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Abstract

Previous studies regarding sham tDCS have indicated that expectation priming (Rabipour et al, 2018; Turi et al, 2016), and also reward promise have been able to modulate sham tDCS (Jones et al. 2015). The current study aimed to investigate how expectation priming and reward promise affected reaction times and accuracy on a flanker task during sham tDCS. Participants were divided into four groups, receiving either positive or neutral expectation priming, and either a reward promise or no reward promise. A two-factor ANOVA was used to analyse the data. Results indicated no effects of expectation priming nor reward promise on reaction times. Results did indicate that participants who were positively primed made less errors compared to neutrally primed participants. Similarly, participants receiving the extra reward instruction made less errors compared to participants in the no reward condition. The current study findings suggest that expectation priming, and reward promise are able to modulate sham tDCS effects. One important note is that the current study only included sham tDCS, therefore conclusions comparing active and sham tDCS cannot be made. We discussed our current findings and how these relate to previous studies. Recommendations were made for future research regarding investigating the effects of expectation priming and reward in sham tDCS.

Modulating tDCS effects through expectations and reward

Non-invasive brain stimulation (NIBS) has seen more and more use in fundamental research but also in the clinical field over the years (Bennabi et al, 2014; Coffman, Clark, and Parasuraman, 2014; Kekic et al, 2016). With low costs and relative ease of use, Transcranial Direct Current Stimulation (tDCS) has gained popularity in its possible applications in modulating cognitive, affective, and motor functions (Filmer, Dux, and Mattingley, 2011; Reis, and Fritsch, 2011; Vanderhasselt et al, 2013), and treating clinical populations on for example neurological conditions such as stroke (Fregni et al, 2005; Hummel et al, 2005), and refractory epilepsy (Fregni et al, 2006). tDCS is a brain stimulation technique in which a continuous electrical current is applied through a set of electrodes placed on the skull, this electrical current has the capability to increase or decrease cortical excitability, and thus the ease at which neurons can produce an action potential (Stagg, & Nitsche, 2011). tDCS consists of anodal and cathodal electrical stimulation, where anodal stimulation usually leads to the previously mentioned increased cortical excitability while cathodal stimulation usually leads to decreased cortical excitability (Stagg, & Nitsche, 2011). Previous research has indicated improvements in multiple cognitive domains such as learning and implicit decision making (Kinces et al, 2004), episodic memory (Sandrini et al, 2014), and executive functions (Au et al, 2016; Dockery et al, 2009). However, a lot of variability is shown between research papers and their results with a lack of reproducible findings (Berlim, van den Eynde, and Daskalakis, 2013). Furthermore, studies have indicated that there exist high inter-individual differences in responsiveness to tDCS and other brain stimulation techniques (Li, Uehara, and Hanakawa, 2015; Lopez-Alonso et al, 2014). One possible explanation for these high inter-individual differences is anatomical differences between people. Research by Kim et al. (2014) on tDCS and a working memory task showed that participants with enhanced working memory task performance after tDCS had a significantly larger electrical current density at the dorsolateral prefrontal cortex, suggesting that inconsistent behavioral outcomes might be due to individual anatomical differences (Kim, et al, 2014). Besides anatomical differences there exist other variables that might attribute to the high inter-individual differences, such as intentional and unconscious preferences, biases and expectations of the participants and researchers, and placebo effects (Turi, Paulus, and Antal, 2016).

The placebo effect is a well-known non-specific psychological effect where a patient or participant exhibits a response to an otherwise simulated intervention. The non-specific effect of placebo means that no biologically plausible explanation exists to account for any

causal relations between clinical outcomes and placebo treatments (Margo, 1999). A placebo intervention is usually delivered in contexts with cues that convey information that imply that therapeutic effects are possible. These cues include things such as white lab coats, the diagnostic instruments used, the appearance of the therapist's room but also how the therapist or researcher communicates with the patient or participant (Colloca, and Miller, 2011).

Previous research by Turi et al. (2016) investigated placebo tDCS and how expectations could possibly alter stimulation effects on a reward learning task. Turi et al. (2016) used two different experimental groups, one group was primed with high uncertainty about tDCS effects, and one primed with low uncertainty about tDCS effects. In the high uncertainty group, the tDCS intervention was introduced as an experimental method whose effectiveness was not yet proven. In the low uncertainty group, the tDCS intervention was introduced as a well-established, performance enhancing method which was certain to improve participants cognitive performance. All participants were made to believe they were to receive active stimulation, however everyone received sham stimulation. Their results indicated that placebo intervention was able to enhance reward learning in healthy individuals in both experimental groups, but more strongly in the high uncertainty group.

Similarly, Rabipour, Wu, Davidson, and Iacoboni (2018) investigated intervention of tDCS and its effect on a working memory task. Rabipour et al. (2018) manipulated two variables in their study using a 2x2 design. Participants were assigned to one of two experimental priming groups, either positive or negative priming. Before the start of the experiment participants read a text that aimed to prime expectations about tDCS. In the high expectation group participants read a text where they were told that they would receive a type of brain stimulation that was known to improve performance. In the low expectation group participants read a text in which they were told they would receive a type of brain stimulation with no known benefits. Furthermore, participants were further divided into one of two stimulation conditions, either active anodal stimulation or placebo stimulation. Their results indicated that people with high expectations induced by the priming about tDCS showed greater improvement, had a more pleasant experience, and greater satisfaction compared to the people with low expectations. This suggests that expectations of outcomes might alter the effects of tDCS.

