The Role of tDCS and Subjective Beliefs in Implicit Approach Behaviour

Lars Jaswetz

Master Science Thesis

Supervised by:

1. Dennis Schutter

2. Eni Becker

20.08.2018

Radboud University

Abstract

Approach-avoidance behaviours play a big role in various parts of our daily life and can range from more controlled, explicit behaviours to more automatic, implicit tendencies. Controlled approach behaviour has been associated with relative greater left than right activity in the dorsolateral prefrontal cortex, with studies inducing this pattern of brain activity finding an increase in controlled approach behaviour. However, it is not known whether or not this also holds true for more implicit approach-avoidance behaviours. It is therefore not known if brain stimulation can increase implicit approach behaviour. Furthermore, subjective beliefs about interventions such as brain stimulation techniques have been shown to influence the results of the interventions. Therefore, it is also not known if inducing the subjective belief that the stimulation increases approach behaviour, actually leads to increased approach behaviour. We expected active compared to sham tDCS and the subjective belief induction compared to control instructions to results in increased approach behaviour, measured in reaction times. In order to test this, 39 healthy volunteers were assigned to either a manipulation condition in which a subjective belief about the transcranial direct current stimulation was induced, or a control condition which did not receive this manipulation. Both groups completed two blocks of a joystick task measuring implicit approach-avoidance behaviour. The first block of the task was accompanied by sham stimulation and the second block was accompanied by active stimulation. The results showed that neither stimulation nor subjective beliefs influenced implicit approach-avoidance behaviour. However, active stimulation led to an overall reduction in reaction times. It is possible that tDCS and subjective beliefs cannot influence implicit approach behaviour.

Approach-avoidance behaviour describes how individuals react to stimuli in their environment. Generally, positively valenced stimuli are approached while negatively valenced stimuli are avoided. These behaviours can range from being more controlled and intentional, to being more automatic and implicit (Hans Phaf, Mohr, Rotteveel, & Wicherts, 2014). On a behavioural level, examples of approach-avoidance behaviour can be found in many parts of daily life. For example, deciding which food to eat (Kemps, Tiggemann, Martin, & Elliott, 2013), stopping with smoking (Wittekind, Feist, Schneider, Moritz, & Fritzsche, 2015) and health-behaviour (Sherman, Mann, & Updegraff, 2006) are just some examples of aspects in which approach-avoidance behaviours play a big role.

On a neurological level, approach-avoidance behaviour can also be traced back to brain activity. For example, several EEG studies have shown that relative greater left than right activity in the dorsolateral prefrontal cortex (DLPFC) has been associated with approach motivation (Coan & Allen, 2004; Harmon-Jones, Gable, & Peterson, 2010; Schutter & Harmon-Jones, 2013). This is called frontal asymmetry in the DLPFC.

Applying these theoretical neurological insights, studies have shown that it is possible to influence approach avoidance behaviour using non-invasive brain stimulation. Non-invasive brain stimulation techniques have been used to modulate and manipulate brain activity and/or cortical excitability in a safe way. One of these techniques is transcranial direct current stimulation (tDCS; Nitsche & Paulus, 2000; Nitsche et al., 2008; Woods et al., 2016), which is a way to alter cortical excitability in a relatively painless, selective, reversible and focal manner. Here, two electrodes, namely a cathode and an anode, are applied to the head and emit weak electrical currents through the skull to the underlying cortical tissue. The anode in this case increases cortical excitability, while the cathode decreases it. This change in excitability is achieved through membrane polarisation. This can be used to build on the aforementioned frontal asymmetry in the DLFPC, as it can induce greater left than right activity in the DLPFC.

This was done in a study which influenced controlled approach motivation (Hortensius, Schutter, & Harmon-Jones, 2012). The authors used an interpersonal provocation paradigm which induced anger. Participants undergoing active tDCS, which induced relative greater left than right activity in the DLPFC, more often chose to aggress on the insulting party, compared to sham tDCS. According to the motivational direction model, this relation between anger and aggression is driven by changes in approach behaviour (Harmon-Jones, 2003). This study signified the neurological and behavioural underpinnings of controlled approach behaviour in anger, using the theoretical knowledge from the frontal asymmetry literature. However, it is not known if more automatic, implicit approach-avoidance behaviours can also be influenced in the same way. One study investigated the effects of tDCS to the anterior part of the prefrontal cortex on approach-avoidance reactions to affectively valenced stimuli (Ly et al., 2016). While the results suggest that tDCS did influence this implicit approach-avoidance behaviour, they did use an electrode setup that does not build upon the frontal asymmetry model. Furthermore, the study did not specifically look into the motivational direction, whereas the frontal asymmetry model does specify the direction of the effect. It is therefore not known if more implicit approach-avoidance behaviour can be influenced in a similar manner as more controlled behaviour can be.

Furthermore, the abovementioned studies did not take into account the role of subjective beliefs about the stimulation. However, subjective beliefs about interventions have been shown to moderate the effects of the respective interventions (Benedetti et al., 2003). One well-known application of subjective beliefs is the placebo effect. Here, a certain belief is induced in the recipient regarding the working mechanism or effect of an intervention (Enck, Benedetti, & Schedlowski, 2008). For example, the belief that a simple sugar pill or a saline injection has analgesic effects can actually induce these analgesic effects (Finniss, Kaptchuk, Miller, & Benedetti, 2010). However, these effects are not limited to analgesic effects. Studies on the effects of psychopharmacological interventions on depression have routinely reported

significant improvements in their respective placebo conditions (Mora et al., 2011). Furthermore, studies with brain stimulation techniques have also shown substantial placebo effects through inductions of subjective beliefs. For example, participants were led to believe that the stimulation they were about to receive would increase their muscle strength, did show higher muscle strength compared to participants in the control condition. In addition to that, a combined brain stimulation and neuroimaging study revealed that placebo tDCS alone can induce changes in brain activity (DosSantos et al., 2014). Seeing that subjective beliefs, specifically about brain stimulation techniques, can elicit such strong effects, it is important to assess their role when administering these types of interventions, as they can moderate the effectiveness.

