A meta-analysis of the effects of
transcranial direct current stimulation
on multiple realms of social behavior

Sarah Beth Bell

University of Kentucky

Abstract

This meta-analysis examines the effects of transcranial direct current brain stimulation (tDCS) applied to the prefrontal cortex on a variety of social behaviors including aggression, overeating, impulsivity, bias, honesty, and risk-taking. 48 studies were included in this meta-analysis, $N=2,196$. tDCS was found to have an overall effect size of $d=-0.2$, which means tDCS reduced the undesirable behavior by a small but significant amount. tDCS was most effective at reducing risk-taking behavior, bias, and overeating. tDCS was not significantly effective at reducing aggression, impulsivity, or dishonesty. Moderators such as brain region of interest, online versus offline stimulation, within versus between subjects designs, dose, and duration were examined. Publication bias was also examined with three different tools, and significant publication bias was found in the literature in this meta-analysis. These findings indicate high likelihood that many tDCS studies with null findings exist and have not been added to our published literature. Taken together, these results suggest that tDCS works better on some social behaviors than others, but overall, can reduce antisocial behavior by a small but significant amount.

Keywords: transcranial direct current stimulation, meta-analysis, social psychology, prefrontal cortex, prosocial behavior

Introduction

Social psychologists have had an interest in the neural underpinnings of behavior since the genesis of the field. fMRI would seem to be an ideal tool to study how the brain affects behavior, considering that it gives us images of the brain in action. However, fMRI has limitations beyond its expense. fMRI cannot establish causality. In addition, while fMRI can peek into the brain, it certainly cannot manipulate neural activity.

Transcranial direct current brain stimulation (tDCS) offers a relatively new tool to understand the relationship between brain and behavior. By applying electricity to a targeted brain region, it can excite that area of the brain, modulating how people think and feel. Moreover, this method is inexpensive and safe (see Filmer, Dux, & Mattingly, 2014 for review).

Despite the increase of social psychologists harnessing this tool in the past ten years, no existing meta-analysis examines the effects of tDCS on multiple realms of social behavior, which makes it difficult to understand patterns across the existing literature. This analysis represents the first paper synthesizing the effect of tDCS on multiple areas of social behavior.

First, I discuss some background information about tDCS. This includes history of tDCS, controversies about tDCS, and use of tDCS in social psychology. Next, I discuss several areas of social behavior that are tested in this paper. These include aggression, maladaptive overeating, impulsivity, bias, honesty, and risk-taking. This

background helps lay the framework for the inclusion criteria that will be discussed in the methods section of this paper.

Overview of tDCS

History of electrical brain stimulation.

People have attempted to change how they think and feel with brain stimulation for a long time. The first recorded attempt to use brain stimulation is from 15 AD. Scribonius Largus, court physician to Roman emperor Claudius, directed electrical rays from the sun to the head in an attempt to alleviate headaches (Gater et al., 2011). In the mid-1700s, the idea of stimulating the brain with electricity started to become more popular, and a sizable minority of people performing it would use an electric eel instead of a machine (for a primary source and illustration, see Hollandsche Maatschappye, 1776). Currents used were also much stronger than now; today, we use 1-2 milliamps of current, but back then, 5-10 milliamps or even more were common (Gater et al., 2011). During this period, brain stimulators were widely available to buy for private use and marketed as being able to induce euphoria and increase cognitive capacity (Kadosh & Elliott, 2013). Unfortunately, during this historical period, we know that much of the experimentation about brain stimulation was performed on slaves (Hollandsche Maatschappye, 1776). During this same period of time, Benjamin Franklin was starting to take an interest in how electricity could affect the brain. In fact, in one these experiments, he accidentally gave himself memory loss by using a dose that was too high (Finger & Zaromb, 2006; Gater et al., 2011).

After some new developments in the 1800s, brain stimulation became popular again around the turn of the 20th century. In 1902, a series of electrosleep studies

began (Robinovitch, 1914), which preceded the modern brain stimulation instruments we have today. These experiments directly led to further development of cranial stimulation and electroanesthesia, which fed into the idea of incorporating a direct electrical current to brain regions in order to increase the likelihood that neurons would fire (Guleyupoglu et al., 2011).

In 1957, the first modern tDCS device was invented. The device used in a sleep study used a direct current for the first time. Soon after, in 1964, the polarity component was added to the device as well (Redfearn et al., 1964). Animal studies were showing that direct current stimulation could result in long lasting changes in brain excitability (Bindman et al., 1964). Several studies validated this type of stimulation, but one study in particular questioned its reliability (Arfai et al., 1970). As a result of this paper, tDCS research underwent a dormant period that lasted decades.

Alberto Priori, a dual medical doctor and psychologist, began investigating direct current, polarized brain stimulation in a study he published in 1998. He found that he could change the excitability of the motor cortex with the current. Researchers continued to learn more about the mechanics of tDCS, and about 10 years after Priori's initial tDCS study, there began to be a large increase of social psychology research relating to tDCS (see Boggio et al., 2016).

Although Priori was interested in social psychology, most tDCS researchers are not. In the methods section of this paper, I explain that the vast majority of tDCS literature is related to physiology, not psychology. My claim that most tDCS reserachers are interested in physiology can be backed up by a literature search I conducted in PsycINFO as a component of this project. PsycINFO is a database that is primarily

focused on psychological phenomenon. When entering the search term “transcranial direct current stimulation”, 1890 articles were returned. However, 1150 of these articles were about physiology only, not psychology. tDCS is often used to treat strokes (Danzl, 2013; Fregni et al., 2005) and other conditions that require adults to do significant motor learning (Boggio et al., 2006; Nitché & Paulus, 2000; Kwon & Jang, 2007). When it is used in psychology, it is often used to treat people with disorders. In the same literature search, 740 articles were returned that were about psychology. Of these 740 articles, 351 tested a population with a psychological disorder. From these patterns, it is easy to see that social psychologists are only a minority of researchers using tDCS. However, it still is not surprising that there is a sizable group of social psychologists who want to study the neurobiology of behavior using tDCS.

Before tDCS regained popularity in the past ten years, social psychologists had already been using transcranial magnetic current stimulation (tMS) to try to manipulate behavior (Wasserman et al., 1998). tMS works similarly to tDCS in that an electrical current is applied to a targeted area of the brain making neurons in that part of the brain more likely to fire. However, unlike tDCS which uses direct current electricity, tMS uses an electromagnet to deliver the current.

tMS is used much more often by social psychologists than tDCS (for review, see Boggio et al., 2016). Although it is used more often, it has multiple disadvantages. tMS can cause seizures (Dobek, 2015; Theodore, 2003). Best practice guidelines for tMS say it is only safe to administer it in a hospital (Rossi et al., 2009). Pain is not a common side effect of tDCS (Filmer, Dux, & Mattingly, 2014). 40% of people who undergo tMS experience physical pain, mostly headaches (Anderson et al., 2009; Loo, McFarquhar,

& Mitchell, 2008). Not only is this physical pain undesirable, but it also may be confounding results of psychological studies, especially since physical pain and social pain are well-connected in the brain (see DeWall et al., 2010; Eisenberger & Lieberman, 2004). tDCS is regarded as safer than tMS (see Hamilton et al., 2011 for review), and tDCS is certainly less expensive and easier to use than tMS (Hummel et al., 2006; Priori et al., 2009). Because of these advantages as compared to tMS, it is not surprising that social psychologists are interested in using this tool.

Although there has been an increase in social psychology research incorporating tDCS to date, only one current review paper (see Boggio et al., 2016) and no meta-analyses on the effects of tDCS on social behavior exist. Because brain stimulation might be more helpful to some social behaviors than others, a meta-analysis with multiple dependent variables is an appropriate way to synthesize this literature.

How tDCS works.

tDCS brain stimulation works by applying a tiny electrical current to a targeted area of the brain, making the neurons in that part of the brain more likely to fire (Bruoni et al., 2012; Filmer, Dux, & Mattingly, 2014). The electrical current partially depolarizes these neurons, which brings them closer to, but not all the way to, an action potential. It is important to note that the currents used in tDCS are exceptionally small (Brunoni et al., 2012; Fregni, 2005; Nitché, 2000). However, even these tiny currents can change how people think and feel (Andrews et al., 2011; Floel, 2014; Fregni et al., 2006).

tDCS can only be applied to areas of the brain that are on the cortex, because the current is too small and uncontrolled to travel to a deeper part of the brain (Berker et al., 2013). Deep brain stimulation can be implanted for this very different type of

stimulation, but naturally, this type of stimulation is dramatically more invasive (Chen et al., 2012; Perlmutter & Mink, 2006). Luckily for social psychologists, tDCS can access a variety of different areas of the prefrontal cortex (Fecteau et al., 2007; Fregni et al., 2005; Javodi & Walsh, 2012).

During tDCS brain stimulation, two electrodes are applied to the brain (Filmer, Dux, & Mattingly, 2014; Nitcher et al., 2000). The stimulating electrode is called the anodal electrode. This is where the electricity goes into the brain. This electrode is applied to the targeted region of the cortex for stimulation. The other electrode is called the cathodal electrode. This is where the electricity comes out of the brain. Researchers typically place this electrode in the contralateral subpraoorbital area, which is right above the eyebrow. This location is chosen because the sinus cavity is there, so the current does not map onto the brain with the same specificity as it would in other areas of the cortex (Bruoni et al., 2012; Filmer, Dux, & Mattingly, 2014).

The current begins at the anodal electrode, and is most concentrated in that region (Fregni et al., 2005; Keeser et al., 2011). However, it is important to note that the targeted region is not the only stimulated area. While the current is most concentrated at the targeted location, the current *travels* across the path between the anode and cathode electrodes. Therefore, there is a whole region that is being stimulated much larger than the targeted area. For example, if a researcher applies the anodal electrode to any part of the prefrontal cortex, the current will actually stimulate the whole prefrontal cortex until it reaches the cathode electrode (Bikson et al., 2010; Wagner et al., 2007). While where you place the electrode on the prefrontal cortex does matter, as this target region is the most active during stimulation, any sort of stimulation that starts

on the prefrontal cortex and ends on the prefrontal cortex can be thought of as stimulating the whole prefrontal cortex (Stagg & Nitsche, 2011). For this reason, this meta-analysis is restricted to the prefrontal cortex, but is not restricted to just one sub-area of the prefrontal cortex. Because of the extensive overlap in where the current goes if it begins anywhere on the prefrontal cortex, I chose to use any papers where the current began and ended on the prefrontal cortex.

There are three main types of tDCS stimulation: anodal, cathodal, and sham. Anodal stimulation is what most people are referring to when discussing brain stimulation. In this type of stimulation, the current begins at the targeted area of the brain and ends at a neutral location, most commonly the contralateral supraorbital area (Boggio et al., 2016; Filmer, Dux, & Mattingly, 2014). The second type of stimulation is cathodal stimulation, also referred to colloquially as reverse stimulation. In this setup, the cathodal electrode where the electricity comes out is placed over the targeted region. The anodal electrode is placed over a neutral location such as above the contralateral eyebrow. Therefore, the electricity goes into a neutral location and comes out of the targeted region. The idea is that instead of exciting the targeted region, that region is actually inhibited.

It is nice to think about cathodal stimulation as reverse analog to anodal stimulation, but research shows us that how cathodal stimulation works is just not that simple. There are countless studies that use anodal and cathodal stimulation where the results show that both are effective at changing a behavior, or where one is effective and the other one looks the same as the placebo, not reversed as expected. Because there is still so much to learn about why cathodal stimulation is often not a reversed

analog for anodal stimulation, this meta-analysis is restricted to results only relating to anodal stimulation and the associated placebo, sham stimulation.

Sham stimulation is an exceptionally effective placebo because participants experience the same mild side effects as people receiving a full stimulation, just for a shorter duration (Bruoni et al., 2012; Filmer, Dux, & Mattingly, 2014). Sham stimulation involves turning the brain stimulator on, ramping it up for 30 seconds as is typical for anodal stimulation, leaving it on for 30 seconds, and ramping it back down for 30 seconds until it turns itself off automatically (Bruoni et al., 2012; Filmer, Dux, & Mattingly, 2014). Mild side effects associated with tDCS include a tingling or itchy feeling while it is first getting into the body (Gandiga et al., 2006). This usually goes away after the device has been on for a minute or two (Gandiga et al., 2006). Therefore, what the participants in the sham condition experience is very similar to what the participants in the anodal condition experience, except the device is not on long enough to meaningfully change the way they think and feel (Bruoni et al., 2012; Filmer, Dux, & Mattingly, 2014; Gandiga et al., 2006).