Motivation in the form of reward expectation is also one way of changing how we think and behave. The promise of reward, be it money or some other form of reward has the ability to modify our cognitive processes such as attention, decision making and the mental rules that we use in how we respond to certain events (Rowe, Eckstein, Braver, and Owen,

2008). Rowe et al. (2008) suggest that motivation through reward is capable of modulating cognition, at least in a positive direction, but what about the omissions of reward? A lot of the evidence regarding reward and cognition interactions has been based around studies involving uncertain reward promises or variable risk-reward promises such as seen in gambling paradigms (Daw, O'Doherty, Dayan, Seymour, and Dolan, 2006; De Martino, Kumaran, Seymour, and Dolan, 2006; Rowe et al, 2008). Less is known about how predictable rewards modulate cognition. A study by Rowe et al. (2008) investigated how predictable rewards modulate cognitive control and behavior. Rowe et al. used a dual task paradigm in which two different tasks (verbal and spatial) competed for attention and rewards were skewed to one of the two tasks. Their behavioral data suggested that participants showed a specific bias toward the reward-relevant modality, increased reward expectations improved reaction times and accuracy in the relevant dimension while being reduced in the non-relevant dimension. Adding to this, a review study by Yee and Braver (2018) discussed motivation and cognitive control, one of the points discussed was how monetary incentives were able to enhance cognitive control performances via increased proactive control. Furthermore, individuals were less willing to engage in cognitively demanding tasks if the effort costs outweigh the expected benefits (Dixon and Christoff, 2012). Lastly, anticipation of reward incentives reduced switch costs in task-switching paradigms (Kleinsorge and Rinkenauer, 2012), and rewards speeded up response inhibition in a stop-signal task without preparatory cues (Boehler et al, 2013).

To further understand this relation, looking at the Reward Prediction Error (RPE) theory could prove fruitful. RPE theory states that dopamine neurons in the Ventral Tegmental Area encode for RPE, or simply put the difference between predicted and received rewards (Lerner, Holloway, and Seiler, 2021). Previous research regarding these RPE's and their results have suggested that participants, be it monkeys or humans, showed a stronger dopamine activity when presented with more reward than originally expected. By contrast, dopamine activity decreases when no, or less than predicted, reward is presented Mollick et al, 2010; Schultz, 2022). Dopamine is an important neurotransmitter suggested to be involved in reward processing such as a participants' motivation or willingness to exert effort (Salamone, & Correa, 2012), or how much someone likes the task and learning (Taber et al, 2012). Therefore, according to this theory we might expect performance decreases when omitting or decreasing a previously offered reward.

Not much is known specifically about the application of reward and tDCS, to our knowledge we have identified one study in which the effect of reward has also been researched. During a working memory task participants performed 15 blocks of 3 trials where

varying amounts of monetary reward were offered for correct trials, which consisted of a low ($.01) and high ($.25) financial incentive in a counterbalanced order. Before each block participants were informed as to whether they would receive the low or high reward for correct trials. Extrinsic motivation through monetary reward was able to modulate working memory performance, the highest performance was seen for the group receiving active stimulation and a high financial incentive (Jones, Gözenman, and Berryhill, 2015). In a different brain stimulation study by Strafella, Ko, and Monchi (2006) repetitive transcranial magnetic stimulation (rTMS) was investigated in a patient group with moderate Parkinson's disease (PD). The main goal was to investigate if expectation of therapeutic benefits, a reward, was able to induce changes in raclopride binding potentials. Participants were invited to an initial talk, during this talk they were told that the rTMS intervention had potential to provide transitory clinical improvement of their PD motor symptoms. In reality none of the participants received active stimulation, all received sham stimulation. Their results indicated that placebo rTMS and the promised reward was able to increase raclopride binding potential compared to baseline, which was indicative of an increase in dopamine neurotransmission.

Studies such as Jones et al. (2015), Strafella et al. (2006), but also more general studies on motivation (Daw et al, 2006; De Martino et al, 2006; Rowe et al, 2008) suggest that it could be possible to modulate tDCS effects through motivation.

The current research aimed to further investigate the effect of expectation and motivation on sham tDCS. Similar to other studies discussed participants were made to believe they were receiving active stimulation, however in reality all of the participants received sham tDCS. Furthermore, participants were primed in their expectations of tDCS by reading a priming text during the experiment, lastly different rewards were offered to participants depending on their experimental group. In line with previous research (Rabipour et al., 2018), we expect positive expectation priming to improve performance relative to neutral expectation priming (i.e, main effect expectation). If positive reward expectation (increased motivation) can augment performance, then we expect higher performance for the participants instructed about the extra reward. As stated before, the omission of reward can lower dopamine (Mollick et al, 2020), dopamine is an important neurotransmitter involved in processes such as a participants willingness to exert effort (Salamone, & Correa, 2012). Therefore, a reduction in performance would be expected in participants receiving the negative reward. Furthermore, an interaction of expectation and reward is possible, such that negative reward reduces the benefit of positive (vs. neutral) expectation priming relative to positive reward.

Methods

1. Study parameters

Participants

We recruited participants through flyers, posts on social media, and the participation recruitment system (Sona Systems) of Utrecht University. We originally aimed for a total participant count of 60, which would mean that each experimental condition consisted of 15 participants. Inclusion criteria were that the participants were between 18 and 30 years old, right-handed, speak English, and with no dyslexia. Data was collected over a time period of roughly 2 months. The majority of participants were recruited through the University recruitment system and posters, and thus the sample was mostly University educated.