Therefore, the aim of the present study was two-fold: First, we wanted to assess the effects of tDCS over the DLPFC on implicit approach-avoidance behaviour. Second, we also wanted to assess the effects of subjective believes about tDCS on approach-avoidance behaviour. Influencing implicit approach-avoidance behaviour can be highly relevant in today's mental health care settings, as many interventions build upon this framework to treat a multitude of mental disorders (Heuer, Rinck, & Becker, 2007; Klein, Becker, & Rinck, 2011; Rinck & Becker, 2007; Wiers, Gladwin, Hofmann, Salemink, & Ridderinkhof, 2013). Likewise, investigating whether or not subjective beliefs about tDCS can influence the results of a given intervention is also highly relevant, as they have been shown to moderate the effect of the respective intervention (Finniss et al., 2010).

Consequently, we set up the present study in the interest of answering the following research question: What are the effects of tDCS and subjective beliefs on implicit approach-avoidance behaviours? According to the neurological insights and the applied research on brain stimulation on approach-avoidance behaviour, we expected participant undergoing active compared to sham tDCS to show higher approach motivation, measured in reaction times. Furthermore, according to the literature on subjective beliefs, we also expected

participants receiving an expectation manipulation about the stimulation they received to show higher approach motivation, compared to participants who did not receive this manipulation.

Methods

Participants

The participants were 39 healthy volunteers, with a mean age of 26.72 (*SD* = 9.77 range = 19 - 61) and 20 being female (51.28%). The initial sample contained data of 44 participants, however in 5 of these the resistance between the electrodes was too high (> 40 Ω) and their data could not be used. Participants were required to be 18 years or older, right-handed, have normal or corrected to normal vision, free of ferromagnetic parts in the skull, and to not have a history of traumatic brain injury or neurosurgery. As a compensation, participants received a 10€ gift voucher. The study was approved by the Medical Ethical Testing Commission (METC; Dutch: Medisch-Ethisch Toetsingscommissie). The METC approved a maximum amount of 40 participants to be tested, with a maximum replacement of six participants in case the data of some were not usable.

Materials

Computer task. Approach-avoidance behaviours were measured using the Approach-Avoidance Task (AAT; Rinck & Becker, 2007). This is a computer task in which participants have to react to stimuli using a joystick, mimicking the movement of either pushing something away or pulling something closer. Reaction times for both movements were obtained in order to calculate approach-avoidance behaviours. We used direct instructions, meaning that we told participants explicitly which types of stimuli should be pushed or pulled. Each stimulus was presented in with both, push and pull instructions. Typically, two different sorts of stimuli are used in the task, with one type being negatively valenced stimuli and the other type being positively valenced stimuli. Presenting both types of stimuli with both

movements creates two blocks, namely a congruent block and an incongruent block. In the congruent block, the likeable stimuli have to be pulled closer while the aversive stimuli have to be pushed away. In the incongruent block the likeable stimuli have to be pushed away while the aversive stimuli have to be pulled closer. The order of the congruent and incongruent blocks was counterbalanced and the order of the stimulus material within each block was randomized.

Joystick. We used a Logitech Attack 3 joystick for the AAT. Push and pull movements were only completed when the maximum position on the z-axis in both directions was reached. Before each trial, participants had to move the joystick in its default (resting) position and press the fire button in order to let the stimuli appear. This was done to get a more accurate estimation of the participants' reaction time, as the participants themselves can start the trial which starts the timer measuring the reaction time. For an illustration of the joystick, see figure 1.

Figure 1. The joystick used in the task in its default position, illustrating the fire button and the axis on which the joystick had to be moved.

Stimulus Material. We used happy and angry faces as stimuli for the AAT, which were taken from the Radboud Faces Database (Langner et al., 2010). This is a database

containing validated pictures of emotional expressions done by trained actors. In total we used 78 front-facing images, with half of them depicting happy faces and the other half depicting angry faces. The images contained the emotional expressions from 39 different actors, which each actor displaying one happy and one angry emotion. Of these 39 actors, 19 were female and 20 were male. For an example of the stimuli, see figure 2.

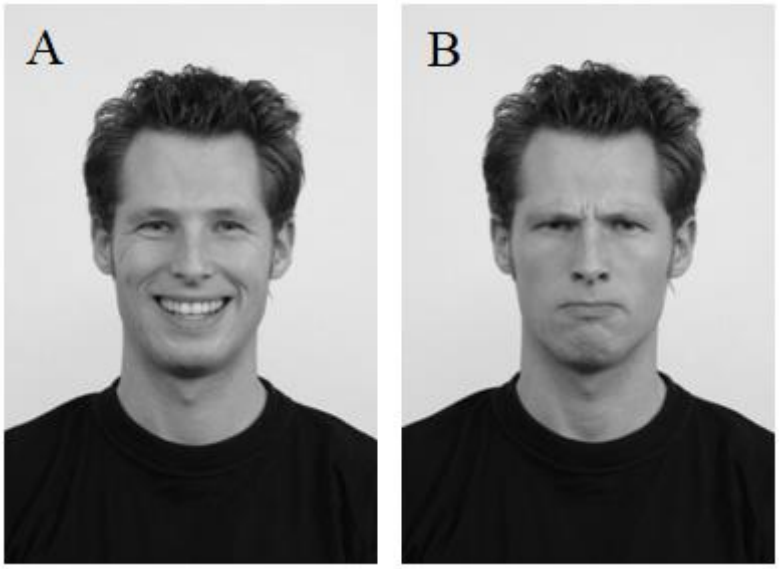

Figure 2. Greyscale example stimuli of a happy face (A) and an angry face (B) from the same actor.