Criticism of tDCS and counter-arguments.

It is important to acknowledge the controversy surrounding tDCS. In 2016, a study where researchers applied tDCS to cadavers and then measured the electrical current gained a large amount of press attention (Dubljevic et al., 2014). These researchers found that only 10% of the current applied was making it to the brain (Underwood, 2016). Therefore, they concluded tDCS may not work at all, since the current was so tiny to begin with. They called for a use of a current of at least 5

milliamps, like people used in the 1700s, which would be excessively uncomfortable to participants and therefore not practical, ethical, or feasible. (Underwood, 2016).

This finding must be balanced with the plethora of literature showing tDCS is able to effectively change how people think and feel in the doses we use now of 1-2 milliamps. Several explanations have been brought forth attempting to reconcile the findings from the cadaver study with the rest of the literature. Scientists are still learning exactly the mechanisms by which tDCS works. One component of how electricity affects the body relates to changes in sodium and calcium channels in the brain. It is important to know that there can be surges in these channels without a change in the local field electrical potential (Monai et al., 2016). Therefore, tDCS may not be obviously changing an electrical potential in the brain but rather operating on a smaller scale in this way. These channels are also closely related to glial cell signaling, while previous studies have focused on neurons (Fertonani & Miniussi, 2016). Whether electricity, sodium/calcium channels, glial cell communication, or some combination of these three or other undiscovered factors affect how tDCS works, the literature contains thousands of studies showing it to be effective (see Boggio et al., 2016 for review).

Because of the controversy surrounding tDCS, I am especially interested in testing for publication bias in this meta-analysis. This will help determine the extent to which there is a “file drawer problem”, which means that researchers have found null results but have not published them, often because journals are generally less interested in null results. This meta-analysis shows the effect of tDCS on a variety of social psychological constructs, but this effect size is an artifact of the literature I was able to obtain. Therefore, I am employing three statistical tools to test for publication

bias, and one of these methods also corrects for it. These tools to test for publication bias are discussed more extensively in the methods section of this paper.

The brain region of interest in this meta-analysis is the prefrontal cortex, or PFC. All the studies in this analysis stimulated a sub-area of the PFC. The next section explains more about the critical role of the PFC in social behavior.

Role of PFC.

The prefrontal cortex has long been known to affect social behavior (Anderson, 1999; Damasio, 1998; Grafman, 1995). Phineas Gage famously suffered an accident that resulted in a rod penetrating his left frontal lobe, which caused his personality to change dramatically, becoming less kind and much more irritable (O'Discoll, 1998). Lesions to the prefrontal cortex in animals change social behavior (De Bruin, 1983; Kolb, 1974; Nonneman et al., 1974). More recently, fMRI work has shown that the activity in the prefrontal cortex changes during social tasks such as aggression (Chester et al., 2013; Eisenberger, 2003; Lotze et al., 2007), risk-taking (Chein et al., 2011; Kuhnen & Knutson, 2005; Rao, 2008), dishonesty (Abe et al., 2007; Ganis et al., 2003; Langleben, 2005), implicit bias (Amodio, 2014; Forie et al., 2014), and more. There is no question that the prefrontal cortex is key to social behavior.

The balance model of the brain lays a theoretical basis for how parts of the prefrontal cortex relate to controlling different types of social behaviors such as aggression, impulsivity, and more (Heatherson and Wagner, 2011). According to this theory, one role of the prefrontal cortex is to control urges for rewards that arise from more central parts of the brain including the nucleus accumbens (NAcc). The prefrontal cortex works in a circuit with reward centers deeper in the brain. When the prefrontal

cortex is more active, we are better at controlling maladaptive social impulses that may arise from the nucleus accumbens and other associated reward-sensitive regions of the brain. However, when the prefrontal cortex is less active, the balance between the two parts of the brain can become off-kilter in favor of the reward areas (Heatherson and Wagner, 2011).

Because of the importance of the prefrontal cortex to social behavior, it was obvious to narrow the scope of this meta-analysis to just that region. Different sub-regions of the prefrontal cortex have different specializations (Davis, 2017; Hare et al., 2014; Vanuk et al., 2017). However, it is important to remember that wherever the current begins in the prefrontal cortex, it still travels across multiple regions in the prefrontal cortex. While I will be looking at distinct brain regions of the prefrontal cortex as moderators in this meta-analysis, overall, due to the nature of how the stimulation travels, all of the studies included in this meta-analysis generally stimulate the prefrontal cortex.

Variability of parameters across studies.

Which region of the prefrontal cortex is stimulated is only one of many parameters that have been examined as moderators in this meta-analysis. Unfortunately, there are quite a few parameters that researchers vary wildly on. There is no gold standard for how to conduct tDCS. This makes comparing our literature difficult. For this reason, I have included several important parameters that people vary as part of my model in this meta-analysis.

I have also examined whether stimulation is online or offline. Online stimulation means that the dependent variable was tested while the device was still on and running.

Offline stimulation means the dependent variable was tested after the device was turned off (Filmer, Dux, and Mattingly, 2014). Sometimes this testing occurs just once, while other researchers see if the stimulation has lasting effects for weeks or months. For the purposes of this study, the definition of offline stimulation was limited to the dependent variable being tested 0-30 minutes after the device was removed, to avoid muddling the definition with various designs where the dependent variable is tested much longer after stimulation has ended.

Another moderator I have examined is whether the researchers used within or between subjects designs. In within subjects designs a participant is compared to herself. This makes the experimental design is especially strong, because the participant is acting as her own control. Therefore, I wanted to see if there would be different effect sizes reported for these two common types of experimental designs.

The final moderators I have examined are dose and duration. The most common doses used are 1 milliamp, 1.5 milliamps, and 2 milliamps (Boggio, 2016; Filmer, Dux, and Mattingly, 2014). Duration of stimulation tends to range from 10 minutes to 30 minutes (Boggio, 2016; Filmer, Dux, and Mattingly, 2014). I used regressions to see if these differences would change how the stimulation affected participants.

Social psychology and tDCS

Brain stimulation has been used to examine how neuromodulation affects a variety of social behaviors. Although tDCS is primarily used in physiology, it is important to remember that the person reignited tDCS research in the late 1990s was trained as a social psychologist. In fact, social psychologists are publishing more tDCS studies each year. In the early 2000s, there was an average of less than 10 new tDCS and social

psychology publications each year. By the late 2000s, there were about 30 new tDCS and social psychology publications each year. By 2015, there were about 80 new tDCS and social psychology publications per year (Boggio et al., 2016). This growth rate is evidence of social psychologists becoming increasingly interested in using tDCS to answer research questions.

In the following sections, I will discuss the importance of various social behaviors that researchers have tried to alter with tDCS. For each behavior, I will first discuss why social psychologists are interested in it, and next, give background of tDCS research that has been done in that area. The following areas of social psychology are used as dependent variables in this meta-analysis.

Aggression.

Society is less aggressive than it has been in the past. Human sacrifices, which was a component of almost every early civilization, has all but disappeared. Corporal punishment is declining dramatically, and in some countries, it is now illegal. Slavery where people are thought of as property is no longer legal in any country (see Pinker, 2013 for a review on the decline of violence in recent history).

With this decline in mind, our society is still plagued with murder, armed robberies, rape and sexual assault, and other violent crimes. While we have come a long way, we still have a long way to go in making our world a more peaceful place. fMRI researchers have looked inside of the brains of aggressive people. However, tDCS offers a non-pharmacological tool to actually attempt to reduce aggressive behavior as well as understand causal relationships between brain and behavior.

Multiple studies have been conducted on tDCS and aggressive behavior with mixed results, which is one reason I wanted to obtain a weighted mean effect size for these studies. A variety of dependent measures have been used in these studies. These include provocation manipulations including the Taylor Aggression Paradigm (Dambacher et al., 2015; Riva et al., 2017) and the Hot Sauce Paradigm (Riva et al., 2015). Other manipulations measure mood after frustrating tasks including tasks with high cognitive loads (Plewina et al., 2015) and mood after the essay criticism paradigm (Kelley et al., 2013). If the mean effect size of these studies indicated that tDCS could significantly reduce aggressive behavior, we would not only better understand what brain regions are recruited during aggression but also have a therapeutic tool to help with excessive aggression.

Overeating.

At first glance, overeating might not seem to be a social psychologist's area of interest. Eating disorders seems to be a clinician's work. However, many social cues influence what and how much we eat, and for that reason, many social psychologists have studied maladaptive overeating (Corning et al., 2006; Fischer et al., 2008; Hesse-Bieber, 2006; Inzlicht et al., 2007; Monro et al., 2005; Piran et al., 2005). Consequences of maladaptive overeating can include not only an unhealthy weight but, perhaps even more important to well-being, an unhealthy self-image and reduced self-esteem (Franklin et al., 2006; Griffiths et al., 2007).

Naturally, researchers were eager to use tDCS as a potential tool to help reduce maladaptive overeating. Two major categories of dependent variables were used. The first category assessed cravings for high calorie, low nutrition foods during or after brain

stimulation (Georgii et al., 2017; Gomez-Azira et al., 2017; Jauch-Chara et al., 2014; Ljubusavlevic et al., 2017). More interestingly, one study included in this analysis actually looked at how many calories college men ate at a large buffet (Goldman, 2011).

While fMRI work has certainly examined areas of the brain that are recruited during cravings (Murdaugh et al., 2012; Siep et al., 2009; Yokum et al., 2011), tDCS has three distinct advantages over fMRI in studying maladaptive overeating. First, it can establish a causal relationship between brain activity and overeating. Second, it can actually help reduce overeating. Third, and perhaps most importantly, it is not safe to eat inside of a big magnet. However, with tDCS studies, it is perfectly fine to study actual eating behavior while the stimulation is online and active. tDCS offers a promising frontier to maladaptive overeating and the social cues that surround it.

Impulsivity.

With the explosion of technology in the past fifteen years, it is no wonder that some would say we are in the age of impulsivity. Psychologists are very concerned that information overload and technological near-addiction is resulting in decreased attention spaced, decreased patience, and increased impulsivity (Billieux, 2008; Rosen et al., 2013; Wilmer & Chein, 2016). Impulsivity can result in decisions that are not well thought through, risky behaviors, and choices for short-term, small rewards over long-term, large rewards.

While technology made have made impulsivity worse, it also might be key to helping as well. Social psychologists have used tDCS in a variety of different ways in an attempt to tamp down impulsive behavior. In this meta-analysis, impulsivity is defined as being unable or unwilling to inhibit hasty and incorrect responses. Error rates on tasks

such as the Stop Signal Task (Bell & Turner, 2017; Stramaccia et al., 2015), problem solving tasks (Oldrati et al., 2016), the sentence completion task (Metzuyananim-Gorlick et al., 2016), and a cognitive control task (Gomez-Azira et al., 2017).

Currently, stimulants such as Adderall and Ritalin are used to treat the impulsivity associated with ADHD. tDCS could potentially be a non-pharmacological alternative to not only clinical levels of impulsivity associated with ADHD but also typical levels of impulsivity associated with overstimulation in the age of technology. The implications of reducing errors due to inattention and impulsivity could have positive implications not only for well-being but also for public safety.

Bias.

Bias is becoming more and more discussed in popular dialogue. Hillary Clinton discussed implicit bias at length during the 2016, the first presidential candidate to do so (Bartlett, 2017). Consequences of implicit bias can include treating people of different races, religions, or sexualities differently without even being consciously aware of such a bias, inadvertently perpetuating inequality (Greenwald & Banaji, 1995). Because of the coverage of implicit bias in the 2016, people are becoming much more familiar with the term and associated consequences. Project Implicit (Greenwald et al., 2011), an online tool where people can volunteer to participate in implicit association task tests and research, has had tens of thousands of voluntary participants wanting to learn more about their own biases. However, all of this resurgence in concern about implicit bias begets the question of how we can reduce it.

Brains scans show that the prefrontal cortex is recruited during implicit bias tasks (Firat et al., 2017; Gammond et al., 2017; Luo et al., 2017). Therefore, people have

attempted to apply tDCS to the prefrontal cortex in an attempt to see if they can reduce this bias. The implications of this, if it works, cannot be understated. It would result in a better understanding of a serious societal problem, and, perhaps in certain circumstances where appropriate, a tool to attempt to reduce this bias.