Material

All of the tasks were performed on a computer provided by the Utrecht University. The screen used for testing was a 24-inch Dell P2419HC The flanker task was coded using plugins from https://jspsych.org/, enabling us to run the task in a web-browser for ease of testing. A Neuroconn stimulator was used to apply sham stimulation to the participants. A fade-in fade-out protocol was used, sham stimulation with 0.5mA ran for 7 minutes. Two 5x5cm electrodes were placed in a frontal setup, both placed over respectively the left and right prefrontal cortex (electrode positions F3 and F4) combined with saline soaked sponges held in place by an EEG cap.

2. variables

Priming text

For our first variable we manipulated participants expectations about tDCS effects. Participants read a text before receiving sham stimulation, this priming text had the intention of altering participants expectations of tDCS. This text was either a positively or neutrally framing text in regard to tDCS. Positive priming text included passages such as "Several studies indicate that ‘brain stimulation’ can lead to improved attention in children and adults.” (Tang and Posner, Trends in Cognitive Science, 2010). While the neutral priming text included passages such as "Available evidence regarding ‘brain stimulation’ remains limited, and the quality of the evidence needs to improve. However, there is still no indication of any significant benefit derived from ‘brain stimulation’.” (Bahar-Fuchs, Clare, and Woods, The Cochrane Collaboration, 2013)". See appendix A for the priming texts.

Reward instruction

For our second variable we manipulated participants motivation through reward promise. Half the participants received instructions that if their performance improved by at least 10% they would receive additional course credit, or money if the participant was participating for money. The advertised reward for participation was 1 course credit or €10, the additional reward would increase this amount to 1.5 course credit or €15. The other half of the participant group were told that due to the study length we had to decrease the course credit or money reward, this group was told they would receive 0.5 course credit or €5 respectively.

3. Tasks and questionnaires

Eriksen flanker task

The flanker task is a set of response inhibition tests used to assess the ability to suppress responses that are irrelevant in a certain condition. The participant is tasked with looking at a target, this target is flanked by either corresponding stimuli (congruent flankers) or is flanked by opposing stimuli (incongruent flankers). Participants are then tasked in responding a certain way dependent on the flankers being congruent or incongruent to the target stimulus (Eriksen, and Eriksen., 1974). The flanker task provided us with attention performances measured through both reaction times and accuracy. From the raw data we computed the flanker effect (RT congruent - RT incongruent) for both experimental blocks, and then computed the difference between these (flanker(pre) - flanker(during)). This difference served as the dependent variable in our analysis. The flanker task was performed on a computer provided by the Langeveld lab space. We used a flanker task setup consisting of lowercase p's and q's, as we were interested in performance increases, we needed a task in which participants would actually make errors and could show improvement over time. We ran a small pilot study comparing a more standard arrows setup vs. the p's and q's setup. Participants made more errors on the p's and q's and general feedback included that they needed to pay attention to the task when p's and q's were used compared to the arrows.

Questionnaire

Following the flanker tasks and tDCS participants were asked about their perceived experiences, two questions were asked regarding their experience: "Did you have any specific expectations how real stimulation would affect a person's performance?" and "Do you think the stimulation you received affected your performance?".

4. Study design

We tested participants on an attention task, the Eriksen flanker task. Participants performed this task twice with a trial count of 240 for each block, which took roughly 7 minutes each. Participants were divided into a total of 4 experimental groups, 2 different variables were manipulated to create these 4 groups. Participants were primed in their expectation of tDCS by reading a text that is either positive or neutral about the effect of tDCS on performance changes. This priming occurred in between the first and second testing of the Eriksen flanker task.

Furthermore, the study manipulated reward by offering half the participants the possibility of earning additional course credit, or additional money if their performance improved by 10% or more between the tasks. Upon advertisement participants were told they would receive 1 course credit, or €10 depending on their choice. Upon participating, half of the participants received the reward instruction where they were told they can earn an additional 0.5 course credit or €5 for a total of 1.5 course credit, or €15. The other half were told that due to circumstances, such as our study being very short, we were not allowed to give participants the advertised course credit or money, instead they would receive 0.5 course credit, or €5. In reality no additional rewards were given, all participants received 1 course credit or €10. This resulted in a 2x2 design: expectation (positive vs. neutral) x promised reward (yes vs. no).

Previous studies regarding placebo effects have reported that the placebo effects are more pronounced when volunteers fully believe that they are actually receiving an active intervention (Colagiuri, 2010; Kirsch, and Weixel, 1988). Therefore, in our study participants were deceived about the type of stimulation they received. Participants were told they would receive active tDCS, however all participants received placebo stimulation. To deceive participants about the nature of stimulation a fade-in fade-out protocol was used.

As stated before, participants performed the flanker task twice during the experiment, once as a baseline measurement and once while participants received placebo stimulation. Following the second flanker task participants were asked about their perceived experience and expectation of tDCS. The current study deceived participants about two different aspects, the nature of stimulation but also the promise of extra reward. Therefore, after the second flanker task participants were presented with a debriefing window explaining the study and its actual goals relating to sham stimulation (see Appendix B for an example). In this debriefing participants were told that they did not receive any real stimulation. They were also informed

about the experimental group they were in, and what types of groups other participants were in.

5. Data analysis

We used a two-factor ANOVA (factor1 = expectation and factor2 = motivation) which also enabled us to measure for an interaction effect. Tukey post-hoc testing was used to assess differences in means, this enabled us to compare all the means between our 4 experimental groups. Next to performance differences, we also examined the effects of expectation priming and reward on the perceived effect of tDCS as measured by the post-task questionnaire. Testing was two tailed, we used standard $p<.05$ criteria to determine if the results were significantly different. Extreme outliers (participants) in reaction times or error rates were excluded from the data, if scores were 3 times above the standard deviation the participant was deemed as an extreme outlier. Single trial outliers (in reaction time) above 3 times the standard deviation were also excluded from the data, such as when a participant "responded" in 1ms or responded in 1500ms when their average response time is around 400ms. If a participant had incomplete data, due to for example terminating the experiment early, this data was excluded from the final analysis.

