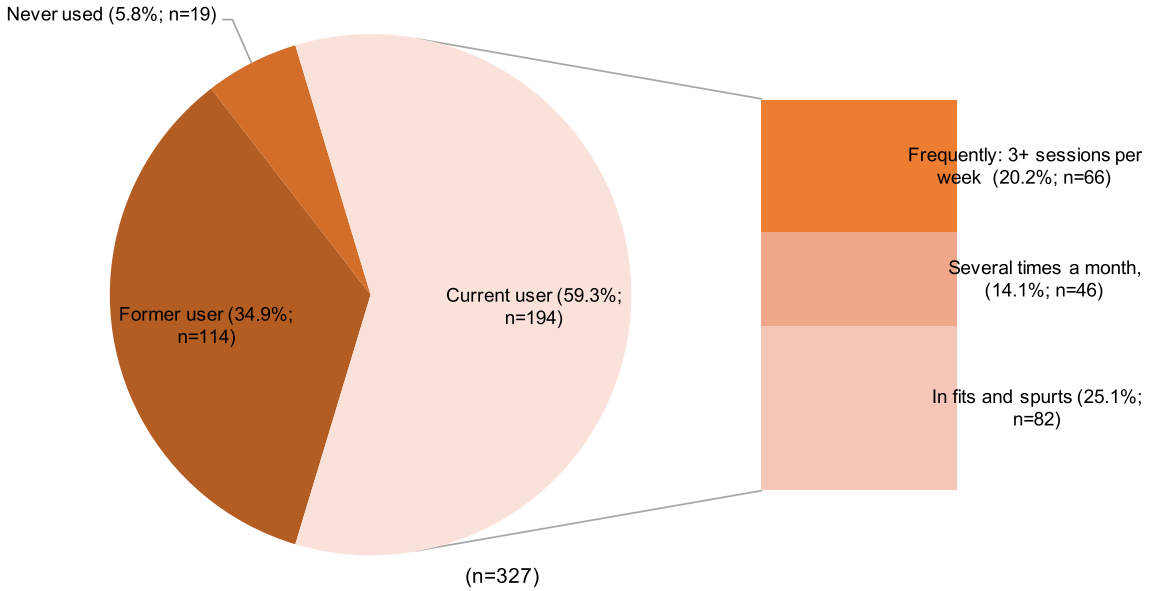

Fig. 6 Participants tDCS usage distribution ($n = 327$): current users, former users, and those who never used tDCS

($n = 10$) reported more serious burns, as determined by mentions of scarring ($n = 5$) or other language that indicated severity ($n = 5$), such as "severe scalp burn," or "red mark that took days to clear."

Engagement with tDCS Subreddit

More than a third of all participants (36.0%) had never heard of the tDCS subreddit (www.reddit.com/r/tDCS), and in total, almost half of all respondents (47.1%) had never visited it. Among the 52.8% who had visited the tDCS subreddit, the vast majority (95.0%) were "lurkers" who reported never or rarely posting to the subreddit. Those who had visited the tDCS subreddit had a higher mean age (46.9; SD = 13.5) than those who did not (43.9; SD = 14.2); this difference approached but did not reach statistical significance [$t(326) = 0.055, p > .05$]. Those who had visited the tDCS subreddit were significantly more likely than those who had not visited to have used a wide

Table 7 Reasons former users quit using tDCS and why they would begin using tDCS again

	n	%
Why did you stop using tDCS?	*n = 114*	
Lack of efficacy	54	47.4
Experienced unwanted effects	19	16.7
Other	18	15.8
Lack of information about stimulation protocol	14	12.3
Concerns about long-term effects	13	11.4
Boredom/lack of time	12	10.5
Broken or defective tDCS unit	6	5.3
Would you use tDCS again, and if so, why?		
Yes, if there was more evidence regarding efficacy	45	39.5
Yes, if the manufacturer provided more guidance about stimulation protocols	22	19.3
Yes, if the device and/or electrodes were improved	19	16.7
Yes (no reason provided)	14	12.3
Yes, if tDCS was safer and had fewer side effects	14	12.3
Yes, if there was guidance from professionals	7	6.1
No, would not use again	7	6.1
Yes, other reasons	6	5.2
Yes, if I needed to	5	4.4
Yes, if the price was lower	5	4.4