A variety of paradigms have been used with tDCS and bias research. The classic implicit association task has been used (Gladwin et al., 2012; Sellaro, 2008). In addition, researchers have examined bias towards threatening versus non-threatening stimuli (Chen et al., 2017; Heeren et al., 2015), negative and positive emotions (Ly et al., 2016; Nord et al., 2017), and biases related to choices in moral dilemmas (Kuehne et al., 2010). The results have been mixed, so this meta-analysis will help clarify how useful tDCS may be in reducing bias.

Honesty.

“I cannot tell a lie...I did cut it with my hatchet.” The famous myth of George Washington and the cherry tree is engrained in our culture as a childhood tale where children are taught to never tell a lie. Our society does not approve of most lies, seeing them as immoral behavior. A plethora of behavioral studies have examined the social factors that contribute to lying (Ashton et al., 2014; Bereby-Myer et al., 2017; Virj, 2000). In addition, neuroscientists have begun to explore the neural correlates of honesty (Abe et al., 2014; Dogan et al., 2016; Fioretti et al., 2015).

Researchers have also used tDCS to attempt to reduce lying. Reaction time in the Trust Game has been examined (Colzaro et al., 2015). The Guilty Knowledge Task, which is popularly known as a lie detector, was used to measure latency for honesty and dishonest responses during tDCS stimulation (Mameli et al., 2010). A card task

where participants indicated whether they did or did not have a certain card, and sometimes lied, was also used to study the effect of tDCS on honesty (Priori et al., 2008). Finally, the die rolling task, where participants can lie about money earned, has also been used during tDCS stimulation (Marechal et al., 2017). If brain stimulation can change lying behavior, there are certainly extensive societal as well as ethical implications.

Risk-taking.

Social psychologists have long been interested in risk-taking. As psychologists interested in judgment and decision-making, we are interested not only in individual differences in risk-taking and why people take risks, but also in the brain regions recruited during risky behavior. fMRI has been used to examine which brain regions are active during risk-taking. These studies have resulted in psychologists confirming the importance of the prefrontal cortex in risk-taking behavior (Schonberg, 2012; Steinberg, 2008; Yu et al., 2017).

Social psychologists have already done some extensive work with tDCS and risk-taking, but the results have been mixed. A variety of paradigms have been used. The Balloon Analog Risk-Taking Task has been used during active stimulation (Bell et al., 2017; Fecteau et al., 2007). The Iowa Gambling Task has also been used (Bell et al., 2017; Fecteau et al., 2007) as well as the Columbia Gambling Task (Pripfl et al., 2013) and other gambling tasks (Bell et al., 2016; Bell et al., 2017; Huang et al., 2017; Ye et al., 2015; Zheng et al., 2017). A riskiness study that incorporated tDCS and a driving simulation has also been done (Belli et al., 2008). It is important to note that these studies do not look at clinical populations but rather typically developing adults.

Therefore, if tDCS can successfully reduce risk-taking behaviors in typically developing adults, then the clinical implications of helping problem gamblers, people with borderline personality, and other risk-takers could be quite helpful therapeutically.

Methods

Eligibility criteria

Information sources and search strategy.

Three search engines were used for this meta-analysis: PsycINFO, PubMed, and Dissertations and Thesis Abstracts Global Proquest. I conducted the PsycINFO search first. I used one search term: “transcranial direct current stimulation”. This returned 1890 articles. I read the abstracts of all of these articles to see if they were appropriate to include in the analysis. I had six criteria. First, the experiment must be about psychology, as opposed to a medical study examining an area such as the motor cortex. Next, the experiment must be about typically developing adults, not people with disorders such as ADHD, schizophrenia, or any other disorders. Third, the research had to be related to social psychology, as opposed to the plethora of cognitive memory experiments and other experiments unrelated to social psychology. Fourth, the experiment had to have at least 10 participants. Fifth, the study had to be available to access in English. Sixth, the experiment had to involve stimulating an area of the prefrontal cortex, as opposed to the inferior frontal junction area, the orbitofrontal cortex, or other areas of the brain that social psychologists are also interested in. These restrictions helped me find studies that make sense to combine into a weighted effect size.

The PsycINFO search resulted in 94 out of the 1890 articles being moved forward to the next phase of the meta-analysis. 1150 were excluded for not being relevant to psychology. 351 were excluded for being about clinical populations rather than typically developing adults. 253 were excluded being unrelated to social psychology, and those were mostly cognitive experiments, with the most popular category being memory experiments. Nothing was removed for having too small of a sample size. 42 experiments had not been translated into English. Finally, 1 of these experiments was not on the prefrontal cortex.

My next search was in PubMed. I used the 94 PsycINFO articles I found and identified 11 common themes and 18 search terms to use in PubMed. A simple search in PubMed found over 3200 hits, so I felt this more targeted search would help me better extract the relevant literature. The 11 themes were decision-making, aggression, impulsivity, cravings, stereotyping, emotion, morality, inhibition, rejection, perception (of others), and cooperation. The 18 search terms were decision-making, risk-taking, aggression, anger, rumination, impulsivity, cravings, stereotyping, prejudice, bias, emotion, morality, honesty, deception, inhibition, rejection, exclusion, perception, cooperation, and altruism.

57 articles from the PubMed search were moved onto the next phase of the meta-analysis. The other 1730 articles returned were not relevant. 1182 were duplicated in the PsycINFO database. Of the non-duplicates, 324 were excluded because they were physiological rather than psychological in nature. 120 were excluded because they were about clinical populations instead of typically developing adults. 86 were not related to social psychology. 1 study was too small. All of the studies were available in

English, so nothing was excluded for language reasons. 17 studies were excluded because they were not related to the prefrontal cortex.

The final literature search was in Dissertations and Theses Global (Proquest). In this search, like in PsycINFO, I used one term, “transcranial direct current stimulation”. This returned 466 hits. 14 articles met criteria.

The next step in this meta-analysis was to carefully review all of the literature I had collected, which was 179 articles, and take a much closer look than the initial search about whether they truly fit into the meta-analysis. 60 articles were removed at this phase. 4 of them did not use anodal tDCS but rather some similar neuromodulation technique such as oscillating tDCS. 28 of them were review papers. 23 of them did not stimulate the prefrontal cortex but instead a different area such as the inferior frontal gyrus, the temporal lobe, or the parietal lobe. 5 of them examined clinical populations, and 4 of those clinical populations were people experiencing alcohol misuse disorder. After this phase of the meta-analysis, 119 moved onto the variable sorting phase of the analysis.

In the next phase of the meta-analysis, I determined which of the existing articles fit with at least one my themes, which were decision-making/risk-taking, aggression, impulsivity, cravings, stereotyping/bias, emotion, morality, inhibition, rejection, perception (of others), and cooperation. My criteria were that at least four articles needed to fit into the theme, or that theme would be removed. At this stage, I dropped following themes for having a k of less than four: emotion, mortality, rejection, perception, and cooperation. I also collapsed the inhibition and impulsivity themes. This led to 91 articles moving onto the next phase of the meta-analysis. It is important to note

that my determination of themes was not the final determination of dependent variables. It removed irrelevant literature, but ultimately, two independent coders sorted the articles for the analysis into dependent variables.

Coding.

The two coders extracted relevant information from the 91 remaining articles. Besides basic information about the articles, they determined brain region of interest, dose of tDCS, duration of tDCS, whether the experimental design was within subjects or between subjects, whether stimulation was online or offline. They also described the dependent variable used and made sure the researchers did use anodal direct current stimulation to the prefrontal cortex. The coders disagreed about 50 out of 833 of these bits of data, resulting in 94% inter-rater reliability. The two coders came to agreements about these differences together and then passed this information onto me.

During this more in-depth phase of article analysis, 26 articles were found to not meet criteria and were removed from the analysis. This resulted in 65 remaining articles that went on to the next phase.

At this point, I extracted relevant statistics needed from each article to compute Cohen's d effect sizes for each result of interest in each article. A result of interest was any analysis that showed the main effect of tDCS on one of the dependent variables included in this analysis. What statistics were extracted depended on what the authors reported. Cohen's d can be computed with a variety of inputs including the following: means and standard deviations; t values, N per group, and p values; means and standard errors, F values, N per group, and p values; and unstandardized regression coefficients and N per group. To compute these effect sizes, I used a web-based

calculator created by David Wilson, based on his 2001 book with Mark Lipsey called *Practical Meta-Analysis*. The formulas I used are also available in this book and its companion website.

Almost every article had one experiment only. However, there were often multiple analyses done to examine the effect of tDCS on social behavior. In each article, I looked at the main effect of tDCS on the independent variable, which often had to be computed by means and standard deviations reported in the article. After computing the main effect of tDCS if it was not already included in the article, I computed Cohen's *d* effect size for each main effect of tDCS on social behavior.

There were 116 relevant effects of tDCS on a dependent variable across the 65 articles. Next, effect sizes from the same article were averaged (Lipsey & Wilson, 2001). There was one exception to this averaging. If the researchers tested more than one area of the prefrontal cortex, each region tested was treated as an independent experiment. For example, it is common for authors to test the effect starting the current on the left side of the prefrontal cortex and then test the effect again starting on the right side of the prefrontal cortex because they had a theoretical reason to hypothesize they would get different results on either side of the brain. For that reason, papers that did this were treated as two separate studies, resulting in 75 effect sizes across the 65 articles. In other words, 10 studies tested two different sides of the prefrontal cortex, so each area of interest was treated as a separate experiment.

Determination of sub-areas of interest.

Next, the 65 studies were sorted into dependent variables by the coders. 34 articles were left after this phase. The variables they identified were aggression,

overeating, impulsivity, bias, cooperation, rejection, honesty, and risk-taking. The rejection and cooperation variables were then dropped, as they each had only three articles each. 25 additional articles were dropped that did not related to the themes in any logical way. The majority of these articles were about different sub-areas of emotion. Emotion as a whole would not make sense as a dependent variable because different brain regions are recruited during the processing of different emotions. The coders agreed on how to categorize 48 out of 65 of these articles, resulting into an inter-rater reliability of 74%. They then resolved these differences together.

Once I narrowed the literature 34 articles, I broke a few of these 34 studies into two studies. I did this when the study examined two different regions of the prefrontal cortex separately. After this step, my total number of experiments included in the study totaled 44 ($k=44$, $N=1,664$). Next, I contacted authors for unpublished data. My criteria were to contact all authors that had two or more studies included in the meta-analysis. This resulted in me contacting two authors. Both responded, but neither had unpublished social psychology data.

Finally, I included my own unpublished data in the analysis. I had four studies to include that used tDCS to test social psychology variables included in this analysis. This resulted in a final count of 38 articles, $k=48$, $N=2,196$. Figure 1 contains a flowchart summarizing the inclusion criteria selection process.

Planned analyses

Computation of overall effect sizes and moderation analyses.

Overall effect sizes were computed using the Lipsey & Wilson macro from their book *Practical Meta-Analysis* (2001). I used random effects models for all analyses in

this paper as opposed to fixed effects models. A fixed effects model allows you to make conditional inferences, which means inferences only about the studies included in the model. A random effects model allows you to make inferences beyond only the studies in the model (Hedges & Vevea, 1998). Because I was interested not just in the effect of tDCS on the studies in my model but also on the effect of tDCS on any existing relevant studies, a random effects model was appropriate.

Moderation was tested with Analog ANOVAS for the categorical moderators and with regressions on continuous moderators. Moderation was explored in the overall model only, as the number of studies in each dependent variable was too small for an appropriate moderation analysis (k ranging from 4 to 12). However, publication bias was tested not only in the overall model but also in each dependent variable.

Tests for publication bias.

I used three methods to assess if there was publication bias in my meta-analysis. Publication bias leads to significant results being published at a higher rate than null results, which could distort the magnitude of the true effect size. The first method I used was trim and fill (Duval & Tweedie, 2000; Duval, 2005). This method relies on weighted standard error in each experiment to estimate how many studies may be missing from the meta-analysis due to them never being published. This non-parametric test can help determine if there is significant publication bias in the data set.

The trim and fill method relies heavily on the funnel plot it creates. Effect sizes are plotted on the x-axis. Standard errors are plotted on the y-axis. The trim and fill method uses these effect sizes and standard errors to systematically delete some of the large effect studies and fills in some small effect studies. The filled in circles on the

graph are actual studies, and the open circles on the graph are studies the trim and fill method is predicting may exist but have not been published and made it into the analysis. If there is not publication bias, this graph looks symmetric. In addition, the trim and fill statistical test would not be significant.

The trim and fill test also corrects for publication bias. If there is significant bias, it outputs an adjusted effect size for the variable of interest. The ability to correct for publication bias is one of the strengths of the trim and fill test, and a large reason of why I chose to use it.