Questionnaires. In order to control for participants characteristics that can have an effect on approach-avoidance behaviours, we used several questionnaires. Depressive symptoms were measured using the Becks Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996), which is a 21-item questionnaire measuring various symptoms of depression on a four-point scale. Anxiety was measured using the Becks Anxiety Inventory (BAI; Steer & Beck, 1997), which consists of 21 items and measures symptoms of anxiety on a four-point scale. Furthermore, we used the Liebowitz Social Anxiety Scale (LSAS; Liebowitz, 1987) in order to control for social anxiety. This is a questionnaire measuring both anxiety and avoidance in 24 hypothetical social situations. We computed total scores for these three questionnaires separately and used these as control variables. Lastly, participants had to fill in a screening questionnaire in the beginning, measuring exclusion criteria for tDCS studies, and

a side-effects questionnaire at the end, asking for any uncomfortable or painful side-effects that might have occurred during the stimulation.

Transcranial Direct Current Stimulation. Online tDCS was delivered via a battery-driven DC current stimulator (Eldith DC Stimulator (CE 0118), Ilmenau) using two 3x5 cm electrodes (15 cm^2) in saline-soaked synthetic sponges at a current intensity of 2 mA. The current density for each electrode was 0.57 A/m^2. The anode and cathode were placed over the left dlPFC (F3) and right dlPFC (F4) respectively. For an illustration of the positioning of F3 and F4 in the EEG 10-20 system, see figure 3.

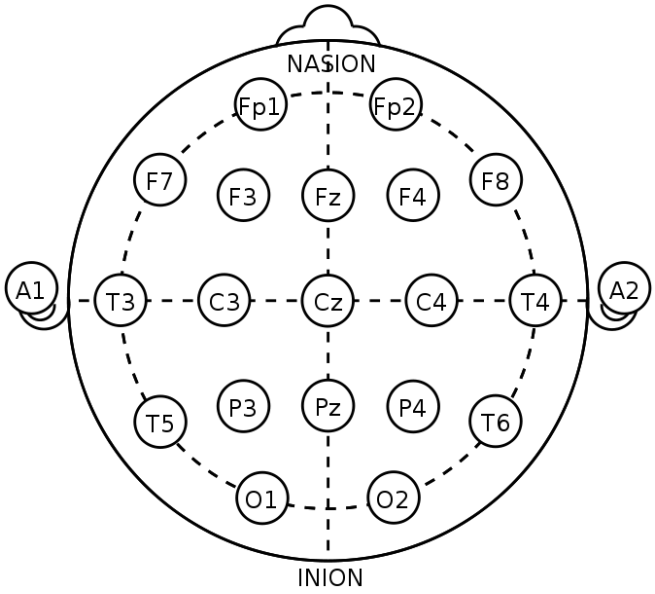

Figure 3. Positions of F3 and F4 in the 10-20 system on the head.

Procedure

For a flowchart of the procedure, see figure 4. The participants were approached via the SONA system, which is website in which researchers can advertise their studies and participants can sign up for them. Upon arrival at the lab, participants had to sign the informed consent and were screened for exclusion criteria. Furthermore, they filled in the abovementioned questionnaires and got the electrodes attached. The participants were randomly assigned to either the manipulation or the control condition. In the manipulation condition, the participants received instructions explaining that the stimulation they were

about to receive would make it easier for them to pull pictures towards them, which was strengthened by references to scientific literature. In the control condition, the participants only received the standard instructions on how to perform the task. The instructions were displayed on the computer screen before the start of the task. After that, the participants had to complete the first block of the AAT. During this block, the participants always received sham stimulation, meaning that the stimulation was ramped up over 30 seconds, in order to convey the illusion of real stimulation, and was then shut down. After completing the first block of the AAT, the participants got a short break, during which they were told that the stimulation would be turned down, but that it would be turned on again for the second block. After finishing both blocks of the AAT, the participants could wash their hair. They were then informed that one block of the AAT was accompanied by placebo stimulation and they had to guess which block it was. After that, they were asked what they thought was the purpose of the stimulation and had to guess which block of the task was accompanied by active stimulation as opposed to placebo stimulation. Lastly, they were debriefed and received their gift voucher.

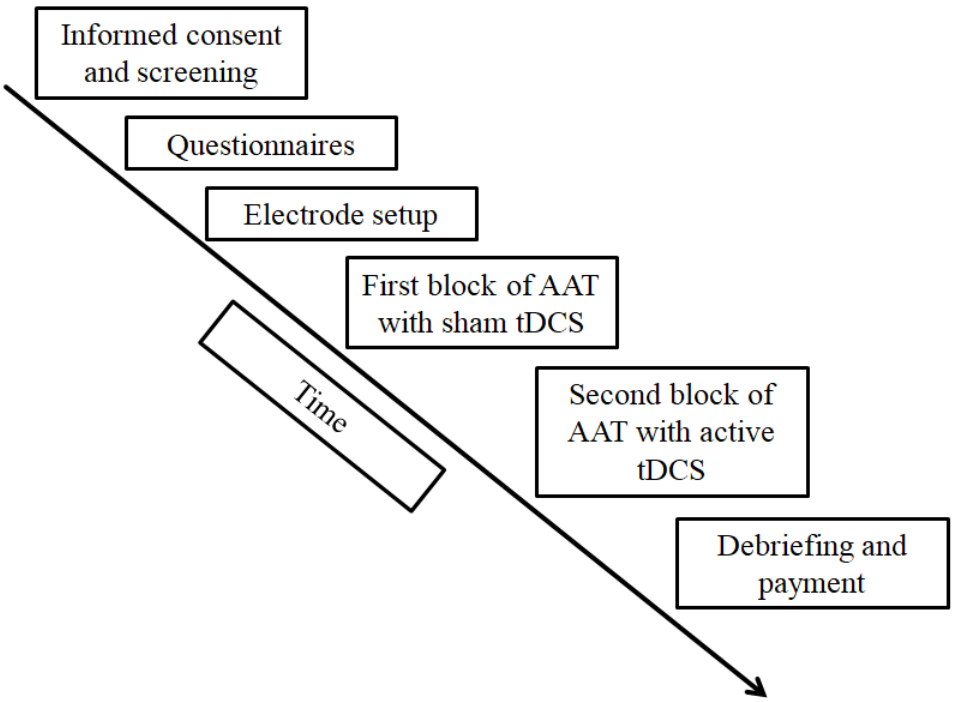

Figure 4. Flowchart of the procedure over time.