Results

In total 15 participants participated in our study, of these participants 20% (N=3) were male, and 80% (N=12) were female. The participants ranged from 19 to 29 years old (M = 22, SD = 2.9). Tables 1 and 2 contain the experimental groups and their performance on the flanker task, as measured by reaction times and their accuracy.

Table 1

Participants and their reaction times.

Group		Pre			During			Difference		
		Con	Incon	RTeffect	Con	Incon	RTeffect	Con	Incon	RTeffect
Expectation+,										
reward +	Mean	617	676	-59	547	570	-23	70	106	-36
	Stdev	118	128	10	90	82	8	28	46	18
Expectation+,										
reward-	Mean	597	625	-28	555	581	-26	42	44	-2
	Stdev	100	106	6	77	76	1	23	30	7
Expectation-,										
Reward+	Mean	625	662	-37	561	568	-7	64	94	-30
	Stdev	117	128	11	79	80	1	38	48	10
Expectation-,										
reward-	Mean	604	628	-24	549	595	-46	55	33	22
	Stdev	111	97	14	83	77	6	28	20	8

Note: Reaction times in milliseconds shown above for the average reaction time and standard deviation to a correctly answered stimulus during the flanker task. Displayed for congruent and incongruent trials, respectively “con” and “incon”, and for baseline and sham stimulation respectively as “Pre” and “During”. The RTeffect is the interference score, obtained by calculating the difference between incongruent and congruent reaction times. RTcon and RTincon are the reaction time differences between the pre and during measurements of each condition.

Table 2

Groups and their error rates.

Group		Pre			During			Difference		
		Con	Incon	ERReffect	Con	Incon	ERReffect	Con	Incon	ERReffect
Expectation+,										
reward +	Mean	5.6	6.7	-1.0	2.3	4.2	-1.9	3.3	2.5	0.8
	Stdev	22.7	24.3	1.6	12.6	16.9	4.3	10.1	7.4	3.7
Expectation+,										
reward-	Mean	3.3	3.1	0.2	2.9	1.7	1.2	0.4	1.5	-1.0
	Stdev	15.2	13.9	1.3	16.0	11.9	4.1	0.8	2.0	2.9
Expectation-,										
Reward+	Mean	2.7	2.7	0	2.5	3.1	-0.6	.2	-0.4	.6
	Stdev	15.8	16.0	0.1	14.9	17.4	2.5	0.9	1.4	0.5
Expectation-,										
reward-	Mean	2.5	0.8	1.7	2.5	1.9	0.6	0	-1.1	1.1
	Stdev	15.0	7.3	7.6	15.5	13.3	2.2	0.6	6.0	5.4

Note: error rates in percentages of errors made for all trials during the flanker task. Displayed for congruent and incongruent trials, respectively "con" and "incon", and for baseline and sham stimulation respectively as "Pre" and "During". The ERReffect is the interference score, obtained by calculating the difference between incongruent and congruent error rates. ERRcon and ERRincon are the error rate differences between the pre and during measurements of each condition.

Accuracy

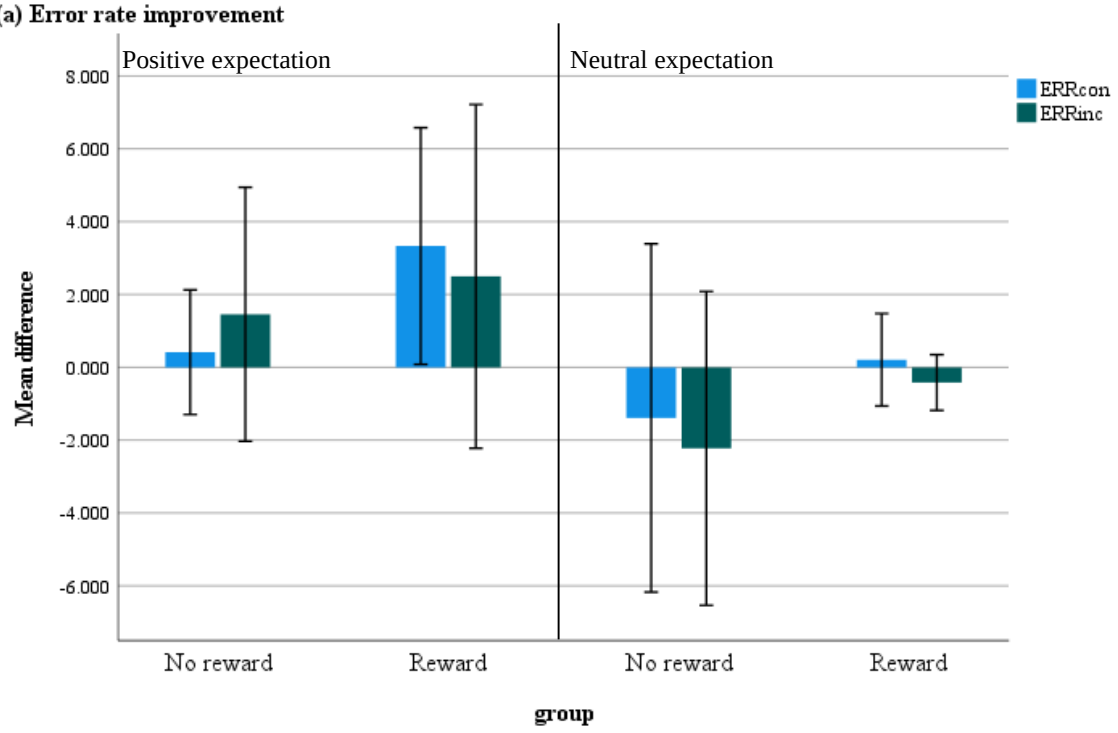
Congruent condition. Both expectation priming and reward modulated performance (expectation: F (1,11) = 9.761, p = .010, η^2 = .470, reward: F (1,11) = 8.181, p = .016, η^2 = .427). Participants in the positive expectation priming group showed a larger improvement between measurement compared to the neutral expectation priming group. Similarly, participants in the positive reward group showed a larger improvement between measurements compared to the no reward group. The interaction between the two was however not significant (F (1,11) = 0.699, p = .421 , η^2 =.060). See figure 1a for the results between the groups.