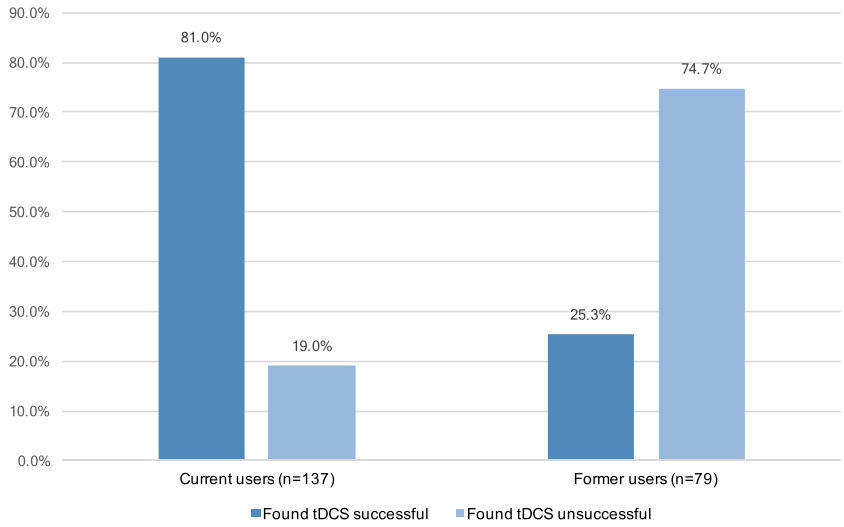

Fig. 7 Relationship between current use and ratings of success of tDCS. [$X^2(1, N = 216) = 65.5$, $p < .001$; Cramer's V = .549]

variety of other brain enhancement/electrical stimulation techniques (see Table 3b).

Participants' Attitudes

All participants ($N = 339$) rated their agreement with 20 statements on a 5-point Likert scale (1 = strongly agree, 5 = strongly disagree). Full results are reported in Table 6; notable findings are highlighted here.

Participants' expectations about tDCS relative to their experiences: Slightly more than half of participants (53.7%) agreed that they expected to get more out of tDCS than they actually did; only 16.2% disagreed with this statement, though disagreement could mean that (a) their expectations of tDCS were met; or (b) tDCS exceeded their expectations.

Opinions about safety: Nearly three-quarters of participants (72.9%) agreed that tDCS is a relatively safe technique; some (21.5%) were not sure, and only a small number (5.6%) disagreed (i.e., felt that tDCS was not safe). However, slightly more than half (54.0%) agreed that tDCS should not be used on children, many were not sure (39.5%), and only a very small proportion (6.5%)