Design

The design was a mixed between-within-subjects design, with condition (manipulation vs. control) as the between-subject factor, stimulation (active vs. sham) as the within-subject factor and reaction time on the AAT as the dependent variable. Depression, anxiety, and social anxiety were used as control variables. The participants were blind to the stimulation they were receiving, while the condition assignment was double-blind.

In order to analyse the effect of the subjective belief induction, we used a two-way interaction with condition (manipulation vs. control) and movement (pull vs. push) as independent variables and reaction time as the dependent variable. Analysing the effect of the stimulation was done using a two-way interaction, with movement (pull vs. push) and stimulation (active vs. sham) as the independent variables and reaction time as the dependent variable.

Data-Analyses

Data were analysed with the help of the statistical analysis programme R (R Core Team, 2016). We employed linear mixed effects models using the package lme4 (Bates, Maechler, Bolker, & Walker, 2015). The packages afex (Singmann, Bolker, Westfall, & Aust, 2016) and pbkrtest (Halekoh & Højsgaard, 2014) were used to compute p-values. This was done using Type 3 bootstrapped Likelihood Ratio tests (1000 simulations) and the optimizer "bbbyqa". We ran two models, one for the effect of the subjective belief induction and one for the effect of the stimulation. In both models, we used random intercepts for participant ID and actor ID and a random slope for either stimulation (active vs. sham) or condition (control vs. manipulation) over the random intercept for participant ID in order to control for differences in the interaction between independent and dependent variables across participants. The random intercept for actor ID was used to control for differences in the stimulus material.

Furthermore, total scores of the questionnaires were added as random intercepts to control for their effects on the dependent variable.

Exploratory Analyses. In order to assess side effects of the stimulation, we computed percentages of participants that either experienced or did not experience any negative side effects. Furthermore, we also assessed what types of side effects occurred and how often these were reported.

In the interest of replicating the AAT effect (faster reaction times for congruent than for incongruent trials) we also analysed the two-way interaction between emotion (happy vs. angry) and movement (push vs. pull) on reaction times. For this analysis we only used the first placebo stimulation block of the control condition group, as they did not experience any manipulation.

Lastly, due to the order of the conditions (sham tDCS first, active tDCS second), we analysed the effect of trial number within each block on reaction time. This was done to ensure order effects did not skew our results.

Results

Main Analyses

Stimulation Effect. The analyses showed that real tDCS did have a significant effect on reaction time (estimate = -0.86 (0.01), F (1, 37) = 32.58, $p < 0.001$). However, the interaction effect between stimulation and movement was not significant (estimate = 0.02 (0.01), F (1, 11087) = 2.38, $p = 0.122$). This means, that the participants showed overall faster reaction times during the real tDCS as compared to the sham tDCS , but that this did not differ across push or pull movements. For a bar-chart depicting reaction times by stimulation, see figure 5.

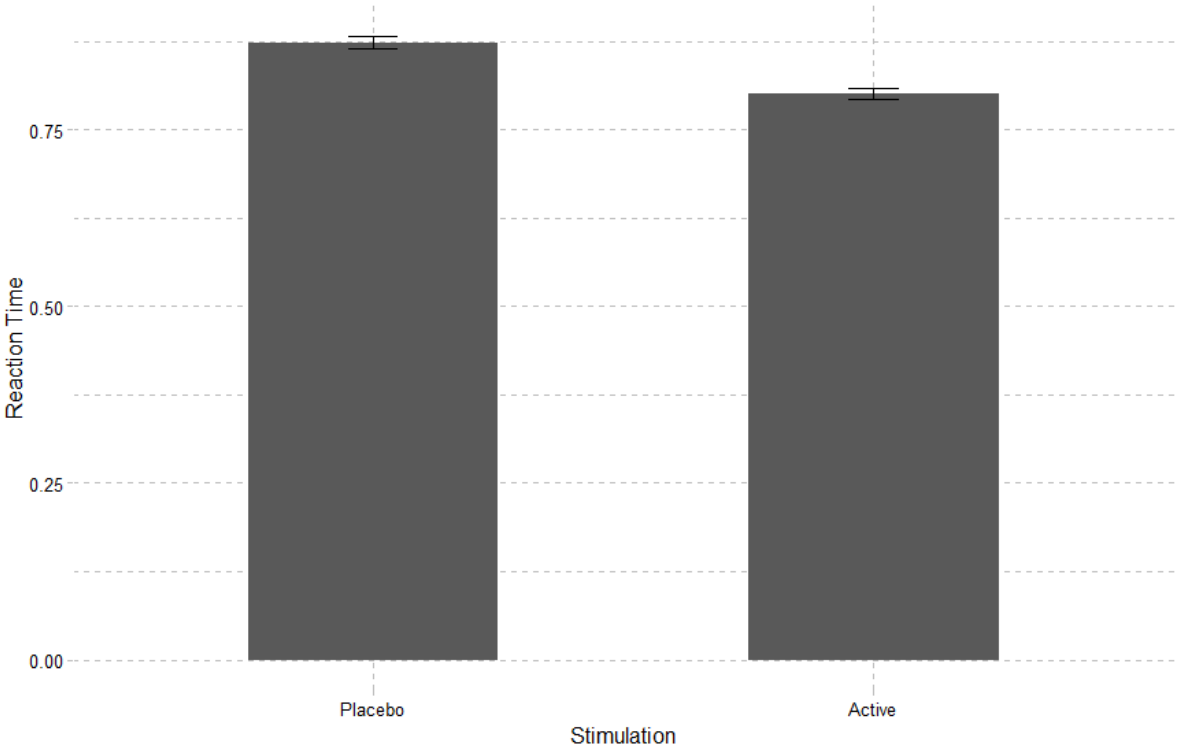

Figure 5. Reaction time by stimulation with error bars showing the standard error of the mean. Reaction times during active stimulation were significantly lower than during placebo stimulation.