Incongruent condition. Expectation priming was able to modulate performance, but not reward promise (expectation: F (1,11) = 9.302, p = .011, η^2 = .458, reward: F (1,11) =

1.733, p = .215, , η^2 = .136). Participants in the positive expectation priming group showed a larger improvement between measurement compared to the neutral expectation priming group. The interaction between the two was not significant (F (1,11) = 0.125, p = .731, η^2 = .011). See figure 1a for the results between the groups.

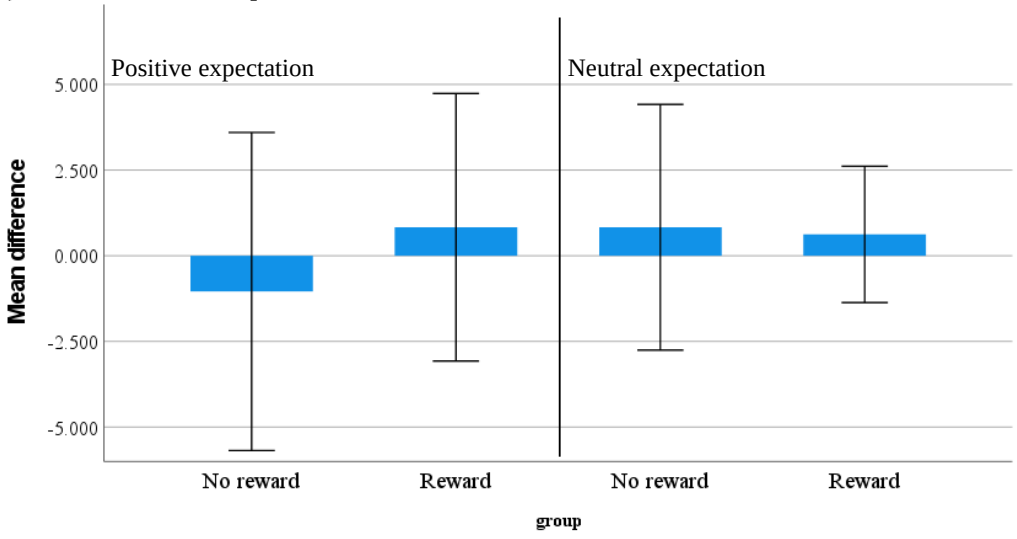
Flanker effect. Neither expectation priming nor reward modulated performance (expectation: F (1,11) = 0.538, p = .479, η^2 = .047, reward: F (1,11) = 0.538, p = .479, η^2 = .047). The interaction between the two was also not significant (F (1,11) = 0.841, p = .379, η^2 = .071). See figure 1b for the results between the groups.

(a) Error rate improvement



Error Bars: 95% CI

(b) Error flanker effect improvement



Error Bars: 95% CI

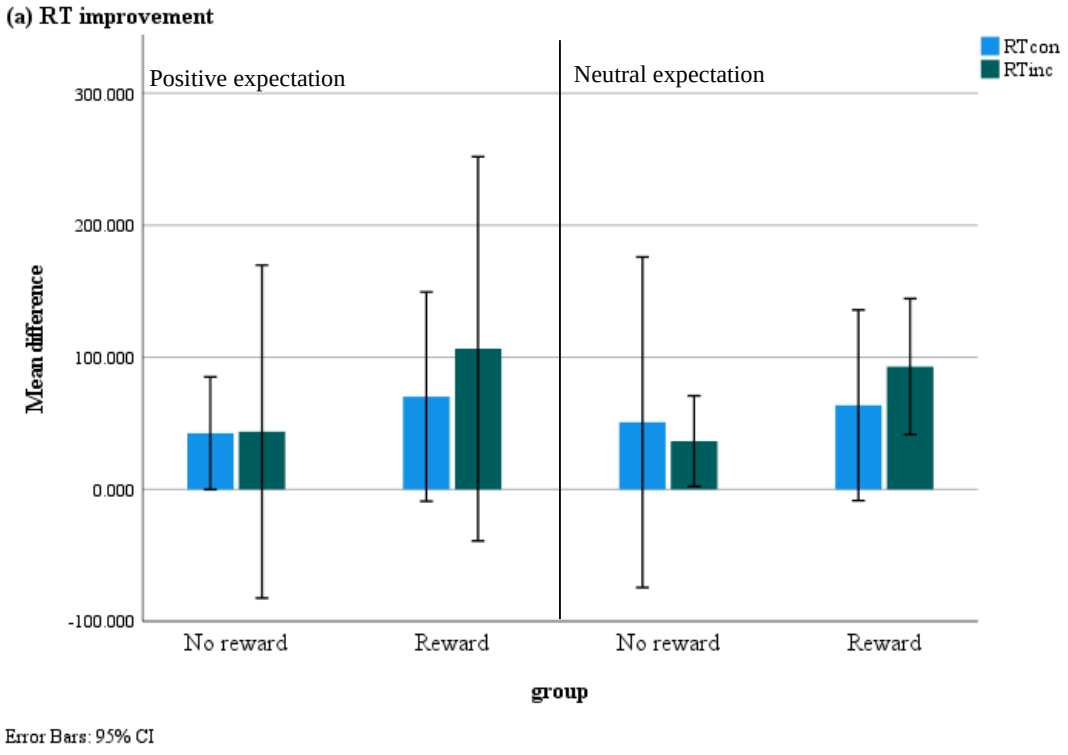
Figure 1. *a*. Mean error rates on the y-axis for the congruent and incongruent trials between our four experimental groups, which are shown on the x-axis. Higher scores indicate more improvement from our pre to during measurement. *b*. Mean error rates on the y-axis for the interference effect between our four experimental groups, which are shown on the x-axis. Lower scores indicate more improvement from our pre to during measurement.