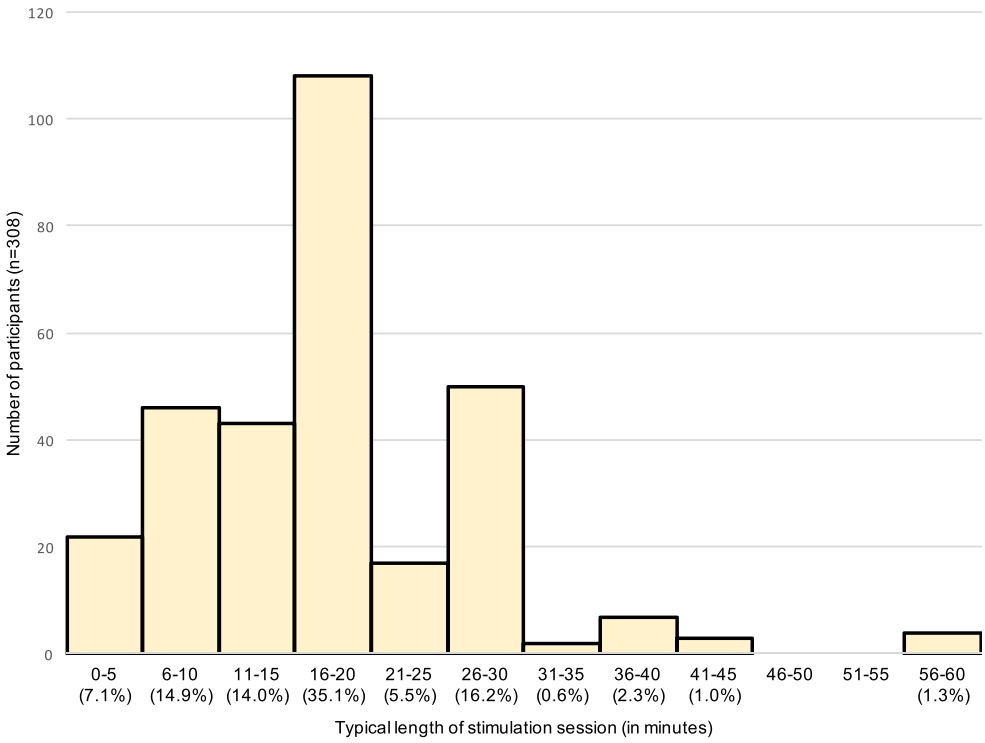

Fig. 8 Typical length of stimulation session (in min)

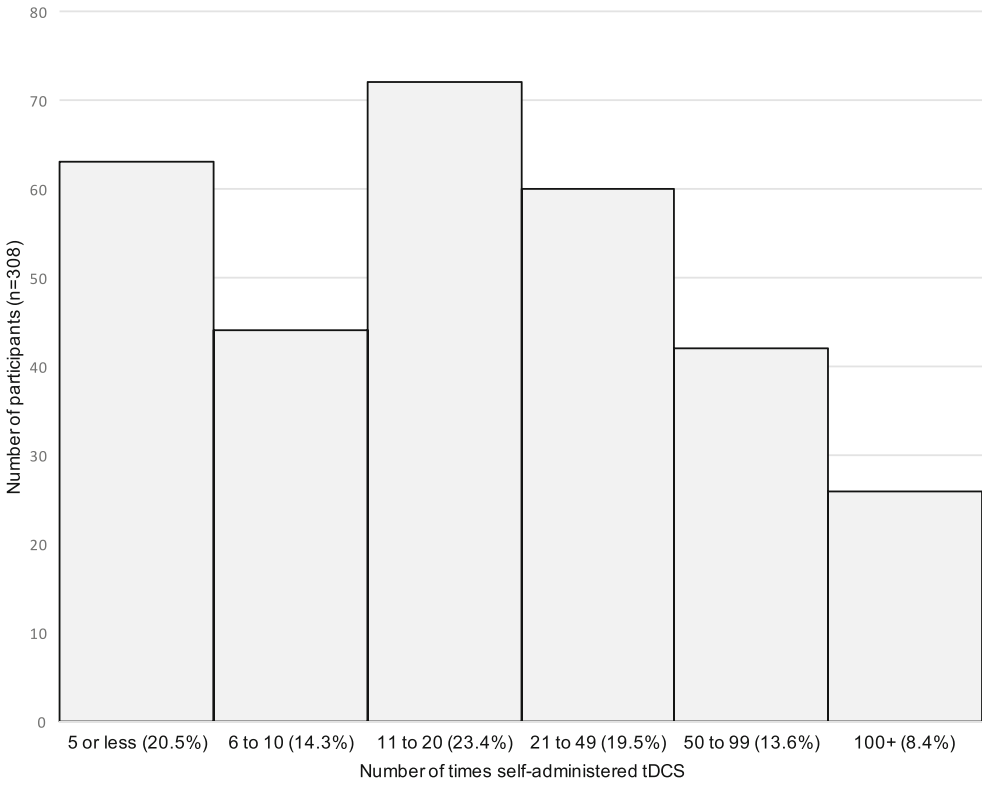

Fig. 9 Number of times participants' self-administered stimulation

disagreed. Thus, while most participants consider tDCS to be relatively safe, many also have significant reservations about the use of the technology (as indicated by their views on the acceptability of using tDCS on children).

Regulation and availability of tDCS to the general public: More than 90% agreed that tDCS should remain available to the public; this was the strongest consensus achieved on any of the attitude questions. However, participants were mixed when it came to views on regulation: though 39.2% disagreed that government regulation should control the technical features of tDCS devices, almost as many (35.5%) were in favor of such regulation.