Subjective Belief Induction. Neither the effect of the subjective belief induction on reaction time was significant (estimate = 0.01 (0.01), F (1, 32) < 0.01, p = 0.982), nor reached the interaction effect between condition and movement statistical significance (estimate = -0.02 (0.01), F (1, 11121) = 2.47, p = 0.161). That means that the expectation manipulation had no effect on overall reaction times, which also did not differ across push or pull trials. For a bar-chart showing the non-significant main effect and interaction, see figure 6. For a table showing means and standard deviations of reaction times across conditions and stimulation blocks, see table 1.

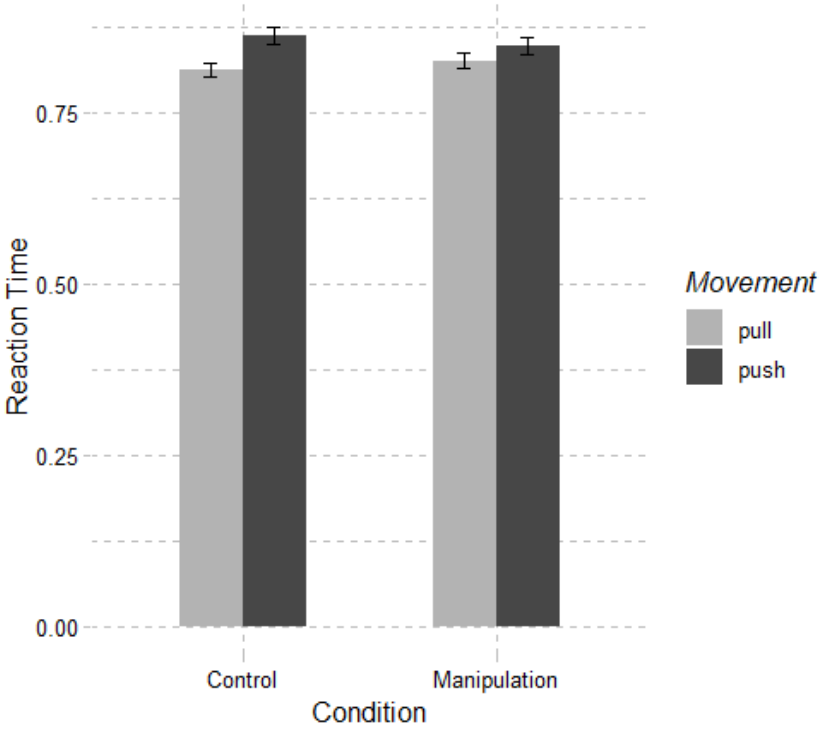

Figure 6. Reaction time by condition, split by movement, with error bars showing the standard error of the mean. Reaction times neither differed across conditions, nor was there an interaction effect between condition and movement.

Table 1

Means and standard deviations of reaction times across conditions and stimulation blocks

Grouping Factor	*M*	*SD*
Subjective Belief Induction		
Control Condition	0.84	0.31
Manipulation Condition	0.83	0.33
Stimulation		
Placebo Stimulation	0.87	0.33
Active Stimulation	0.80	0.31

Note: *M* = Mean, *SD* = Standard deviation.

Exploratory Analyses

Side-Effects. In the interest of assessing reported side-effects and tolerability of the stimulation, we analysed the side-effects questionnaire given to the participants at the end of the experiment. Out of all 39 participants, 17 (38.64%) reported to have experienced side-effects. Since participants could report more than one side-effect, the number of reported side-effects surpassed the number of participants reporting side-effects. An overview of the side-

effects can be found in table 2. In total, only one participant out of the initial 44 terminated the experiment because they found the stimulation to be too uncomfortable.

Table 2

Types and occurrences of side-effects

Type of side-effect	Number of occurrences	Percentage of occurrences
Itching	6	26.09
Burning	5	21.74
Tingling	4	17.38
Skin irritation	2	8.69
Dizziness	4	17.38
Headache	2	8.69

AAT-Effect. In order to try and replicate the AAT effect, we analysed the data of the placebo bock in the control condition, as no manipulation was present here. The results reveal that there was a significant effect of congruency on reaction time ($F(1, 2764) = 3.92$, $p = 0.047$). This shows that congruent trials were done slightly faster than incongruent trials. For a visual representation, see figure 7.

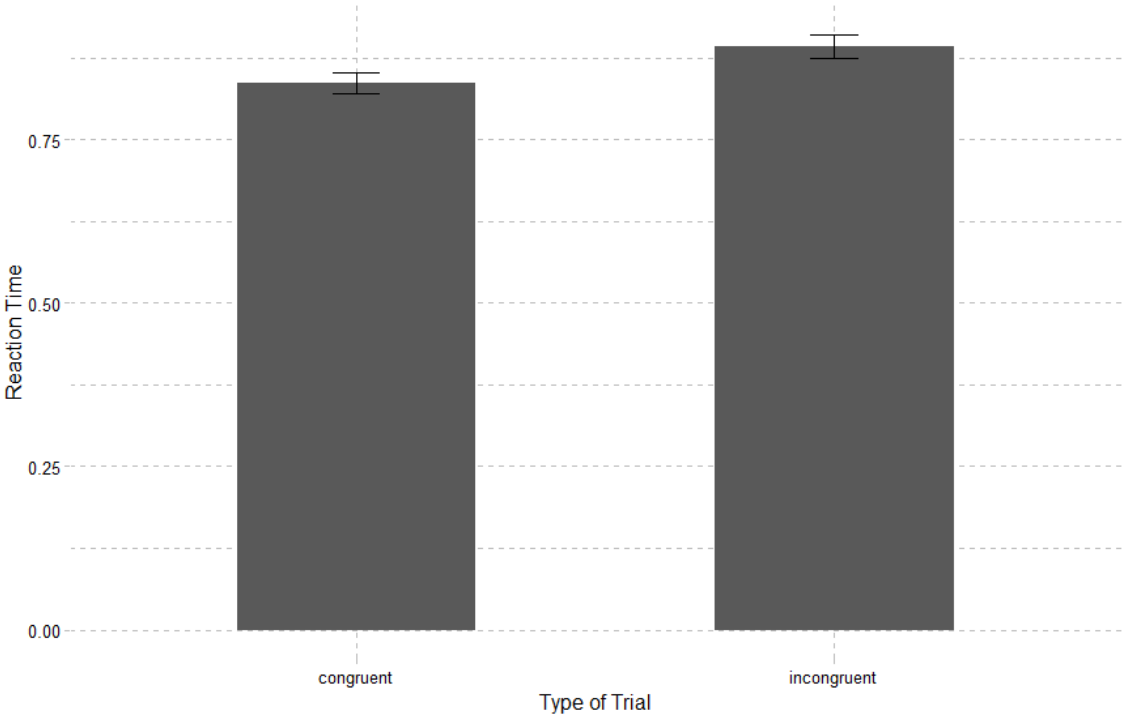

Figure 7. Reaction times by type of trial, with error bars showing the standard error of the mean. Reaction times on congruent trials are lower than on incongruent trials.