Reaction times

Congruent condition. Neither expectation priming nor reward modulated performance (expectation: F (1,11) = 0.001, p = .970, η^2 = .000, reward: F (1,11) = 0.802, p = .390, η^2 = .068). The interaction between the two was also not significant (F (1,11) = 0.108, p = .748, η^2 =.010). See figure 2a for the results between the groups.

Incongruent condition. Neither expectation priming nor reward modulated performance (expectation: F (1,11) = 0.090, p = .769, η^2 = .008, reward: F (1,11) = 3.044, p = .109, η^2 = .217). The interaction between the two was also not significant (F (1,11) = 0.009, p = .928, η^2 = .001). See figure 2a for the results between the groups.

Flanker effect. Neither expectation priming nor reward modulated performance (expectation: F (1,11) = 0.164, p = .693, η^2 = .015, reward: F (1,11) = 2.038, p = .181, η^2 = .156). The interaction between the two was also not significant (F (1,11) = 0.024, p = .879, η^2 = .002). See figure 2b for the results between the groups.



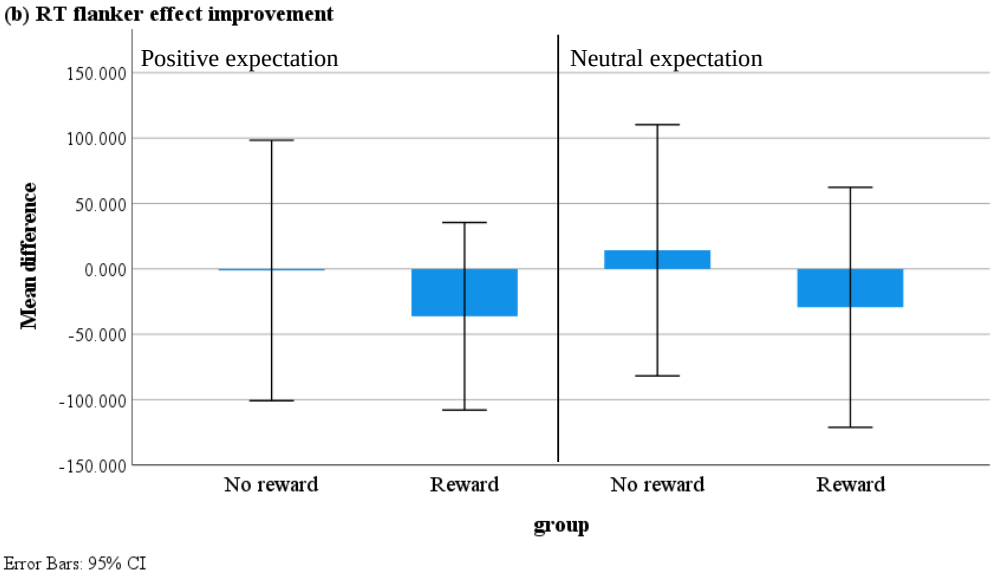


Figure 2. *a*. Mean reaction times on the y-axis for the congruent and incongruent trials between our four experimental groups, which are shown on the x-axis. Higher scores indicate more improvement from our pre to during measurement. *b*. Mean reaction times on the y-axis for the interference effect between our four experimental groups, which are shown on the x-axis. Lower scores indicate more improvement from our pre to during measurement.

Discussion

We aimed to investigate the effects of expectations and reward on sham tDCS measured through a flanker task. The current study had two major goals we wanted to investigate. Firstly, how do expectations of stimulation affect flanker task performance, and secondly how do reward promises affect flanker task performance.

The results following our analysis indicated that expectations and reward were not able to modulate sham tDCS effects for reaction times on the flanker task, however we did see some modulation of expectation and reward of the error rates on the flanker task. These results were partially consistent with expectations we drew from previous literature. As stated before, expectations have been indicated as being able to modulate tDCS effects (Rabipour et al, 2018; Turi et al, 2016). Furthermore, motivation through reward has also been indicated as being able to modulate brain stimulation effects, one tDCS study (Jones et al, 2015) was identified and one rTMS study (Strafella et, 2006). Our results indicated that expectations and reward modulated error rates on the flanker task. However, one important point to make is that our study only investigated modulation of sham tDCS. At this point in time, we cannot

conclude that active tDCS effects are solely through expectations and rewards. However, we can conclude that sham tDCS effects are atleast partially explained by stimulation expectations and reward and that they might play a role in active tDCS.