Identification with "do-it-yourself" tDCS: Approximately half of all participants (48.2%) reported identifying with the "do-it-yourself tDCS movement,"

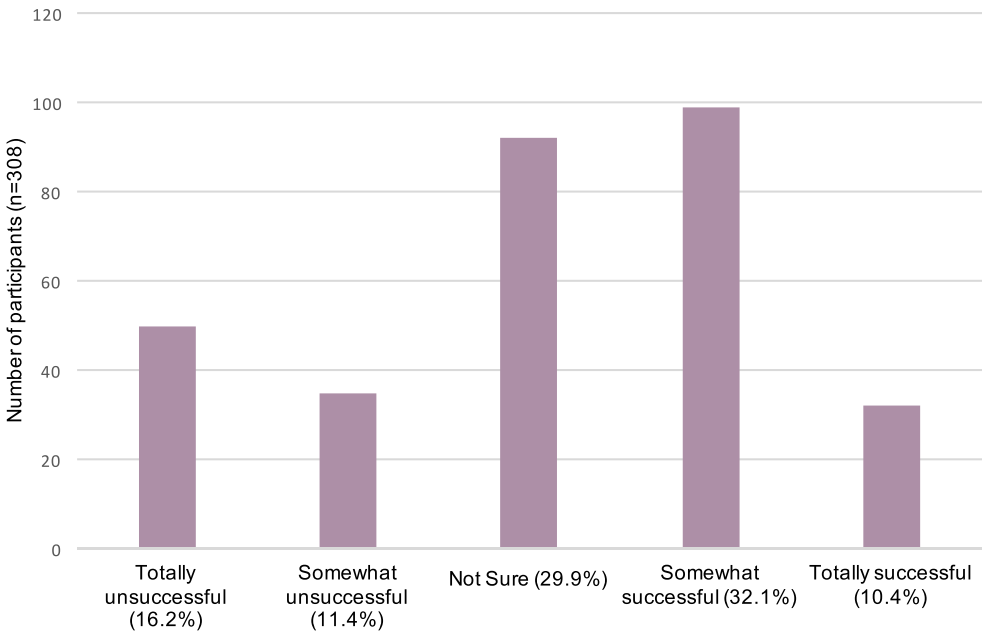

Fig. 10 Participants' ratings of the extent to which they felt tDCS was successful

implying that many interpret DIY tDCS broadly, to refer not just to those who build their own devices, but more generally to the use of tDCS outside of medical/academic settings.

Discussion

This study provides the largest and most comprehensive survey to-date of users of consumer tDCS devices. Although there have been over a dozen studies of users of pharmacological cognitive enhancement—ranging from large-scale surveys to in-depth focus groups—there is a dearth of empirical work on how users utilize brain stimulation *devices* marketed for cognitive enhancement. The methodology employed here was unique in that rather than recruiting via an online forum, it involved partnering with seven companies who sell direct-to-consumer brain stimulation devices; as a result, the sample was comprised of participants who had purchased a consumer tDCS device. The majority of respondents reported residing in North America.

One of the most important unanswered questions regarding the home use of non-invasive brain stimulation is the prevalence and popularity of the phenomenon. Previously, the closest measure of the popularity of tDCS was the number of subscribers to the tDCS subreddit forum, which increased from roughly 1000 subscribers in October 2012 to approximately 10,000 as of October 2017. However, subscribing to the tDCS subreddit is relatively meaningless, as one can visit (and post to) the tDCS subreddit without subscribing (Wexler and Reiner 2017). Thus, the growth in number of subscribers to the tDCS subreddit should be taken as a proxy for increasing *interest* in the home use of tDCS, rather than increasing *use* of tDCS.