The second method I used to test for publication bias was PET-PEESE. PET stands for precision-effect test. First, a matrix is created with effect sizes and standard errors. Then, the standard errors are used to predict effect sizes with weighted least squares (Stanley, 2008). A regression line is fit to this scatterplot. A significant slope indicates potential publication bias. PEESE is almost exactly the same as PETs, but is uses squared standard errors to predict effect sizes. PET tends to underestimate the effect when there is a significant effect, and in that case, PEESE can be a less biased test to use (Stanley & Doucouliagos, 2014). I used both tests.

The third method I used to assess publication bias was the fail-safe N calculation. I used the Rosenthal approach (Rosenthal, 1979). Fail-safe N indicates the number of non-significant studies that would be needed to be added to the meta-analysis to change the overall effect size to non-significant (Oswald & Plonsky, 2010).

Results

Study characteristics

Results of individual studies

Table 1 summarizes all of the studies in this meta-analysis. Figure 1 shows a forest plot of all of the studies included in this meta-analysis. The squares represent the effect sizes of each individual study included in the meta-analysis. The lines show 95% confidence intervals for each study included in the meta-analysis. The 95% confidence intervals for each study are also written on the side of the plot. This is a visual representation of the size of effects and variability in each study included. At the bottom, the overall effect size is shown visually.

Effect sizes and moderators in the overall model

The overall effect of tDCS.

Overall, across domains, tDCS reduced maladaptive problems by a small but significant amount, $d=-0.20$, $SD_{weighted}=0.45$, $p<.001$. There was significant heterogeneity in this model, $Q(45)=78.17$, $p=0.002$. This amount of heterogeneity is considered to be small (Higgins et al., 2003; Kovalchik, 2013).

Analog ANOVAs on brain region, online/offline stimulation, and experimental design.

Analog ANOVAs were conducted on the three categorical moderators: different brain regions, online/offline stimulation, and experimental design. No significant difference was found among the 5 brain regions that were included in this meta-analysis, $Q=46.17$, $p=0.42$. I then tested for heterogeneity in each of the 5 brain regions using a weighted Cochran's Q (Higgins et al., 2003). There was no significant heterogeneity in any of the 5 brain regions. Finally, I looked at the mean effect size for each of the 5 brain regions. Stimulation to the IDLPFC resulted in a small but significant reduction in maladaptive behavior, $d=-0.22$, $Q(14)=14.43$, $p=0.04$. Stimulation to the rDLPFC also resulted in a small but significant reduction in maladaptive behavior, $d=-$

0.25, $Q(21)=26.13$, $p=0.01$. The other 3 brain regions did not significantly affect behavior, but they had much smaller K s than the other 2 brain regions, reducing the power of these three analyses. The mean effect size of stimulation to the rVLPFC was $d=-0.10$, $Q(5)=2.64$, $p=0.45$. There was only one study that examined the baPFC, so there was no variability that would result in a Q statistic. The mean effect size of stimulation for the baPFC was $d=-0.25$, $p=0.46$. The mean effect size of stimulation to the mPFC was $d=-0.20$, $Q(1)=1.98$, $p=0.48$. Tables 3, 4, and 5 provide more information about these results.

Online stimulation means the dependent variable was tested while the brain stimulator was still on, and offline stimulation means the dependent variable was tested 0-30 minutes after the brain stimulator was taken off. An analog ANOVA showed no significant difference between the two types of stimulation, $Q=52.22$, $p=0.21$. I then tested for heterogeneity in online versus offline stimulation using a weighted Cochran's Q . There was no significant heterogeneity in either type of stimulation. Finally, I looked at the mean effect size for both online and offline stimulation. The mean effect size for online stimulation was small but significant, $d=-0.14$, $Q(28)=37.62$, $p=0.02$. The mean effect size for offline stimulation was small to medium and significant, $d=-0.34$, $Q(16)=11.70$, $p=0.01$. Tables 6, 7, and 8 provide more information about these results.

The third analog ANOVA compared studies that used within subjects designs and studies that used between subjects designs. An analog ANOVA showed no significant difference between the two types of designs, $Q=48.22$, $p=0.34$. I then tested for heterogeneity in both designs using a weighted Cochran's Q . There was no significant heterogeneity in either design. Finally, I looked at the mean effect size for

both designs. The mean effect size for within subjects designs stimulation was small but not significant, which may relate to power as there were only 11 degrees of freedom, $d=-0.15$, $Q(11)=4.81$, $p=0.13$. The mean effect size for between subjects designs was small and significant, $d=-0.23$, $Q(33)=43.06$, $p<0.001$. Tables 9, 10, and 11 provide more information about these results.

Regressions on dose and duration.

Regressions were used to examine continuous moderators. The two moderators that were examined with regressions were dose of tDCS in milliamps and duration of tDCS in seconds. There was not significant heterogeneity for either variable. There was no significant effect of tDCS dose on behavior, $B=0.08$, $Q(45)=48.29$, $p=0.58$. There was also no significant effect of tDCS duration on behavior, $B=0$, $Q(45)=48.29$, $p=0.39$. Tables 12 and 13 provide more information about the effect of dose on behavior. Tables 14 and 15 provide more information about the effect of duration of stimulation on behavior.

Risk of publication bias in the overall model

Trim and fill.

Trim and fill uses weighted standard error to estimate how many studies may be missing from the meta-analysis because they were never published (Duval & Tweedie, 2000; Duval, 2005). It tests for publication bias and corrects for publication bias by providing a new estimate.

The trim and fill statistical test I used was a non-parametric weighed regression with multiplicative dispersion. The predictor was standard error. The test for funnel

asymmetry was significant, indicating probable publication bias, $t(44)=-4.21$, $p<.001$.

The graph in Figure 1 is a visual representation of this bias.

Importantly, this test corrected the effect size of tDCS on overall social behavior. The effect size computed from the random effects model above was $d=-0.20$. The adjusted effect size from the trim and fill method was $d=0.11$.

PET and PEESE.

In PET-PEESE, standard errors or squared standard errors are used to predict effect sized with weighted least squares. This can be plotted as a scatterplot. The line of best fit on the scatterplot would be flat if there is no publication bias. A significant slope indicates publication bias (Stanley, 2008).

Both the PET test and the PEESE test suggested publication bias in this meta-analysis. For PET, $B=-2.05$, $p=0.01$. For PEESE, $B=-2.63$, $p=0.002$. Figure 4 provides two-panel a visual representation of these bias tests. It is important to note that PET and PEESE tests normally have positive regression lines when there is publication bias. These regression lines are negative because I measured whether tDCS could reduce maladaptive behavior, resulting in negative effect sizes.

Fail safe sample size.

Fail safe N reveals the number of studies that would have to be added to the meta-analysis to make it non-significant (Oswald & Plonsky, 2010). The fail-safe N I computed was 375, and the test was significant at the $p<0.001$ level. This suggests a lack of publication bias in this meta-analysis.

Dependent variables: effect sizes, variability, and publication bias

Aggression.

tDCS did not reduce aggressive behavior by a significant amount, $d=-0.18$, $SD_{weighted}=0.30$, $p=0.19$. These studies were relatively homogenous, $Q(5)=7.09$, $p=0.21$. There was not significant publication bias in this literature, $t(4)=-0.17$, $p=0.87$. Therefore, no corrected effect size was needed. Figure 5 shows a forest plot of the aggression studies in this analysis. Figure 6 shows a funnel plot of the trim and fill method used on this data.

Overeating.

tDCS significantly reduced maladaptive overeating by a small amount, $d=-0.29$, $SD_{weighted}=0.33$, $p=0.03$ (see Table 2). These studies were relatively homogenous, $Q(6)=7.29$, $p=0.29$. There was significant publication bias in this literature, $t(5)=-3.58$, $p=0.02$. Using the trim and fill method, the effect size of overeating was adjusted from $d=-0.29$ to $d=-0.15$. Figure 7 shows a forest plot of the overeating studies in this analysis. Figure 8 shows a funnel plot of the trim and fill method used on this data.

Impulsivity.

tDCS did not reduce impulsivity by a significant amount, $d=-0.04$, $SD_{weighted}=0.27$, $p=0.70$ (see Table 2). These studies were relatively homogenous, $Q(8)=11.97$, $p=0.15$. There was not significant publication bias in this literature, $t(7)=-1.75$, $p=0.12$. Therefore, no correct effected size was needed. Figure 9 shows a forest plot of the impulsivity studies in this analysis. Figure 10 shows a funnel plot of the trim and fill method used on this data.

Bias.

tDCS significantly reduced bias by a small amount, $d=-0.25$, $SD_{weighted}=0.25$, $p=0.02$ (see Table 2). These studies were relatively homogenous, $Q(6)=6.88$, $p=0.33$.

There was not significant publication bias in this literature, $t(5)=-2.34$, $p=0.07$.

Therefore, no correct effect size was needed. Figure 11 shows a forest plot of the bias studies in this analysis. Figure 12 shows a funnel plot of the trim and fill method used on this data.

Honesty

tDCS did not reduce dishonest behavior by a significant amount, $d=-0.06$, $SD_{weighted}=0.05$, $p=0.57$ (see Table 2). These studies were relatively homogenous, $Q(3)=0.22$, $p=0.97$. There was not significant publication bias in this literature, $t(2)=0.22$, $p=0.84$. Therefore, no correct effect size was needed. Figure 13 shows a forest plot of the bias studies in this analysis. Figure 14 shows a funnel plot of the trim and fill method used on this data.

Risk-taking.

tDCS significantly reduced risk-taking by a small to medium amount, $d=-0.36$, $SD_{weighted}=0.47$, $p=0.01$ (see Table 2). These studies showed moderate heterogeneity, $Q(12)=34.79$, $p<.001$. There was significant publication bias in this literature, $t(11)=-2.24$, $p=0.046$. Using the trim and fill method, the effect size of overeating was adjusted from $d=-0.36$ to $d=-0.35$. Figure 15 shows a forest plot of the risk-taking studies in this analysis. Figure 16 shows a funnel plot of the trim and fill method used on this data.

Discussion

Summary of findings.

This meta-analysis found that overall, there is a small but significant effect of tDCS reducing maladaptive social behavior. However, two out of the three tests performed to assess publication bias indicated that there was significant publication bias

in these studies. Therefore, this small but significant effect of tDCS may be an artifact of biased literature, and therefore, all of these results must be considered with this bias in mind.

tDCS effectively reduced maladaptive overeating by a small amount, bias by a small amount, and risk-taking by a small to medium amount. tDCS did not significantly reduce aggressive behavior, impulsivity, or honesty. These differences suggest that tDCS is more effective to treat some types of maladaptive social behavior more effectively than others.

It is not surprising that the brain region that was stimulated did not affect results as long as this region was in the prefrontal cortex. As discussed in the introduction, the electrical current is the most concentrated in the target region, but it still travels across the entire prefrontal cortex. This striking result provides evidence for the idea that tDCS stimulation is relatively global across larger regions rather than being so specific to smaller regions. In addition, it shows that there might not be much utility in comparing brain regions that are close together, as the path of the current will overlap quite a bit.

Offline and online stimulation were both found to be effective, as were within subjects and between subjects' designs. However, dose and duration of tDCS did not affect results. Although there was not excessive heterogeneity in the data, differences across studies could have contributed to these null results. Comparisons on an individual study level might be more useful in learning more about how these two factors influence the efficacy of tDCS.

I did not have enough power to make an appropriate assessment of how the dependent variables in this meta-analysis interfaced with the moderators in this study.

This is because not enough tDCS studies exist that meet the criteria for this analysis. As this young area of research continues to grow, more in-depth analyses can be examined.

Limitations

One limitation of this meta-analysis is lack of consistency in tDCS paradigms. There is no gold standard for how to conduct tDCS. I would have been able to potentially learn a lot more about the dependent variables if the parameters were not so variable. With ks of 4-12 and variability about online versus offline stimulation, dose, duration, and more, it is difficult to compare these studies. A push for standard guidelines with tDCS is desperately needed. While conferences and conceptual papers discuss a variety of best practice ideas, the field is certainly lacking consensus on the parameters with which tDCS should be conducted.

An additional limitation of this study is that most of the included data is published. My criteria for contacting authors for unpublished results was that they needed to appear in the literature twice. This only ended up including two authors and my own unpublished literature. It is not surprising that to find publication bias in this area to begin with, and in addition, there was not much unpublished data in this meta-analysis.