Order Effects. We analysed the effects of trial number within the placebo stimulation block and the active stimulation block on reaction time, which showed that the effect of trial number on reaction time was not significant (estimate < 0.01 (0.01), F (1, 11342) = 0.16, p = 0.689). This means, that the participants did not react slower or faster across subsequent trials during neither the placebo stimulation nor the active stimulation.

Questionnaires. We computed total scores on the questionnaires we used for every participant and used these as random intercepts in the main analyses. The means and standard deviations for the total scores can be found in table 3.

Table 3

Means and standard deviations of the total scores on the questionnaires

Questionnaire	*M*	*SD*
BDI	8.11	8.85
BAI	8.04	9.16
LSAS	17.57	13.39

Note: BDI = Beck Depression Inventory; BAI = Beck Anxiety Inventory; LSAS = Liebowitz Social Anxiety Scale; PANAS = Positive and Negative Affect Schedule; *M* = Mean; *SD* = Standard deviation

Blinding. In the interest of checking the blinding of the stimulation blocks (sham vs. active), the number of participants guessing the order of the stimulation blocks correctly were counted. Out of 39 participants, 23 (58.9%) guessed correctly. However, most participants reported that they only became aware of that after being asked.

Discussion

The present study investigated the effects of tDCS to the DLPFC on implicit approach-avoidance behaviours, measured with the AAT. Furthermore, we also investigated how subjective beliefs about the tDCS could influence approach-avoidance behaviours. We expected participants receiving active tDCS to shower faster reaction times on pull trials, compared to sham tDCS. Additionally, we also expected participants being primed with the expectation that the tDCS will reduce their reaction times on pull trials to show faster reaction times on pull trials, as opposed to participants who were not primed. The results show that while active stimulation does significantly reduce reaction time compared to sham, it does not do so specifically for pull trials, i.e. approach. The hypothesis that the stimulation would lead to higher approach motivation was therefore rejected. There was also no effect of subjective beliefs on either overall reaction time or specifically for pull (and push) trials. The hypothesis that the expectation manipulation could influence reaction times for pull trials was not confirmed.

A general explanation for the null-effects in the present study is its sample size. The METC allowed for a maximum of 40 participants, which could lead to problems concerning power. It is therefore possible that we did not have enough power to detect some of our hypothesized effects.

With respect to the results of the stimulation it can be said that the stimulation led to faster overall reaction times. This effect cannot be attributed to order effects, as participants did not get faster the more trials they completed. However, this effect does not align with the hypothesis, since the stimulation did not reduce reaction times for pull trials specifically. While the literature on the frontal asymmetry on motivational direction suggests that relative greater left than right activity is associated with approach-behaviour (Coan & Allen, 2004; Harmon-Jones et al., 2010; Schutter & Harmon-Jones, 2013) and brain stimulation evoking this specific pattern elicited an increase in approach-behaviour (Hortensius et al., 2012), it is possible that this differs from the approach-avoidance behaviour measured in the present study. For example, in the aforementioned literature on the frontal asymmetry of motivational direction, approach-avoidance behaviour was assessed with the help of the Behavioural Inhibition System/Behavioural Activation System Scale (BIS/BAS; Carver & White, 1994), which asks about more deliberate, controlled approach-behaviour. However, the AAT measures more implicit and automatic tendencies (Heuer et al., 2007; Klein et al., 2011; Rinck & Becker, 2007). Therefore it is possible that the brain stimulation can only influence controlled approach-avoidance behaviour, while the AAT measures only implicit approach-avoidance behaviour.

Nevertheless, there was a reduction in overall reaction times during active stimulation. It is possible that the stimulation resulted in different non-specific cognitive effects, which enhance performance on tasks like the AAT. A meta-analysis on the effects of anodal tDCS over F3 on cognitive task also found a non-specific reaction time reduction across several different cognitive tasks (Dedoncker, Brunoni, Baeken, & Vanderhasselt, 2016). The authors analysed a wide variety of papers which assessed the effects of tDCS on different cognitive tasks, using electrode setups with the anode placed over F3 and the cathode placed over varying other target sites. Across tasks, anodal tDCS over F3 led to faster responses in healthy

participants, which is in line with our results. However, the authors do not provide an explanation for this effect.

A different meta-analysis postulates that electrode setups similar to the one used in the present study enhances working memory performance in healthy participants (Hill, Fitzgerald, & Hoy, 2016). Here too, the authors analysed a variety of studies investigating the effects of anodal tDCS over F3 on cognitive tasks, while only including studies using tasks that measure specifically working memory performance. They also found that anodal tDCS improved reaction times in healthy samples. According to them, working memory is implicated in a variety of processes, including, but not limited to, selective attention and complex decision making. It is therefore possible that an improvement in working memory performance influences reaction times on the AAT, since the AAT requires participants to selectively attend to the features of the stimuli presented and then make a decision based on that.