A more accurate—though still highly imperfect—measure of the extent of the home use of tDCS can be gleaned from the total number of consumer tDCS devices sold. Indeed, purchasing a device is a financial commitment: it requires not just clicking "subscribe" on the tDCS subreddit, but actually spending a significant sum of money on a stimulation device (on average, participants in the present study paid $177). In this study, which included seven of the ten companies selling tDCS devices directly to consumers as of June 2016, companies' customer lists totaled approximately 10,000 individuals. As noted above, these lists may have included a small percentage of individuals who purchased accessories (and not devices); on the other hand, some individuals purchased more than one device. Thus, this figure should be taken as a rough, ballpark estimate of the number of devices sold across the seven companies.

Given that response rates were relatively constant (i.e., within a few percentage points) across customers from each of the seven companies, it is likely that the distribution of tDCS devices across the companies in this study (as shown in Table 4**)** represents a rough approximation of the market distribution across the companies surveyed (e.g., one dominant company, several medium-sized companies, and a handful of much smaller ones). Additionally, given my previous work studying the consumer tDCS landscape and knowledge of the three companies who declined to participate—i.e., length of time in business, extent of publicity received—it is possible to speculate that the missing companies have only medium or small shares of the market. Thus, it is likely that the total number of consumer tDCS devices sold as of June 2016 is a relatively low, five-digit figure. It should be emphasized that this figure does not reflect the total number of active users of tDCS, as even among the present sample—which itself may not be representative of all users of consumer tDCS devices—approximately 40% had quit using tDCS or had never used it.

Despite the lack of data on the prevalence of the home use of tDCS, media reports and scholarly articles have reported that the home use of brain stimulation is increasing and may become mainstream (Denejkina 2016; Fitz and Reiner 2014). This characterization is not unique to tDCS: Partridge et al. (2011) found that 94% of media articles related to the use of cognitive enhancement drugs characterized the phenomenon as either "common" or increasing, despite there being little evidence to justify such claims. Similar to Jwa (2015)—who speculated that there "may be some hype" around the estimates of the size of DIY tDCS—I argue that there is little evidence to support the notion that the home use of tDCS is increasing. While there was certainly more attention paid to the movement in 2014 and 2015 (by the media, academia, regulatory authorities, and others), this should not be taken to reflect an increase in the *use* of consumer tDCS devices, but rather an increase in *attention* towards those who use them.

The results of this study suggest that media reports may in fact be driving individuals to utilize tDCS. The effect of media attention on interest in tDCS is also evident from increases in subscribers to the tDCS subreddit that appear immediately after high-profile media reports (e.g., see http://redditmetrics.com/r/tDCS following release of *Wired* article on May 5, 2014, and *Radiolab* podcast on June 26, 2014). The role of the media in "inciting" individuals to turn to cognitive enhancement has also been suggested in the context of pharmacological enhancement (Forlini and Racine 2009; Outram 2010). Indeed, it is possible that there is an amplification effect when it comes to media reports and uptake of tDCS: media attention may lead to an increase in reports from a variety of outlets (i.e., additional media, academic scholarship, conferences, and meetings), which in turn may drive further media attention as press outlets report that "experts" are discussing the phenomenon, which may in turn drive more

individuals to utilize tDCS. Further research is needed to better elucidate the possibility of this effect.

Overall, those who own consumer tDCS devices tend to be highly educated, wealthy, and politically liberal; they are early adopters of technology with a penchant for reading scientific articles. Most do not attend religious services; this finding is particularly salient given that a recent Pew report found that Americans who were more religious were less likely to report being comfortable with the use of hypothetical future enhancement technologies (Pew Research Center 2016b). Although the hypothetical enhancement technologies presented in the Pew study (synthetic blood transfusions, brain chip implants, gene editing) are far more invasive than tDCS, this study—which found that consumers of tDCS devices are less religious than the US population—suggests that religiosity may be a factor in individual willingness to adopt even less invasive enhancement technologies such as tDCS. Indeed, a study comparing Swiss student users of cognitive enhancement drugs to non-users found that a higher percentage of users were not affiliated with any religion, and that more users than non-users rated religion as "not important" (Ott and Biller-Andorno 2014).