This meta-analysis was restricted to the prefrontal cortex. Collapsing across the whole brain for the effect of tDCS would not make sense. However, it would be interesting to examine and compare different global regions of the brain to examine the efficacy of tDCS. Comparisons would need to be on the level of lobes of the brain or at least sub-lobes, because the path of the current is so large. Social psychologists have been especially interested in stimulating the inferior frontal junction of the brain (Gomez-

Azira, 2017; Strobach et al., 2015; Votinov, 2013), which is related to cognitive control (see Brass et al., 2005 for review).

Finally, there are several parameters of tDCS procedures that were not addressed in this meta-analysis, and that is due to most authors not even reporting many of these important parameters. These include amount of saline used. Since it conducts the electricity, that would seem to be a very important parameter to examine, as it could change the magnitude of the stimulation dramatically. In addition, the salinity of the saline solution used is often not reported, and neither is whether it is sterile or potentially contaminated with tiny bits of metal from local water sources. Another parameter often not reported is if the electrodes were held on the head by a headband and if so, how tight this headband was. A tighter attachment of the electrode would increase the amount of electricity getting into the brain, so this is also an important parameter to consider. Finally, exclusion criteria for participants vary, including whether researchers test people who take psychotropic medicine and if so, which ones. More standardization in this emerging field could help make findings more appropriate to compare.

Concluding remarks

The results of this meta-analysis are promising. While there is a degree of publication bias in this literature, overall, tDCS was effective at reducing maladaptive social problems, at least to a small degree, even when the effect size was corrected by the trim and fill method. In addition, it was found to be much more effective in some realms of social psychology as opposed to others. These differences can help guide future research.

tDCS is now commercially available for only \$149, and anyone can buy it without a prescription. It is being marketed as helping people become better at sports, and become more motivated. More tDCS studies are being published every year; in fact, the amount being published are growing at an exponential rate (Boggio et al., 2016). If these trends continue, neuromodulation will become less experimental and more often used in therapeutic setting as a non-pharmacological alternative to treatment.

Scientists have long been fascinated with the relationship between brain and behavior. tDCS offers a relatively inexpensive, easy to use tool to learn more. At the same time, brain stimulation has only become a popular tool to investigate social behavior in the past 10 years. We are on the frontier of exciting discoveries about how neuromodulation can influence social behavior.

Acknowledgements

I would like to acknowledge the two coders, Tori Dennie and Lesley Phillips of University of Kentucky, for their contribution to this work.

References

- Abe, N., Suzuki, M., Mori, E., Itoh, M., & Fujii, T. (2007). Deceiving others: distinct neural responses of the prefrontal cortex and amygdala in simple fabrication and deception with social interactions. *Journal of Cognitive Neuroscience*, 19(2), 287-295.
- Abe, N., Suzuki, M., Mori, E., Itoh, M., & Fujii, T. (2007). Deceiving others: distinct neural responses of the prefrontal cortex and amygdala in simple fabrication and deception with social interactions. *Journal of Cognitive Neuroscience*, 19(2), 287-295.
- Amodio, D. M., & Devine, P. G. (2006). Stereotyping and evaluation in implicit race bias: evidence for independent constructs and unique effects on behavior. *Journal of personality and social psychology*, 91(4), 652.
- Anderson, S. W., Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1999). Impairment of social and moral behavior related to early damage in human prefrontal cortex. *Nature neuroscience*, 2(11), 1032-1037.
- Andrews, S. C., Hoy, K. E., Enticott, P. G., Daskalakis, Z. J., & Fitzgerald, P. B. (2011). Improving working memory: the effect of combining cognitive activity and anodal transcranial direct current stimulation to the left dorsolateral prefrontal cortex. *Brain stimulation*, 4(2), 84-89.
- Arfai, E., Theano, G., Montagu, J. D., & Robin, A. A. (1970). A controlled study of polarization in depression. *The British Journal of Psychiatry*, 116(533), 433-434.

- Ashton, M. C., Lee, K., & De Vries, R. E. (2014). The HEXACO Honesty-Humility, Agreeableness, and Emotionality factors: A review of research and theory. *Personality and Social Psychology Review, 18*(2), 139-152.
- Bartlett, T. (2017). Can we really measure implicit bias? Maybe not. *The Chronicle of Higher Education*.
- Beeli, G., Koeneke, S., Gasser, K., & Jancke, L. (2008). Brain stimulation modulates driving behavior. *Behavioral and Brain Functions, 4*(1), 34.
- Bell, S.B. & DeWall, C.N. (2017) The effects of tDCS on risk-taking. Unpublished results.
- Bell, S.B. & DeWall, C.N. (2017). The effects of tDCS of risk-taking behavior. Unpublished results.
- Bell, S.B., Barnett, S., & DeWall, C.N. (2016). The effects of glucose and tDCS brain stimulation on self-control. Unpublished results.
- Bell, S.B., Turner, B., & DeWall, C.N. (2017). The effects tDCS brain stimulation on cognitive inhibition. Unpublished results.
- Bereby-Meyer, Y., & Shalvi, S. (2015). Deliberate honesty. *Current Opinion in Psychology, 6*, 195-198.
- Bikson, M., Datta, A., Rahman, A., & Scaturro, J. (2010). Electrode montages for tDCS and weak transcranial electrical stimulation: role of “return” electrode’s position and size. *Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology, 121*(12), 1976.

- Billieux, J., Van der Linden, M., & Rochat, L. (2008). The role of impulsivity in actual and problematic use of the mobile phone. *Applied Cognitive Psychology*, 22(9), 1195-1210.
- Bindman, L. J., Lippold, O. C. J., & Redfearn, J. W. T. (1964). The action of brief polarizing currents on the cerebral cortex of the rat (1) during current flow and (2) in the production of long-lasting after-effects. *The Journal of physiology*, 172(3), 369-382.
- Boggio, P. S., Castro, L. O., Savagim, E. A., Brite, R., Cruz, V. C., Rocha, R. R., ... & Fregni, F. (2006). Enhancement of non-dominant hand motor function by anodal transcranial direct current stimulation. *Neuroscience letters*, 404(1), 232-236.
- Boggio, P. S., Rêgo, G. G., Marques, L. M., & Costa, T. L. (2016). Social Psychology and Noninvasive Electrical Stimulation. *European Psychologist*.
- Brunoni, A. R., Nitsche, M. A., Bolognini, N., Bikson, M., Wagner, T., Merabet, L., ... & Ferrucci, R. (2012). Clinical research with transcranial direct current stimulation (tDCS): challenges and future directions. *Brain stimulation*, 5(3), 175-195.
- Chein, J., Albert, D., O'Brien, L., Uckert, K., & Steinberg, L. (2011). Peers increase adolescent risk taking by enhancing activity in the brain's reward circuitry. *Developmental science*, 14(2).
- Chen, J. C., Hämmerer, D., D'ostilio, K., Casula, E. P., Marshall, L., Tsai, C. H., ... & Edwards, M. J. (2014). Bi-directional modulation of somatosensory mismatch negativity with transcranial direct current stimulation: an event related potential study. *The Journal of physiology*, 592(4), 745-757.

Chen, N. T., Basanovic, J., Notebaert, L., MacLeod, C., & Clarke, P. J. (2017).

Attentional bias mediates the effect of neurostimulation on emotional vulnerability. *Journal of Psychiatric Research*.

Chester, D. S., Eisenberger, N. I., Pond Jr, R. S., Richman, S. B., Bushman, B. J., &

DeWall, C. N. (2013). The interactive effect of social pain and executive functioning on aggression: an fMRI experiment. *Social cognitive and affective neuroscience*, 9(5), 699-704.

Colzato, L. S., Sellaro, R., van den Wildenberg, W. P., & Hommel, B. (2015). tDCS of

medial prefrontal cortex does not enhance interpersonal trust. *Journal of Psychophysiology*.

Corning, A. F., & Gondoli, D. M. (2012). Who is most likely to fat talk? A social

comparison perspective. *Body image*, 9(4), 528-531.

Damasio, A. R., Tranel, D., & Damasio, H. (1990). Individuals with sociopathic

behavior caused by frontal damage fail to respond autonomically to social stimuli. *Behavioural brain research*, 41(2), 81-94.

Dambacher, F., Schuhmann, T., Lobbestael, J., Arntz, A., Brugman, S., & Sack, A. T.

(2015). No effects of bilateral tDCS over inferior frontal gyrus on response inhibition and aggression. *PloS one*, 10(7), e0132170.

Danzl, M. M., Chelette, K. C., Lee, K., Lykins, D., & Sawaki, L. (2013). Brain

stimulation paired with novel locomotor training with robotic gait orthosis in chronic stroke: a feasibility study. *NeuroRehabilitation*, 33(1), 67-76.

- De Bruin, J. P., Van Oyen, H. G., & Van De Poll, N. (1983). Behavioural changes following lesions of the orbital prefrontal cortex in male rats. *Behavioural brain research*, 10(2), 209-232.
- DeWall, C. N., MacDonald, G., Webster, G. D., Masten, C. L., Baumeister, R. F., Powell, C., ... & Eisenberger, N. I. (2010). Acetaminophen reduces social pain: Behavioral and neural evidence. *Psychological science*, 21(7), 931-937.
- Dobek, C. E., Dipinto, A. A., Kuan, A. J., Lam, R. W., Blumberger, D. M., Downar, J., ... & Vila-Rodriguez, F. (2016). Sinus tachycardia induced by Methocarbamol and repetitive Transcranial Magnetic Stimulation (rTMS). *Brain Stimulation: Basic, Translational, and Clinical Research in Neuromodulation*, 9(1), 156-158.
- Dogan, A., Morishima, Y., Heise, F., Tanner, C., Gibson, R., Wagner, A. F., & Tobler, P. N. (2016). Prefrontal connections express individual differences in intrinsic resistance to trading off honesty values against economic benefits. *Scientific reports*, 6.
- Dubljević, V., Saigle, V., & Racine, E. (2014). The rising tide of tDCS in the media and academic literature. *Neuron*, 82(4), 731-736.
- Eisenberger, N. I., & Lieberman, M. D. (2004). Why rejection hurts: a common neural alarm system for physical and social pain. *Trends in cognitive sciences*, 8(7), 294-300.
- Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). Does rejection hurt? An fMRI study of social exclusion. *Science*, 302(5643), 290-292.
- Fecteau, S., Knoch, D., Fregni, F., Sultani, N., Boggio, P., & Pascual-Leone, A. (2007). Diminishing risk-taking behavior by modulating activity in the prefrontal

- cortex: a direct current stimulation study. *Journal of Neuroscience*, 27(46), 12500-12505.
- Fecteau, S., Pascual-Leone, A., Zald, D. H., Liguori, P., Théoret, H., Boggio, P. S., & Fregni, F. (2007). Activation of prefrontal cortex by transcranial direct current stimulation reduces appetite for risk during ambiguous decision making. *Journal of Neuroscience*, 27(23), 6212-6218.
- Fertonani, A., Ferrari, C., & Miniussi, C. (2015). What do you feel if I apply transcranial electric stimulation? Safety, sensations and secondary induced effects. *Clinical Neurophysiology*, 126(11), 2181-2188.
- Filmer, H. L., Dux, P. E., & Mattingley, J. B. (2014). Applications of transcranial direct current stimulation for understanding brain function. *Trends in neurosciences*, 37(12), 742-753.
- Finger, S., & Zaromb, F. (2006). Benjamin Franklin and shock-induced amnesia. *American Psychologist*, 61(3), 240.
- Fioretti, M., & Marden, S. (2015). Suboptimal Dishonesty: Rationality in the Absence of Strategic Behavior in Honesty Experiments. *Journal of Neuroscience*, 35(5), 1817-1818.
- Fischer, S., & Smith, G. T. (2008). Binge eating, problem drinking, and pathological gambling: Linking behavior to shared traits and social learning. *Personality and individual Differences*, 44(4), 789-800.
- Flöel, A. (2014). tDCS-enhanced motor and cognitive function in neurological diseases. *Neuroimage*, 85, 934-947.

Fourie, M. M., Thomas, K. G., Amodio, D. M., Warton, C. M., & Meintjes, E. M. (2014).

Neural correlates of experienced moral emotion: an fMRI investigation of emotion in response to prejudice feedback. *Social neuroscience*, 9(2), 203-218.

Franklin, J., Denyer, G., Steinbeck, K. S., Caterson, I. D., & Hill, A. J. (2006). Obesity and risk of low self-esteem: a statewide survey of Australian children. *Pediatrics*, 118(6), 2481-2487.

Fregni, F., Boggio, P. S., Lima, M. C., Ferreira, M. J., Wagner, T., Rigonatti, S. P., ... & Nitsche, M. A. (2006). A sham-controlled, phase II trial of transcranial direct current stimulation for the treatment of central pain in traumatic spinal cord injury. *Pain*, 122(1), 197-209.