Regarding the null-effect of the subjective belief manipulation, it is possible that the simple instructions that were used in the present study cannot influence implicit psychological functioning like approach-avoidance behaviour. There is evidence that subjective beliefs about interventions have beneficial effects on multiple aspects such as psychiatric and physiological illnesses (Enck et al., 2008; Finniss et al., 2010) and motor function (Fiorio, Emadi Andani, Marotta, Classen, & Tinazzi, 2014; Fuente-fernández et al., 2001). Specifically, there is also evidence for subjective beliefs about tDCS having effects on both behaviour and neurological functioning (DosSantos et al., 2014; Fiorio et al., 2014). However, it is possible higher order cognitive functions that are recruited during the AAT remain unaffected by subjective beliefs. This could indicate, that studies assessing the effects of tDCS on higher order functioning could rule out preconceptions about the stimulation as a confounding variable. Alternatively, it is possible that our manipulation was not strong enough, as we only primed the participants once, in the beginning of the experiment. It could also be possible that the task itself was cognitively challenging, as the participants had to

make quick decisions about the stimuli they were presented with and perform arm movements based on the input, while also having to adjust to changing instructions across the span of the task. It is therefore possible that the complexity of the task itself made the participants focus more on the task while forgetting about the instructions.

Looking at the side-effects, we can conclude that there were no adverse effect and that tDCS presented itself as a safe and largely tolerable method for non-invasive brain stimulation in our study. The reported side-effects fall in line with those reported in the literature (McCreery, Agnew, Yuen, & Bullara, 1990; M. A. Nitsche & Paulus, 2000; Michael A. Nitsche et al., 2008) and were mild and temporal in nature. Only one participant out of 44 terminated the experiment on the grounds that the itching sensation was too uncomfortable.

Regarding our exploratory analysis into the AAT effect, we can see that there was a small effect of congruency on reaction time, meaning that congruent trials were completed quicker than incongruent trials. This is in line with previous literature on approach-avoidance behaviour in general and the AAT specifically (Hans Phaf et al., 2014). The small effect and high p-value might be due to the fact that the sample size of the study was rather small and that the analysis for this effect was performed on a sub-sample that did not receive any manipulation.

Having these limitations and alternative explanations in mind, we can give some suggestions for future research. With respect to the effects of subjective beliefs, future research could consider using primes more frequently to remind participants of their presence, especially in tasks that require the participants to expend cognitive effort. On the topic of approach-avoidance behaviour, more clarity regarding the relationship between controlled and implicit/automatic behaviours is needed. Therefore, it could be useful to see if approach-avoidance behaviour on the AAT correlates with BIS/BAS scores expressing approach motivation, or with the frontal asymmetry in the DLPFC found in the aforementioned EEG

studies. This would shed some light onto the differences and similarities between controlled and implicit/automatic approach-avoidance behaviours.

Regarding the effect of the stimulation, it could be beneficial for future research to include a cognitive task measuring working memory in addition to the AAT. Thereby, it would be possible to see whether or not reductions in reaction times on the AAT are driven by changes in working memory performance. Furthermore, future studies could adopt a between-subject approach or a within-subject approach with separate testing sessions, in order to avoid order effects from the beginning

In conclusion, our study has shown that tDCS and the subjective belief manipulation did not affect approach-avoidance behaviour measured with the AAT. We did however find a significant reduction in reaction times during active tDCS, which might be driven by an effect of tDCS on working memory performance.

References

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using {lme4}. R package version 1.1.12. *Journal of Statistical Software*, *67*, 1-48. http://dx.doi.org/10.18637/jss.v067.i01

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). Beck depression inventory-II. *San Antonio*, *78*(2), 490-498.

Benedetti, F., Pollo, A., Lopiano, L., Lanotte, M., Vighetti, S., & Rainero, I. (2003). Conscious expectation and unconscious conditioning in analgesic, motor, and hormonal placebo/nocebo responses. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *23*(10), 4315–4323. https://doi.org/23/10/4315

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS scales. *Journal of personality and social psychology*, *67*(2), 319.

Coan, J. A., & Allen, J. J. B. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology*, *67*(1–2), 7–49. https://doi.org/10.1016/j.biopsycho.2004.03.002

Dedoncker, J., Brunoni, A. R., Baeken, C., & Vanderhasselt, M.-A. (2016). A Systematic Review and Meta-Analysis of the Effects of Transcranial Direct Current Stimulation (tDCS) Over the Dorsolateral Prefrontal Cortex in Healthy and Neuropsychiatric Samples: Influence of Stimulation Parameters. *Brain Stimulation*, *9*(4), 501–517. https://doi.org/10.1016/j.brs.2016.04.006

DosSantos, M. F., Martikainen, I. K., Nascimento, T. D., Love, T. M., DeBoer, M. D., Schambra, H. M., … DaSilva, A. F. (2014). Building up analgesia in humans via the endogenous μ-opioid system by combining placebo and active tDCS: A preliminary report. *PLoS ONE*, *9*(7), 1–9. https://doi.org/10.1371/journal.pone.0102350

Enck, P., Benedetti, F., & Schedlowski, M. (2008). New Insights into the Placebo and Nocebo Responses. *Neuron*, *59*(2), 195–206. https://doi.org/10.1016/j.neuron.2008.06.030

Finniss, D. G., Kaptchuk, T. J., Miller, F., & Benedetti, F. (2010). Biological, clinical, and ethical advances of placebo effects. *The Lancet*, *375*(9715), 686–695. https://doi.org/10.1016/S0140-6736(09)61706-2

Fiorio, M., Emadi Andani, M., Marotta, A., Classen, J., & Tinazzi, M. (2014). Placebo-Induced Changes in Excitatory and Inhibitory Corticospinal Circuits during Motor Performance. *Journal of Neuroscience*, *34*(11), 3993–4005. https://doi.org/10.1523/JNEUROSCI.3931-13.2014

Fuente-fernández, R. De, Ruth, T. J., Sossi, V., Schulzer, M., Calne, D. B., & Stoessp, A. J. (2001). Expectation and Dopamine Release : Mechanism of the Placebo Effect in

Parkinson's Disease, *293*(August), 1164–1167. https://doi.org/10.1126/science.1060937

Halekoh, U., & Højsgaard, S. (2014). A Kenward-Roger approximation and parametric bootstrap methods for tests in linear mixed models - the R package pbkrtest. R package version 0.4.6. *Journal of Statistical Software, 59*(9), 1-30. http://dx.doi.org/10.18637/jss.v059.i09