In one sense, the finding that participants are in higher income brackets relative to the US population can be expected, as those in lower income brackets likely do not have spare funds to spend on an experimental technique of questionable efficacy, and a similar income distribution would be expected for those who opt for other expensive enhancement techniques (e.g., cosmetic surgery). Still, Fig. 3 may provide empirical support for concerns expressed by bioethicists regarding distributive justice (i.e., that enhancement technologies may be used by those who are wealthier, thereby increasing current inequality gaps). An alternative interpretation of the figure, however, is that tDCS users are relatively well-distributed across income brackets, and that it is the US income distribution that is skewed.

The most surprising demographic finding was a far higher mean age (45.3) than expected, as home users have typically been portrayed as being in their twenties and thirties (Jwa 2015; Wexler 2016b). This difference cannot be sufficiently explained by variations in recruitment between the present study and previous ones (which recruited via online avenues, mainly the tDCS subreddit) as the mean age of visitors to the tDCS subreddit (43.9 years) and non-visitors (46.9 years) were both relatively high. It is therefore likely that the mean age of home users has shifted over time—the extensive media coverage in 2014 and 2015 may have attracted a group of slightly older individuals, especially those interested in treatment or restoration—and thus a phenomenon that was initially dominated by younger individuals is now more evenly distributed across generations.

The higher proportion of females (15.3%) in the present study as compared to the 4% previously reported by Jwa (2015) is especially interesting, as it suggests while the home use of tDCS is still a male-dominated activity, more women are using the technique, especially to self-treat depression. With regard to geographic distribution, the large number of respondents based in North America cannot be attributed to the companies' locations. Although five of the seven companies participating in this study were based in North America, a more important measure is the company's market share: in the present sample, participants reported owning more devices from international companies as compared to US-based ones. Interestingly, the present study found approximately the same percentage of participants based in North America as Jwa (2015). The consistency of this result across studies could reflect a lower prevalence of use of tDCS outside North America; indeed, a similarly low prevalence of usage of cognitive enhancement drugs has been suggested for those outside North America (Ragan et al. 2013).

With regard to purpose of use, approximately one-quarter of participants reported purchasing tDCS out of curiosity and interest in experimentation (on the open-ended response); indeed, a recent study on the use of neuroenhancement drugs in England also found curiosity to be a motivating factor for a subset of users (Vargo and Petróczi 2016). Thus, some individuals are not driven by a specific purpose (i.e., treatment or enhancement) but rather are curious about the latest technology, which is line with the finding that most participants reported being early adopters of technology. Furthermore, the border between treatment and enhancement indications is not always clear-cut. Indeed, coding participants' responses to the open-ended response questions—as either treatment or enhancement—was challenging, particularly with regard to indications for attention (i.e., is using tDCS to improve focus/concentration meaningfully different for those who mentioned a diagnosis of ADD vs. those who did not) and mood disorders (where some participants reported using tDCS to improve the cognitive sluggishness that often accompanies depression). Additionally, on the forced-choice questions, a large percentage of participants selected multiple indications (treatment/enhancement/restoration).

The number of participants who reported using tDCS for depression is particularly striking: put in perspective, of all individuals who purchased and used a tDCS device on themselves at least once ($n = 308$), approximately one-third (31.5%; $n = 97$) have used it specifically to treat depression—despite the fact that almost all consumer tDCS devices are marketed for enhancement, not treatment. The population of home users self-treating for depression merits further study, especially as tDCS has been viewed as a potentially promising at-home treatment for depression.

Regarding efficacy, one of the most notable findings is that those who have used tDCS for treatment rate the technology as more effective than those who used it for non-treatment purposes (i.e., only enhancement and/or restoration). One

explanation is that tDCS may actually be more effective when used for treatment as opposed to enhancement/restoration; this possibility is line with current reports in the tDCS literature, which suggest that the effects of tDCS may be stronger for depression than for other disease or cognitive enhancement indications (Horvath et al. 2015; Lefaucheur et al. 2017). Another possibility is that the effects of stimulation may be more pronounced for treaters than non-treaters (who are using tDCS only for enhancement and/or restoration); in other words, a small percentage increase on a cognitive domain—if one does exist—may not be apparent to the average non-treater; whereas symptom relief from depression may be more salient. A third possibility is that tDCS is not effective for either purpose, but that there is a greater placebo effect for those who use it for treatment than for those who use it for only enhancement and/or restoration. The findings here suggest that bioethical concerns with regard to tDCS for enhancement may not be pressing; indeed, only a third of participants who utilize tDCS purely for non-treatment purposes found it to be effective. Thus, more pertinent ethical issues may arise with regard to the home use of tDCS for treatment, particularly for depression.