Fregni, F., Boggio, P. S., Nitsche, M., Berman, F., Antal, A., Feredoes, E., ... & Pascual-Leone, A. (2005). Anodal transcranial direct current stimulation of prefrontal cortex enhances working memory. *Experimental brain research*, 166(1), 23-30.

Gandiga, P. C., Hummel, F. C., & Cohen, L. G. (2006). Transcranial DC stimulation (tDCS): a tool for double-blind sham-controlled clinical studies in brain stimulation. *Clinical neurophysiology*, 117(4), 845-850.

Ganis, G., Kosslyn, S. M., Stose, S., Thompson, W. L., & Yurgelun-Todd, D. A. (2003). Neural correlates of different types of deception: an fMRI investigation. *Cerebral cortex*, 13(8), 830-836.

- Gater Jr, D. R., Dolbow, D., Tsui, B., & Gorgey, A. S. (2011). Functional electrical stimulation therapies after spinal cord injury. *NeuroRehabilitation*, 28(3), 231-248.
- Georgii, C., Goldhofer, P., Meule, A., Richard, A., & Blechert, J. (2017). Food craving, food choice and consumption: The role of impulsivity and sham-controlled tDCS stimulation of the right dlPFC. *Physiology & Behavior*, 177, 20-26.
- Gladwin, T. E., den Uyl, T. E., & Wiers, R. W. (2012). Anodal tDCS of dorsolateral prefrontal cortex during an Implicit Association Test. *Neuroscience letters*, 517(2), 82-86.
- Goldman, R. L., Borckardt, J. J., Frohman, H. A., O'Neil, P. M., Madan, A., Campbell, L. K., ... & George, M. S. (2011). Prefrontal cortex transcranial direct current stimulation (tDCS) temporarily reduces food cravings and increases the self-reported ability to resist food in adults with frequent food craving. *Appetite*, 56(3), 741-746.
- Gomez-Ariza, C. J., Martín, M. C., & Morales, J. (2017). Tempering proactive cognitive control by means of tDCS of the lateral prefrontal cortex. *Brain Stimulation: Basic, Translational, and Clinical Research in Neuromodulation*, 10(2), 360.
- Grafman, J. (1995). Similarities and distinctions among current models of prefrontal cortical functions. *Annals of the New York Academy of Sciences*, 769(1), 337-368.
- Greenwald et al. (2011). Project Implicit.

- Greenwald, A. G., & Banaji, M. R. (1995). Implicit social cognition: attitudes, self-esteem, and stereotypes. *Psychological review*, 102(1), 4.
- Griffiths, L. J., Parsons, T. J., & Hill, A. J. (2010). Self-esteem and quality of life in obese children and adolescents: A systematic review. *Pediatric Obesity*, 5(4), 282-304.
- Guleyupoglu, B., Schestatsky, P., Edwards, D., Fregni, F., & Bikson, M. (2013). Classification of methods in transcranial electrical stimulation (tES) and evolving strategy from historical approaches to contemporary innovations. *Journal of neuroscience methods*, 219(2), 297-311.
- Hamilton, R., Messing, S., & Chatterjee, A. (2011). Rethinking the thinking cap Ethics of neural enhancement using noninvasive brain stimulation. *Neurology*, 76(2), 187-193.
- Heatherton, T. F., & Wagner, D. D. (2011). Cognitive neuroscience of self-regulation failure. *Trends in cognitive sciences*, 15(3), 132-139.
- Hedges, L. V., & Vevea, J. L. (1998). Fixed-and random-effects models in meta-analysis. *Psychological methods*, 3(4), 486.
- Heeren, A., Baeken, C., Vanderhasselt, M. A., Philippot, P., & De Raedt, R. (2015). Impact of anodal and cathodal transcranial direct current stimulation over the left dorsolateral prefrontal cortex during attention bias modification: an eye-tracking study. *PLoS One*, 10(4), e0124182.
- Hesse-Biber, S., Leavy, P., Quinn, C. E., & Zoino, J. (2006, April). The mass marketing of disordered eating and eating disorders: The social psychology of

- women, thinness and culture. In *Women's studies international forum* (Vol. 29, No. 2, pp. 208-224). Pergamon.
- Higgins, J. P., Thompson, S. G., Deeks, J. J., & Altman, D. G. (2003). Measuring inconsistency in meta-analyses. *BMJ: British Medical Journal*, 327(7414), 557.
- Huang, D., Chen, S., Wang, S., Shi, J., Ye, H., Luo, J., & Zheng, H. (2017). Activation of the DLPFC reveals an asymmetric effect in risky decision making: evidence from a tDCS study. *Frontiers in psychology*, 8.
- Inzlicht, M., & Gutsell, J. N. (2007). Running on empty: Neural signals for self-control failure. *Psychological science*, 18(11), 933-937.
- Jauch-Chara, K., Kistenmacher, A., Herzog, N., Schwarz, M., Schweiger, U., & Oltmanns, K. M. (2014). Repetitive electric brain stimulation reduces food intake in humans. *The American journal of clinical nutrition*, 100(4), 1003-1009.
- Javadi, A. H., & Walsh, V. (2012). Transcranial direct current stimulation (tDCS) of the left dorsolateral prefrontal cortex modulates declarative memory. *Brain stimulation*, 5(3), 231-241.
- Kadosh, R. C., & Elliott, P. (2013). Neuroscience: Brain stimulation has a long history. *Nature*, 500(7464), 529-529.
- Keeser, D., Meindl, T., Bor, J., Palm, U., Pogarell, O., Mulert, C., ... & Padberg, F. (2011). Prefrontal transcranial direct current stimulation changes connectivity of resting-state networks during fMRI. *Journal of Neuroscience*, 31(43), 15284-15293.
- Kekic, M., McClelland, J., Campbell, I., Nestler, S., Rubia, K., David, A. S., & Schmidt, U. (2014). The effects of prefrontal cortex transcranial direct current stimulation

- (tDCS) on food craving and temporal discounting in women with frequent food cravings. *Appetite*, 78, 55-62.
- Kelley, N. J., Eastwick, P. W., Harmon-Jones, E., & Schmeichel, B. J. (2015). Jealousy increased by induced relative left frontal cortical activity. *Emotion*, 15(5), 550.
- Kolb, B., & Nonneman, A. J. (1974). Frontolimbic lesions and social behavior in the rat. *Physiology & Behavior*, 13(5), 637-643.
- Kovalchik, S. (2013). Tutorial on meta-analysis in R. *R useR*, 204.
- Kuehne, M., Heimrath, K., Heinze, H. J., & Zaehle, T. (2015). Transcranial direct current stimulation of the left dorsolateral prefrontal cortex shifts preference of moral judgments. *PloS one*, 10(5), e0127061.
- Kuhnen, C. M., & Knutson, B. (2005). The neural basis of financial risk taking. *Neuron*, 47(5), 763-770.
- Kwon, Y. H., & Jang, S. H. (2011). The enhanced cortical activation induced by transcranial direct current stimulation during hand movements. *Neuroscience letters*, 492(2), 105-108.
- Langleben, D. D., Loughhead, J. W., Bilker, W. B., Ruparel, K., Childress, A. R., Busch, S. I., & Gur, R. C. (2005). Telling truth from lie in individual subjects with fast event-related fMRI. *Human brain mapping*, 26(4), 262-272.
- Ljubisavljevic, M., Maxood, K., Bjekic, J., Oommen, J., & Nagelkerke, N. (2016). Long-term effects of repeated prefrontal cortex transcranial direct current stimulation (tDCS) on food craving in normal and overweight young adults. *Brain stimulation*, 9(6), 826-833.

Loftus, A. M., Yalcin, O., Baughman, F. D., Vanman, E. J., & Hagger, M. S. (2015).

The impact of transcranial direct current stimulation on inhibitory control in young adults. *Brain and behavior*, 5(5).

Loo C. K., McFarquhar T. F., Mitchell P. B. (2008). A review of the safety of repetitive transcranial magnetic stimulation as a clinical treatment for depression.

International Journal of Neuropsychopharmacology, 11, 131–147.

Lotze, M., Veit, R., Anders, S., & Birbaumer, N. (2007). Evidence for a different role of the ventral and dorsal medial prefrontal cortex for social reactive aggression:

An interactive fMRI study. *Neuroimage*, 34(1), 470-478.

Luo, J., Ye, H., Zheng, H., Chen, S., & Huang, D. (2017). Modulating the activity of

the dorsolateral prefrontal cortex by tDCS alters distributive decisions behind the veil of ignorance via risk preference. *Behavioural Brain Research*, 328, 70-80.

Luo, Q., Nakic, M., Wheatley, T., Richell, R., Martin, A., & Blair, R. J. R. (2006). The neural basis of implicit moral attitude—an IAT study using event-related

fMRI. *Neuroimage*, 30(4), 1449-1457.

Ly, V., Bergmann, T. O., Gladwin, T. E., Volman, I., Usberti, N., Cools, R., & Roelofs,

K. (2016). Reduced affective biasing of instrumental action with tDCS over the prefrontal cortex. *Brain stimulation*, 9(3), 380-387.

Mameli, F., Mrakic-Sposta, S., Vergari, M., Fumagalli, M., Macis, M., Ferrucci, R., ... &

Priori, A. (2010). Dorsolateral prefrontal cortex specifically processes general—but not personal—knowledge deception: multiple brain networks for lying. *Behavioural brain research*, 211(2), 164-168.

- Mark W., Lipsey, & Wilson, D. B. (2001). *Practical meta-analysis* (Vol. 49). Thousand Oaks, CA: Sage publications.
- Metzuyanim-Gorlick, S., & Mashal, N. (2016). The effects of transcranial direct current stimulation over the dorsolateral prefrontal cortex on cognitive inhibition. *Experimental brain research*, 234(6), 1537-1544.
- Monai, H., Ohkura, M., Tanaka, M., Oe, Y., Konno, A., Hirai, H., ... & Hirase, H. (2016). Calcium imaging reveals glial involvement in transcranial direct current stimulation-induced plasticity in mouse brain. *Nature communications*, 7.
- Monro, F., & Huon, G. (2005). Media-portrayed idealized images, body shame, and appearance anxiety. *International Journal of Eating Disorders*, 38(1), 85-90.
- Murdaugh, D. L., Cox, J. E., Cook, E. W., & Weller, R. E. (2012). fMRI reactivity to high-calorie food pictures predicts short-and long-term outcome in a weight-loss program. *Neuroimage*, 59(3), 2709-2721.
- Nitsche, M. A., & Paulus, W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *The Journal of physiology*, 527(3), 633-639.
- Nonneman, A. J., Voigt, J., & Kolb, B. E. (1974). Comparisons of behavioral effects of hippocampal and prefrontal cortex lesions in the rat. *Journal of comparative and physiological psychology*, 87(2), 249.
- Nord, C. L., Forster, S., Halahakoon, D. C., Penton-Voak, I. S., Munafò, M. R., & Roiser, J. P. (2017) Maréchal, M. A., Cohn, A., Ugazio, G., & Ruff, C. C. (2017). Increasing honesty in humans with noninvasive brain stimulation. *Proceedings of the National Academy of Sciences*, 114(17), 4360-4364.

O'Driscoll, K., & Leach, J. P. (1998). "No longer Gage": an iron bar through the head:

Early observations of personality change after injury to the prefrontal cortex. *BMJ: British Medical Journal*, 317(7174), 1673.

Oldrati, V., Patricelli, J., Colombo, B., & Antonietti, A. (2016). The role of dorsolateral prefrontal cortex in inhibition mechanism: A study on cognitive reflection test and similar tasks through neuromodulation. *Neuropsychologia*, 91, 499-508.

Perlmutter, J. S., & Mink, J. W. (2006). Deep brain stimulation. *Annu. Rev. Neurosci.*, 29, 229-257.

Pinker, S. (2013). The decline of war and conceptions of human nature.

Plewnia, C., Schroeder, P. A., Kunze, R., Faehling, F., & Wolkenstein, L. (2015).

Keep calm and carry on: improved frustration tolerance and processing speed by transcranial direct current stimulation (tDCS). *PLoS One*, 10(4), e0122578.

Priori, A., Berardelli, A., Rona, S., Accornero, N., & Manfredi, M. (1998). Polarization of the human motor cortex through the scalp. *Neuroreport*, 9(10), 2257-2260.

Priori, A., Hallett, M., & Rothwell, J. C. (2009). Repetitive transcranial magnetic stimulation or transcranial direct current stimulation?. *Brain stimulation*, 2(4), 241-245.