Hans Phaf, R., Mohr, S. E., Rotteveel, M., & Wicherts, J. M. (2014). Approach, avoidance, and affect: A meta-analysis of approach-avoidance tendencies in manual reaction time tasks. *Frontiers in Psychology*, *5*(MAY), 1–16. https://doi.org/10.3389/fpsyg.2014.00378

Harmon-Jones, E. (2003). Clarifying the emotive functions of asymmetrical frontal cortical activity. *Psychophysiology*, *40*(6), 838–848. https://doi.org/10.1111/1469-8986.00121

Harmon-Jones, E., Gable, P. A., & Peterson, C. K. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: A review and update. *Biological Psychology*, *84*(3), 451–462. https://doi.org/10.1016/j.biopsycho.2009.08.010

Heuer, K., Rinck, M., & Becker, E. S. (2007). Avoidance of emotional facial expressions in social anxiety: The Approach-Avoidance Task. *Behaviour Research and Therapy*, *45*(12), 2990–3001. https://doi.org/10.1016/j.brat.2007.08.010

Hill, A. T., Fitzgerald, P. B., & Hoy, K. E. (2016). Effects of Anodal Transcranial Direct Current Stimulation on Working Memory: A Systematic Review and Meta-Analysis of Findings from Healthy and Neuropsychiatric Populations. *Brain Stimulation*, *9*(2), 197–208. https://doi.org/10.1016/j.brs.2015.10.006

Hortensius, R., Schutter, D. J. L. G., & Harmon-Jones, E. (2012). When anger leads to aggression: Induction of relative left frontal cortical activity with transcranial direct current stimulation increases the anger-aggression relationship. *Social Cognitive and Affective Neuroscience, 7*(3), 342–347. https://doi.org/10.1093/scan/nsr012

Kemps, E., Tiggemann, M., Martin, R., & Elliott, M. (2013). Implicit approach-avoidance associations for craved food cues. *Journal of Experimental Psychology: Applied*, *19*(1), 30–38. https://doi.org/10.1037/a0031626

Klein, A. M., Becker, E. S., & Rinck, M. (2011). Approach and Avoidance Tendencies in Spider Fearful Children: The Approach-Avoidance Task. *Journal of Child and Family Studies*, *20*(2), 224–231. https://doi.org/10.1007/s10826-010-9402-7

Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D. H., Hawk, S. T., & Van Knippenberg, A. D. (2010). Presentation and validation of the Radboud Faces Database. *Cognition and emotion*, *24*(8), 1377-1388.

Liebowitz, M. R. (1987). Social Phobia. *Modern Problems of Pharmacopsychiatry 2*, 141-173.

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. https://doi.org/10.1016/j.brs.2016.02.002

McCreery, D. B., Agnew, W. F., Yuen, T. G. H., & Bullara, L. (1990). Charge density and charge per phase as cofactors in neural injury induced by electrical stimulation. *IEEE Transactions on Biomedical Engineering*, *37*(10), 996–1001. https://doi.org/10.1109/10.102812

Mora, M. S., Nestoriuc, Y., Rief, W., B, P. T. R. S., Mora, M. S., Nestoriuc, Y., & Rief, W. (2011). Lessons learned from placebo groups in antidepressant trials, 1879–1888. https://doi.org/10.1098/rstb.2010.0394

Nitsche, M. A., Cohen, L. G., Wassermann, E. M., Priori, A., Lang, N., Antal, A., … Pascual-Leone, A. (2008). Transcranial direct current stimulation: State of the art 2008. *Brain Stimulation*, *1*(3), 206–223. https://doi.org/10.1016/j.brs.2008.06.004

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. https://doi.org/10.1111/j.1469-7793.2000.t01-1-00633.x

R Core Team (2017). R: A language and environment for statistical computing [computer software]. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from http://www.R-project.org/.

Rinck, M., & Becker, E. S. (2007). Approach and avoidance in fear of spiders. *Journal of Behavior Therapy and Experimental Psychiatry*, *38*(2), 105–120. https://doi.org/10.1016/j.jbtep.2006.10.001

Schutter, D. J. L. G., & Harmon-Jones, E. (2013). The corpus callosum: A commissural road to anger and aggression. *Neuroscience and Biobehavioral Reviews*, *37*(10), 2481–2488. https://doi.org/10.1016/j.neubiorev.2013.07.013

Sherman, D. K., Mann, T., & Updegraff, J. A. (2006). Approach/avoidance motivation, message framing, and health behavior: Understanding the congruency effect. *Motivation and Emotion*, *30*(2), 165–169. https://doi.org/10.1007/s11031-006-9001-5

Singmann, H., Bolker, B., Westfall, J., & Aust, F. (2016). afex: Analysis of factorial experiments. R package version 0.16-1 [computer software]. Retrieved from https://CRAN.R-project.org/package=afex

Steer, R. A., & Beck, A. T. (1997). Beck Anxiety Inventory.

Wiers, R. W., Gladwin, T. E., Hofmann, W., Salemink, E., & Ridderinkhof, K. R. (2013). Cognitive bias modification and cognitive control training in addiction and related psychopathology: Mechanisms, clinical perspectives, and ways forward. *Clinical Psychological Science*, *1*(2), 192–212. https://doi.org/10.1177/2167702612466547

Wittekind, C. E., Feist, A., Schneider, B. C., Moritz, S., & Fritzsche, A. (2015). The approach-avoidance task as an online intervention in cigarette smoking: A pilot study. *Journal of Behavior Therapy and Experimental Psychiatry*, *46*, 115–120. https://doi.org/10.1016/j.jbtep.2014.08.006

Woods, A. J., Antal, A., Bikson, M., Boggio, P. S., Brunoni, A. R., Celnik, P., … Nitsche, M. A. (2016). A technical guide to tDCS, and related non-invasive brain stimulation tools. *Clinical Neurophysiology*, *127*(2), 1031–1048. https://doi.org/10.1016/j.clinph.2015.11.012