Accuracy

On task accuracy, Turi et al. (2017) and Rabipour et al. (2018) investigated sham tDCS effects on tasks measuring for respectively reward learning and working memory. Both papers indicated that task accuracy improved following sham tDCS and expectation priming, which is in line with our current study. Similarly results by Jones et al. (2015) indicated that monetary reward was able to modulate task accuracy, our results however indicated this modulation was only present for congruent trials in the flanker task. Jones et al. (2015) did not investigate a flanker task however, thus we cannot draw any conclusions regarding incongruent and congruent performance differences based on their study.

Furthermore, one explanation might be that our offered reward was not motivationally salient enough to cause significant increases on all our measurements. As stated earlier the Jones et al. (2015) study investigated how reward could modulate tDCS effects on a working memory task. Most importantly what they found was that task performance was significantly higher for experimental blocks in which monetary rewards were high. Similarly, Veling and Aarts (2010) concluded that higher reward promises resulted in faster RT's and less error rates during a stroop task compared to low monetary rewards. However, the current study did not investigate different reward magnitudes, therefore we cannot draw any conclusion about the effects that larger rewards could have. But we can argue that the reward used in our current study was perhaps rated as low by our participants. Our initial reward promise was 1 course credit or €10, with the possibility of earning an additional 0.5 course credit or €5. And then for participants in the no reward group they were told they would receive 0.5 course credit or €5, instead of the initial reward promise. Psychology students collecting course credit points need to collect a total amount of 12 points over their three-year bachelor's degree, our additional reward of 0.5 course credit is only a small percentage of this total needed. Additionally, course credit can also be obtained through, for example, completing online questionnaires. These online questionnaires sometimes offer 0.5 course credit for roughly 15-20 minutes of a student's time, possibly due to these circumstances students did not value our extra reward as much as we had hoped for.

Limitations

One limitation regarding our reward manipulation might be in how we set-up our experimental groups. Our expectation groups consisted of a clearly positive and neutral

expectation, when it came to our reward groups we opted for a positive reward and removal of reward group essentially. Due to data collection restraints, it was not possible to also include a neutral reward group, but the inclusion of a neutral group might have been insightful to use a baseline measurement. Additionally, there remains the question of how effective our no reward group was. Although it was not analysed or noted down as it was not part of our initial expectations, some participants, upon being informed about the reward being halved expressed no signs of negative emotion. Participants would sometimes even respond saying "that is no problem, I just wanted to experience brain stimulation", so this brings into question the effectivity of our no reward condition.

Future research

For future research it could be insightful to further investigate points raised about our reward condition. As discussed, our reward promise was set as a fixed value that was possibly not large enough. In future research it could be insightful to offer varying magnitudes of reward such as in the Jones et al. (2015) study, compared to the fixed value used in the current study. Additionally, for future research it could be insightful to build upon our reward groups and add in a neutral reward condition to the current reward groups.

Reaction time

Our current study did not find any evidence that expectation priming, nor reward promise modulated reaction times. Previous work by Rabipour et al. (2018) however indicated that expectation priming was able to modulate reaction times. One possible explanation for a discrepancy between speed and accuracy might be the speed-accuracy trade-off. The speed-accuracy trade-off is a cognitive phenomenon in which someone, given the task difficulty, can choose to either favour speed or accuracy at the cost of the other. You might see that decisions are typically faster in tasks that favor speed, and slower when tasks favor accuracy (Standage, Blohm, and Dorris, 2014).

A study by Hübner and Schlösser (2010) on monetary reward and attentional effort during a flanker task investigated the speed-accuracy tradeoff, Hübner and Schlösser (2010) used blocks in which the deadline, the maximum time allowed to answer, was altered between blocks. Following each response participants were given feedback regarding their RT, the RT deadline in this block, and also if their answer was correct. Their results indicated that participants were the fastest but made the most errors when the deadline was 450ms, but the slowest and most accurate when the deadline was 650ms (Hübner and Schlösser, 2010). Adding to this, another study on the flanker task showed that for congruent trials, accuracy was higher than for incongruent trials, but only for fast response times (Stins, Polderman,

Boomsma, and de Geus, 2007). Lastly, another study on speed-accuracy trade-offs in the flanker task with Parkinson's disease (PD) patients concluded that PD patients did not differ from healthy controls when instructions favouring accuracy were given (Wylie et al, 2009). However, when pressed for time, such as by instructing them to emphasize speed over accuracy their interference effects were significantly different compared to healthy controls (Wylie et al, 2009).

Limitations

Instructions in our task did not necessarily favor one or the other, participants in the reward group were told that if either accuracy or speed increased, they would receive an extra reward. Moreover, in a traditional speed-accuracy trade-off you always see either speed or accuracy increasing, while the other decreases. In our current study we are not seeing this exact relation, while accuracy increases, we do not see any decrease for the reaction times. However, these three studies (Hübner and Schlösser, 2010; Stins et al, 2007; Wylie et al, 2009) indicate that response deadlines can have differing effects on RT's and accuracy in a flanker task. Compared to these studies the current study used a design in which the response deadline was 1500ms, considerably longer compared to for example the Hübner and Schlösser (2010) study where response deadlines varied between 450, 550, and 650ms. The current study design did not press participants for time, such as in the discussed studies (Hübner and Schlösser, 2010; Stins et al, 2007; Wylie et al, 2009). As there was no tight response deadline, participants might have been more focussed on high accuracy, making this measure more susceptible to both our reward promise. However, we did not ask participants if and what their improvement strategy was during the task, therefore we cannot make any conclusions regarding their strategy.

Future research

As previous studies (Hübner and Schlösser, 2010; Stins et al, 2007; Wylie et al, 2009) indicated these reaction time deadlines do have an effect on reaction times and accuracy, which our current study did not consider. Regarding future research, it could be insightful to investigate the effect of shorter and/or more reaction time deadlines. Furthermore, in the current study we essentially gave participants the option to improve either accuracy or speed for the reward condition. We did not ask if participants made a conscious decision to improve one over the other, in future studies it might be interesting to ask participants if they favoured improving either their accuracy or their RT's.