Priori, A., Mameli, F., Cogiamanian, F., Marceglia, S., Tiriticco, M., Mrakic-Sposta, S., ... & Sartori, G. (2007). Lie-specific involvement of dorsolateral prefrontal cortex in deception. *Cerebral Cortex*, 18(2), 451-455.

Rao, H., Kordzykowski, M., Pluta, J., Hoang, A., & Detre, J. A. (2008). Neural correlates of voluntary and involuntary risk taking in the human brain: an fMRI Study of the Balloon Analog Risk Task (BART). *Neuroimage*, 42(2), 902-910.

- Redfearn, J. W. T., Lippold, O. C. J., & Costain, R. (1964). Preliminary account of the clinical effects of polarizing the brain in certain psychiatric disorders. *The British Journal of Psychiatry*, 110(469), 773-785.
- Riva, P., Romero Lauro, L. J., DeWall, C. N., Chester, D. S., & Bushman, B. J. (2014). Reducing aggressive responses to social exclusion using transcranial direct current stimulation. *Social cognitive and affective neuroscience*, 10(3), 352-356.
- Riva, P., Romero Lauro, L. J., Vergallito, A., DeWall, C. N., & Bushman, B. J. (2015). Electrified emotions: Modulatory effects of transcranial direct stimulation on negative emotional reactions to social exclusion. *Social neuroscience*, 10(1), 46-54.
- Robinovitch, L. G. (1914). Electrical analgesia, sleep and resuscitation. *Anesthesia*. New York: Appleton.
- Rosen, P. J., & Factor, P. I. (2015). Emotional impulsivity and emotional and behavioral difficulties among children with ADHD: an ecological momentary assessment study. *Journal of Attention Disorders*, 19(9), 779-793.
- Rossi S., Hallett M., Rossini P. M., Pascual-Leone A. (2009). Safety, ethical considerations, and application guidelines for the use of transcranial magnetic stimulation in clinical practice and research. *Clinical Neurophysiology*, 120, 2008–2039
- Schonberg, T., Fox, C. R., Mumford, J. A., Congdon, E., Trepel, C., & Poldrack, R. A. (2012). Decreasing ventromedial prefrontal cortex activity during sequential

risk-taking: an fMRI investigation of the balloon analog risk task. *Frontiers in neuroscience*, 6.

Sellaro, R., Derks, B., Nitsche, M. A., Hommel, B., van den Wildenberg, W. P., van Dam, K., & Colzato, L. S. (2015). Reducing prejudice through brain stimulation. *Brain stimulation*, 8(5), 891-897.

Siep, N., Roefs, A., Roebroek, A., Havermans, R., Bonte, M. L., & Jansen, A. (2009). Hunger is the best spice: an fMRI study of the effects of attention, hunger and calorie content on food reward processing in the amygdala and orbitofrontal cortex. *Behavioural brain research*, 198(1), 149-158.

Stagg, C. J., & Nitsche, M. A. (2011). Physiological basis of transcranial direct current stimulation. *The Neuroscientist*, 17(1), 37-53.

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental review*, 28(1), 78-106.

Stramaccia, D. F., Penolazzi, B., Sartori, G., Braga, M., Mondini, S., & Galfano, G. (2015). Assessing the effects of tDCS over a delayed response inhibition task by targeting the right inferior frontal gyrus and right dorsolateral prefrontal cortex. *Experimental brain research*, 233(8), 2283-2290.

Strobach, T., Soutschek, A., Antonenko, D., Flöel, A., & Schubert, T. (2015). Modulation of executive control in dual tasks with transcranial direct current stimulation (tDCS). *Neuropsychologia*, 68, 8-20.

Underwood, E. (2016). Cadaver study challenges brain stimulation methods. *Science*, 352(6284), 397-397.

- Votinov, M., Aso, T., Koganemaru, S., Fukuyama, H., & Mima, T. (2013). Transcranial direct current stimulation changes human endowment effect. *Neuroscience research*, 76(4), 251-256.
- Vrij, A., & Baxter, M. (1999). Accuracy and confidence in detecting truths and lies in elaborations and denials: Truth bias, lie bias and individual differences. *Expert evidence*, 7(1), 25-36.
- Wagner, T., Fregni, F., Fecteau, S., Grodzinsky, A., Zahn, M., & Pascual-Leone, A. (2007). Transcranial direct current stimulation: a computer-based human model study. *Neuroimage*, 35(3), 1113-1124.
- Wassermann, E. M. (1998). Risk and safety of repetitive transcranial magnetic stimulation: report and suggested guidelines from the International Workshop on the Safety of Repetitive Transcranial Magnetic Stimulation, June 5–7, 1996. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, 108(1), 1-16.
- Wilmer, H. H., & Chein, J. M. (2016). Mobile technology habits: patterns of association among device usage, intertemporal preference, impulse control, and reward sensitivity. *Psychonomic bulletin & review*, 23(5), 1607-1614.
- Ye, H., Chen, S., Huang, D., Wang, S., Jia, Y., & Luo, J. (2015). Transcranial direct current stimulation over prefrontal cortex diminishes degree of risk aversion. *Neuroscience letters*, 598, 18-22.
- Yokum, S., Ng, J., & Stice, E. (2011). Attentional bias to food images associated with elevated weight and future weight gain: an fMRI study. *Obesity*, 19(9), 1775-1783.

Zheng, H., Wang, S., Guo, W., Chen, S., Luo, J., Ye, H., & Huang, D. (2017).

Enhancing the Activity of the DLPFC with tDCS Alters Risk Preference without Changing Interpersonal Trust. *Frontiers in neuroscience*, 11.

Figure 1.

Flow chart of inclusion process for articles in analysis.

Figure 2.

Funnel plot examining publication bias in the overall model.

Model: weighted regression with multiplicative dispersion, predictor: standard error. Test for funnel asymmetry: $t(44)=-4.21, p<.001$, signifying likely publication bias.

Figure 3.

Forest plot showing effect sizes across studies.

Figure 4.

Pet (left) and peese (right) publication bias graphs, both suggesting publication bias.

Figure 5.

Forest plot of the effect of tDCS on aggression.

Figure 6.

Funnel plot of the effect of tDCS on aggression.

This funnel plot suggests there is not publication bias in the literature on the effect of tDCS on aggression, $t(4)=-0.17$, $p=0.88$.

Figure 7.

Forest plot of the effect of tDCS on overeating.

Figure 8.

Funnel plot of the effect of tDCS on overeating.

This funnel plot suggests there is significant publication bias in the literature on the effect of tDCS on overeating, $t(5)=-3.58$, $p=0.02$.

Figure 9.

Forest plot on the effect of tDCS on impulsivity.

Figure 10.

Funnel plot on the effect of tDCS on impulsivity.

This funnel plot suggests there is not significant publication bias in the literature about the effect of tDCS on impulsivity, $t(7)=-1.75$, $p=0.12$.

Figure 11.

Forest plot on the effect of tDCS on bias.

Figure 12.

Funnel plot on the effect of tDCS on bias.

This funnel plot suggests there is not significant publication bias in the literature about the effect of tDCS on bias, $t(5)=-2.34$, $p=0.07$.

Figure 13.

Forest plot on the effect of tDCS on dishonesty.

Figure 14.

Funnel plot on the effect of tDCS on dishonesty.

This funnel plot suggests there is not significant publication bias in the literature about the effect of tDCS on dishonesty, $t(2)=0.22$, $p=0.85$.

Figure 15.

Forest plot on the effect of tDCS on risk-taking.

Figure 16.

Funnel plot of the effect of tDCS on risk-taking.

This funnel plot suggests significant publication bias in the literature about the effect of tDCS on risk-taking, $t(11)=-2.23$, $p=0.046$.

Table 1.

Summary of studies included in analysis.

Authors & year	n tDCS	n sham	Dependent variable	Article title	Journal Title	Brain region	Online/offline	Stimulation duration	Design	Dose in mA	Task used for DV
Dambacher et al., 2015	16	16	aggression	Reducing proactive aggression through non-invasive brain stimulation	SCAN	rDLPFC	online	750s	between	2	Taylor Aggression Paradigm--total aggression
Plewnia et al., 2015	14	14	aggression	Keep Calm and Carry On: Improved Frustration Tolerance and Processing Speed by Transcranial Direct Current Stimulation (tDCS)	PLOS One	IDL PFC	online	600s	between	1	PANAS negative affect after frustrating task (PASAT)
Kelley et al., 2013	30	30	aggression	When anger leads to rumination: induction of relative right frontal cortical activity with transcranial direct current stimulation increases anger-related rumination	Psychological Science	IDL PFC	online	900s	between	2	essay criticism paradigm--anger
Kelley et al., 2013	30	30	aggression	When anger leads to rumination: induction of relative right frontal cortical activity with transcranial direct current stimulation increases anger-related rumination	Psychological Science	rDLPFC	online	900s	between	2	essay criticism paradigm--state rumination

Authors & year	n tDCS	n sham	Dependent variable	Article title	Journal Title	Brain region	Online/offline	Stimulation duration	Design	Dose in mA	Task used for DV
Riva et al., 2015	40	40	aggression	Reducing aggressive responses to social exclusion using transcranial direct current stimulation	SCAN	rVLPFC	online	1200s	between	1.5	hot sauce paradigm for provoked and unprovoked people
Riva et al., 2017	40	39	aggression	Neuromodulation can reduce aggressive responses elicited by video games	SCAN	rVLPFC	online	1200s	between	1.5	Taylor Aggression Paradigm
Fregni et al., 2008	21	21	overeating	Transcranial direct current stimulation on the prefrontal cortex modulates the desire for specific foods	Appetite	IDL PFC	offline	1200s	within	2	calories eaten (tempting, unhealthy snack foods available)
Georgii et al., 2017	42	42	overeating	Food craving, food choice and consumption: The role of impulsivity and sham-controlled tDCS stimulation of the right dlPFC	Physiology and Behavior	rDLPFC	online	1200s	within	1	desire to eat high calorie foods
Georgii et al., 2017	42	42	overeating	Food craving, food choice and consumption: The role of impulsivity and sham-controlled tDCS stimulation of the right dlPFC	Physiology and Behavior	rDLPFC	online	1200s	within	1	desire to eat high calorie foods

Authors & year	n tDCS	n sham	Dependent variable	Article title	Journal Title	Brain region	Online/offline	Stimulation duration	Design	Dose in mA	Task used for DV
Goldman, 2011	19	19	overeating	Prefrontal cortex transcranial direct current stimulation (tDCS) temporarily reduces food cravings and increases the self-reported ability to resist food in adults with food craving	Appetite	rDLPFC	online	1200s	within	2	food cravings
Jauch-Chara et al., 2014	7	7	overeating	Repetitive electric brain stimulation reduces food intake in humans	The American Journal of Clinical Nutrition	rDLPFC	offline	1200s	between	2	8 days of stimulation; on 8th day, anode versus sham on appetite for sweets food cravings (general)
Kekic et al., 2014	17	17	overeating	The effects of prefrontal cortex direct current stimulation (tDCS) on food cravings and delay discounting in women with frequent food cravings	Appetite	rDLPFC	offline	1200s	within	2	
Ljubisavljevic et al., 2017	15	15	overeating	Long-term effects of repeated prefrontal cortex transcranial direct current stimulation (tDCS) on food craving in normal and overweight young adults	Brain Stimulation	rDLPFC	offline	1200s	between	2	Sweets cravings—one month follow up

Authors & year	n tDCS	n sham	Dependent variable	Article title	Journal Title	Brain region	Online/offline	Stimulation duration	Design	Dose in mA	Task used for DV
Gomez-Azira et al., 2017	24	23	impulsivity	Modulating behavioral inhibition by tDCS combined with cognitive training	Frontiers in Neuroscience	IDL PFC	online	900s	between	2	IDL PFC avg error rate online
Gomez-Azira et al., 2017	24	23	impulsivity	Modulating behavioral inhibition by tDCS combined with cognitive training	Frontiers in Neuroscience	rDLPFC	online	900s	between	2	IDL PFC avg error rate online
Lofus et al., 2015	14	14	impulsivity	The impact of transcranial direct current stimulation on inhibitory control in young adults	Brain and Behavior	IDL PFC	offline	600s	between	2	stroop error rate
Metzuyanim-Gorlick et al., 2016	10	10	impulsivity	The effects of transcranial direct current stimulation over the dorsolateral prefrontal cortex on cognitive inhibition	Experimental Brain Stimulation	IDL PFC	offline	1200s	between	2	sentence completion task: errors in easy condition
Oldrati et al., 2016	13	13	impulsivity	The role of dorsolateral prefrontal cortex in inhibition mechanism: A study on cognitive reflection test and similar tasks through neuromodulation	Neuropsychologia	rDLPFC	offline	1200s	between	1.5	CRT problem solving task Impulsive errors on incorrect trials
Stramaccia et al., 2015	20	18	impulsivity	Assessing the effects of tDCS over a delayed response inhibition task by targeting the right inferior frontal gyrus and right dorsolateral prefrontal cortex	Experimental Brain Stimulation	rDLPFC	offline	1200s	between	1.5	stop signal reaction time in stop signal task