Safety, or the potential harm to users, is the most widely discussed topic in the literature related to the home use of tDCS. The unwanted effects reported by participants in the present study are consistent with the typical side effects reported in the tDCS literature (Antal et al. 2017). That a small number of subjects report persistent burns is in line with several reports of "skin lesions" in the tDCS literature that have occurred while tDCS is being administered by trained professionals in laboratory settings (Matsumoto and Ugawa 2017; Rodríguez et al. 2014; Wang et al. 2015). Thus, it should not necessarily be concluded that users had skin burns/lesions because they "misused" tDCS, as such burns/lesions have occurred in controlled laboratory settings. Still, reports of severe burns, even among a small number of participants, are concerning. The present study found that while home users generally adhere to scientific protocols with regard to current level and length of session, they depart from them most notably with regard to frequency of stimulation, with many users stimulating far more frequently than in scientific studies of tDCS. Overall, the present study suggests that rather than focusing on abstract notions of "safety" and "risk" with regard to the home use of tDCS, two specific concerns warrant attention: severe burns and frequency of stimulation.

The methodology employed here allowed for the examination of the population of users who have stopped using tDCS; results showed that a significant number of users (~ 40%) stop using tDCS (or have never used it), with the most common reason for quitting being lack of efficacy. Thus, it is not side effects or concern about long-term effects that are driving individuals away from tDCS, rather it is the fact that they are not experiencing benefits from the technique. This finding, combined with the dearth of data on prevalence, indicate that bioethical concerns regarding explicit or implicit coercion in the realm of tDCS may not be relevant, as the home use of tDCS—at least in its current incarnation—is not a technique that individuals, especially those who utilize it for non-treatment purposes, find to be overwhelmingly effective (see also Voarino et al. 2017).

Although previous studies have focused on the tDCS subreddit (and related online tDCS sources), the present study found that approximately one-third of respondents had never heard of the tDCS subreddit, and it total, more than half had never visited. Even among those who had visited, the vast majority were lurkers who never or rarely posted to the forum. Thus, the tDCS subreddit should not be taken to be representative of home users of tDCS.

The study had a number of limitations. First, the aggregate response rate (3.9%) was relatively low, which raises issues regarding the representativeness of the sample. However, response rates were relatively similar (within a few percentage points) across all seven companies, and a low response rate was expected given that participants were not offered incentives for participation. Second, the study was based on self-report measures; no independent verification was conducted to ensure that participants had purchased and used tDCS devices. However, additional checks were performed on the data to ensure that those coming from each company's unique link reported purchasing a device from that company. Third, although former users (and those who had never used tDCS) were encouraged to complete the survey (in recruitment emails), it is likely that respondents skewed towards being active users of tDCS or former users who had negative experiences with the device. Fourth, the study focused only on those individuals who had purchased direct-to-consumer tDCS devices, not those who had built their own devices or those who repurpose iontophoresis devices (although some participants reported owning these devices). However, as direct-to-consumer devices have become more affordable and have improved in quality, it is likely that fewer users today build their devices from scratch or repurpose iontophoresis devices, compared to the "early days" of DIY tDCS from 2011 to 2013.

Though the home use of non-invasive brain stimulation has been a subject of much discussion in the academic literature, there has been little empirical data on the practices and motivations of home users. This study provides the largest and most comprehensive survey to-date of users of consumer tDCS devices. Obtaining a deeper knowledge of what drives home users—to purchase and use a consumer tDCS device (or for many, to cease to use it)—has important implications, both for ongoing debates about the ethical implications of the home use of tDCS, as well as for discussions of the regulation of direct-to-consumer neurotechnology. Thus, the present study not only provides an empirical foundation on which to base

policy recommendations, but also offers a concrete, empirical perspective on a debate that has too-often been one step removed from reality.

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Compliance with Ethical Standards

Conflict of Interest The author declares that she has no conflict of interest.

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