Authors & year	n tDCS	n sham	Dependent variable	Article title	Journal Title	Brain region	Online/offline	Stimulation duration	Design	Dose in mA	Task used for DV
Bell & Barnett et al., 2016 Bell et al., 2017	77	74	impulsivity	unpublished work	unpublished work	rVLPFC	online	1200s	between	1.5	impulsivity in money task
	108	116	impulsivity	unpublished work	unpublished work	rVLPFC	online	1500s	between	1.5	impulsivity in progressive ratio task error rate in stop signal task
Bell & Turner, 2017	48	47	impulsivity	unpublished work	unpublished work	rVLPFC	online	1200s	between	1.5	ABM--see angry and neutral faces, trained to attend to neutral ones only: time to first fixation on angry faces
Heeren et al., 2015	18	19	bias	Impact of anodal and cathodal transcranial direct current stimulation over the left dorsolateral prefrontal cortex during attention bias modification: an eye tracking study	PLOS One	IDL PFC	online	1500s	between	2	Moral dilemma value judgement score: tDCS made people less utilitarian in their morality (utilitarian = would kill one person to save several)
Kuehne et al., 2010	26	26	bias	Transcranial direct current stimulation of the left dorsolateral prefrontal cortex shifts preference of moral judgments	PLOS One	IDL PFC	online	1200s	within	2	Affective biasing task with emotional go no go
Ly et al., 2016	40	40	bias	Reduced affective biasing of instrumental action with tDCS over the prefrontal cortex	Brain Stimulation	bilateral anterior PFC	online	1500s	within	1	

Authors & year	n tDCS	n sham	Dependent variable	Article title	Journal Title	Brain region	Online/offline	Stimulation duration	Design	Dose in mA	Task used for DV
Nord et al., 2017	75	75	bias	Prefrontal cortex does not affect emotional bias, but may slow emotion identification	SCAN	IDL PFC	online	1500s	within	1	Comparison of processing speed of negative emotions and positive emotions in tDCS and sham on reaction time in emotional ID task
Sellaro et al., 2008	20	20	4	Reducing prejudice through brain stimulation	Brain Stimulation	mPFC	online	1200s	between	1	race IAT--D-IAT (higher = more bias)
Chen et al., 2017	25	23	bias	Attentional bias mediates the effect of neurostimulation on emotional vulnerability	Journal of Psychiatric Research	IDL PFC	offline	1200s	between	2	dual video stressor task--bias toward looking at threatening stimuli over neutral stimuli
Gladwin et al., 2012	20	20	bias	Anodal tDCS of dorsolateral prefrontal cortex during an Implicit Association Test	Neuroscience Letters	rDL PFC	offline	600s	within	1	IAT--congruent target reaction time
Colzaro et al., 2015	20	20	honesty	tDCS of Medial Prefrontal Cortex Does Not Enhance Interpersonal Trust	Journal of Psychophysiology	mPFC	online	1200s	between	1	reaction time in Trust Game

Authors & year	n tDCS	n sham	Dependent variable	Article title	Journal Title	Brain region	Online/offline	Stimulation duration	Design	Dose in mA	Task used for DV
Mameli et al., 2010	10	10	honesty	Dorsolateral prefrontal cortex specifically processes general – but not personal – knowledge deception: Multiple brain networks for lying	Behavioral Brain Research	rDLPFC	offline	1200s	between	2	reaction time for truth response about personal information
Marechal et al., 2017	127	125	honesty	Increasing honesty in humans with noninvasive brain stimulation Lie-Specific Involvement of Dorsolateral Prefrontal Cortex in Deception	PNAS	rDLPFC	online	1800s	between	2	Lying
Priori et al., 2008	5	5	honesty	Brain stimulation modulates driving behavior	Cerebral Cortex	rDLPFC	offline	600s	between	2	lies on selection trials -- reaction time
Belli et al., 2008	21	21	risk-taking	Activation of Prefrontal Cortex by Transcranial Direct Current Stimulation Reduces Appetite for Risk during Ambiguous Decision Making	Behavioral Brain Functions	rDLPFC	online	900s	between	2	driving simulation-- revs per minute
Fecteau et al., 2007	12	12	risk-taking	Activation of Prefrontal Cortex by Transcranial Direct Current Stimulation Reduces Appetite for Risk during Ambiguous Decision Making	The Journal of Neuroscience	IDLPCF	online	900s	between	1	# of pumps in BART
Fecteau et al., 2007	12	12	risk-taking	Activation of Prefrontal Cortex by Transcranial Direct Current Stimulation Reduces Appetite for Risk during Ambiguous Decision Making	The Journal of Neuroscience	rDLPFC	online	900s	between	1	# of pumps in BART

Authors & year	n tDCS	n sham	Dependent variable	Article title	Journal Title	Brain region	Online/offline	Stimulation duration	Design	Dose in mA	Task used for DV
Fecteau et al., 2007	12	12	risk-taking	Diminishing Risk-Taking Behavior by Modulating Activity in the Prefrontal Cortex: A Direct Current Stimulation Study	The Journal of Neuroscience	rDLPFC	online	600s	between	2	high risk choice in gambling task
Fecteau et al., 2007	12	12	risk-taking	Diminishing Risk-Taking Behavior by Modulating Activity in the Prefrontal Cortex: A Direct Current Stimulation Study	The Journal of Neuroscience	IDL PFC	online	600s	between	2	high risk choice in gambling task
Huang et al., 2017	30	30	risk-taking	Activation of the DLPFC Reveals an Asymmetric Effect in Risky Decision Making: Evidence from a tDCS Study	Frontiers in Psychology	IDL PFC	online	900s	between	2	riskiness in gains frame of riskiness task
Huang et al., 2017	30	30	risk-taking	Activation of the DLPFC Reveals an Asymmetric Effect in Risky Decision Making: Evidence from a tDCS Study	Frontiers in Psychology	rDLPFC	online	900s	between	2	riskiness in loss frame of riskiness task
Priffl et al., 2013	25	25	risk-taking	tDCS Study Modulating the activity of dorsolateral prefrontal cortex by tDCS alters distributive decisions behind the veil of ignorance via risk preference	European Journal of Neuroscience	IDL PFC	offline	900s	within	2	"cold" risk taking on Columbia Card Task

Authors & year	n tDCS	n sham	Dependent variable	Article title	Journal Title	Brain region	Online/offline	Stimulation duration	Design	Dose in mA	Task used for DV
Priffl et al., 2013	25	25	risk-taking	Modulating the activity of dorsolateral prefrontal cortex by tDCS alters distributive decisions behind the veil of ignorance via risk preference	European Journal of Neuroscience	rDLPFC	offline	900s	within	2	"hot" risk taking on Columbia Card Task in nonsmokers
Ye et al., 2015	20	20	risk-taking	Transcranial direct current stimulation over prefrontal cortex diminishes degree of risk aversion	Neuroscience Letters	rDLPFC	offline	900s	between	2	riskiness females in gambling task
Ye et al., 2015	20	20	risk-taking	Transcranial direct current stimulation over prefrontal cortex diminishes degree of risk aversion	Neuroscience Letters	IDL PFC	offline	900s	between	2	riskiness females in gambling task
Zheng et al., 2017	30	30	risk-taking	Enhancing the Activity of the DLPFC with tDCS Alters Risk Preference without Changing Interpersonal Trust	Frontiers in Neuroscience	rDLPFC	offline	1200s	between	2	riskiness in trust game, exp. 2
Bell et al., 2017	89	89	risk-taking	unpublished work	unpublished work	rVLPFC	online	1200s	within	1.5	risk taking in BART and IGT

Table 2.

The overall effect of tDCS and the effect of tDCS on different dependent variables.

DV	k	N	d	Q	P
Aggression	6	339	-0.18	7.09	0.19
Overeating	7	326	-0.29 (-0.15 _c)	7.29	0.03*
Impulsivity	9	667	-0.04	11.97	0.70
Bias	7	447	-0.25	6.88	0.02*
Honesty	4	322	-0.06	0.22	0.57
Risk-taking	13	676	-0.36 (-0.35 _c)	34.79	0.01*
Overall	46	2196	-0.20 (-0.10 _c)	78.17	<.001***

Note: Some of the numbers under d have numbers in parentheses next to them with a subscript of c. These numbers are corrected effect sizes from using the trim and fill method.

* = $p < .05$, ** = $p < .01$, *** = $p < .001$; SD_w = weighted standard deviation.

Table 3.

Analog ANOVA table for different brain regions.

	Q	df	p
Between	0.99	4	0.91
Within	45.18	41	0.30
Total	46.17	45	0.42

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 4.

Q by group for different brain regions.

	Q^w	df	p
lDLPFC	14.43	14	0.41
rDLPFC	26.13	21	0.20
rVLPFC	2.64	5	0.75
baPFC	--	0	--
mPFC	1.98	1	--

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$; Q_w = weighted Cochran's Q; lDLPFC = left dorsolateral prefrontal cortex, rDLPFC = right ventrolateral prefrontal cortex; rVLPFC = right ventrolateral prefrontal cortex; baPFC = bilateral anterior prefrontal cortex, mPFC = medial prefrontal cortex.

Table 5.

Overall effect size from different brain regions.

	k	d	SE	z	p
IDLPFC	15	-0.22	0.11	-2.08	0.04*
rDLPFC	22	-0.25	0.09	-2.80	0.01**
rVLPFC	6	-0.10	0.13	-0.75	0.45
baPFC	1	-0.25	0.34	-0.73	0.46
mPFC	2	-0.20	0.29	-0.70	0.48

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$; IDLPFC = left dorsolateral prefrontal cortex,

rDLPFC = right ventrolateral prefrontal cortex; rVLPFC = right ventrolateral prefrontal cortex;

baPFC = bilateral anterior prefrontal cortex, mPFC = medial prefrontal cortex.

Table 6.

Analog ANOVA table for offline and online stimulation.

	Q	df	p
Between	2.91	1	0.09
Within	49.32	44	0.27
Total	52.22	45	0.21

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$; offline stimulation = measured the effects of tDCS 0-30 minutes after it was removed; online stimulation = measured the effects of tDCS while it was still on.

Table 7.

Q by group for offline and online stimulation.

	Q^w	df	p
offline	11.70	16	0.76
online	37.62	28	0.11

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$; Q_w = weighted Cochran's Q.

Table 8.

Overall effect size for offline and online stimulation.

	k	d	SE	z	p
offline	17	-0.34	0.10	-3.41	0.01***
online	29	-0.14	0.06	-2.21	0.02*

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 9.

Analog ANOVA table for within subjects designs and between subjects designs.

	Q	df	p
Between	0.34	1	0.55
Within	47.88	44	0.32
Total	48.22	45	0.34

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 10.

Q by group for within subjects designs and between subjects designs.

	Q^w	df	p
within	4.81	11	0.94
between	43.06	33	0.11

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$; Q_w = weighted Cochran's Q.

Table 11.

Overall effect size for within subjects designs and between subjects designs.

	k	d	SE	z	p
within	12	-0.15	0.10	-1.48	0.13
between	34	-0.23	0.07	-3.35	<.001***

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 12.

Homogeneity table for regression on tDCS dose in milliamps.

	Q	df	p
Model	0.31	1	0.58
Residual	47.98	44	0.31
Total	48.29	45	0.34

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 13.

Regression on tDCS dose in milliamps.

	B	β	SE	z	p
Constant	-0.33	0	0.24	-1.38	0.17
Dose	0.08	0.08	0.14	0.55	0.58

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 14.

Homogeneity table for regression on tDCS duration in seconds.

	Q	df	p
Model	0.31	1	0.58
Residual	47.98	44	0.31
Total	48.29	45	0.34

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.

Table 15.

Regression on tDCS duration in seconds.

	B	β	SE	z	p
Constant	-0.40	0	0.25	-1.63	0.10
Duration	0	0.13	0	0.86	0.39

Note: * = $p < .05$, ** = $p < .01$, *** = $p < .001$.