Interference effect

Lastly, as it stands our results only indicated effects of expectations and reward on

congruent and incongruent trial error rates, but not for the interference effect. The current study not finding any differences for the interference effect is due to the fact that the interference effect is calculated as a difference score between incongruent and congruent trials. If performance improvements between congruent and incongruent trials were similar, then we might see no interference effect, which is possibly what happened in our current study (see figures 1a and 2a for the plots).

Conclusion

The current study expanded upon previous findings by further confirming that accuracy is able to be modulated by sham tDCS, and also offering more information on the relation between RT's and sham tDCS. Furthermore, our study was a novel setup investigating expectations and reward concurrently for sham tDCS and attention measures, as compared to working memory and reward learning from previous studies (Jones et al, 2015; Rabipour et al, 2018; Turi et al, 2017).

In summary, the current study found evidence for the modulating effects of expectations and reward on sham tDCS effects. No significant results were found between our expectation and reward groups for RT's, which was contrary to previous research (Turi et al, 2017). However, expectations were able to modulate accuracy in the congruent and incongruent conditions, participants who were positively primed showed less errors compared to neutrally primed participants. Expectations did not modulate the interference effect for accuracy. These results were in line with previous research (Rabipour et al, 2018; Turi et al, 2017). Lastly, reward was able to modulate congruent accuracy, participants receiving the extra reward instruction made less errors compared to participants in the no reward condition. Reward was not able to modulate incongruent trials, and the interference effect. This was partially in line with expectations drawn from previous studies (Jones et al, 2015; Strafella et al, 2006). No interaction effects were found for our expectation and reward groups. Our study contained several strengths, such as this being a novel study design including both reward and expectation priming in sham tDCS. An important conclusion to draw is that it is possible to modulate task performance during sham tDCS, namely accuracy, by altering people's expectations and reward promises. However, the current study did not investigate active stimulation, we do not know how expectations and reward could have influenced active tDCS compared to sham tDCS. Therefore, we cannot conclude that tDCS effects are solely due to expectations and reward. Suggestions are made for future research, such as reducing RT deadlines and increasing and varying reward incentives.

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Appendix A

Positive priming text

You are about to start a single-session brain stimulation intervention designed by neuroscientists, based on work proven effective in scientific studies. Research shows that this intervention can improve mental functions such as memory, concentration, learning, and reasoning. This improvement has been especially strong in young adults where cognitive skills are well developed and brain capacity is at one of its highest points in life. This is similar to the way physical exercise improves muscle tone and performance. Just like stimulating your body with exercise, stimulating your brain can help you feel better and perform better. The technology of the intervention boosts your brain activity in the stimulated regions, just like a personal trainer would boost your performance at the gym. Neuroplasticity is where your brain changes its neuronal configuration in response to certain types of activity, including brain stimulation. Research shows that brain stimulation produces real changes that last up to several years. Below are examples of points made in scientific articles that support brain stimulation (citations provided for your reference):

'Several studies indicate that brain stimulation can lead to improved attention in children and adults.' Tang & Posner, *Trends in Cognitive Science*, 2010.

'This study offers neural and behavioural evidence of generalized positive effects from brain stimulation on cognitive control abilities of young adults.' Anguera et al., *Nature*, 2013, 2010.

Young adults who underwent a single session of brain stimulation saw improvements in reasoning skills and processing speed that could be detected as long as 5 years after the stimulation ended.' Steenhuysen, *Science*, 2018

Neutral priming text

You are about to start a single-session brain stimulation intervention to examine the effect of brain stimulation on attention. Existing research remains inconclusive about whether tDCS does or does not improve attentional functioning in young adults. Some theories state that brain stimulation might improve mental functions, but these claims have not yet been proven scientifically. In other words, it is unclear if any real change can result from brain stimulation at this point in time. Below are examples of points made in scientific articles regarding brain

stimulation (citations provided for your reference):

'Available evidence regarding brain stimulation remains limited, and the quality of the evidence needs to improve. There is still no indication of any significant benefit derived from brain stimulation.' Bahar-Fuchs, Clare, & Woods, *The Cochrane Collaboration*, 2013

'Brain stimulation techniques such as TDCS have been able to alter cortical excitability and cognitive-behavioral variables in some studies, however large differences exist between individuals, and it is unclear why.' Polanía, Nitsche, & Ruff, *Brain Stimulation*, 2018

'Despite some advances in the investigation of the efficacy of tDCS to improve attention in young adults, more large-scale, systematic studies are needed to reconcile the observed outcome variability.' Paulus, Iacoboni, & Bikson, *Neuron*, 2019

Appendix B

Study debriefing (Positive primed + reward text)

Thank you for participating in our study.

Please read the material on this form carefully to fully learn important information about your experience in this experimental study and ask the researcher any questions you might still have. After this debriefing, you may still choose to have information that we collected about you to be removed from this study.

For this study it was important that we withheld some information from you about some aspects of the study. Now that data collection is completed, you will be informed about the information that was withheld.

What you should know about the study

Before you participated in this study you were told that the goal of the study was to investigate whether transcranial direct current stimulation (tDCS) affects cognitive performance. However, the actual goal of the study is to determine whether cognitive performance can be changed solely by altering participants' expectations about tDCS. In the instruction you received prior to tDCS application, you were told that tDCS would have a positive effect on your performance. Other participants received instructions stating that tDCS would have no effect on their performance. Furthermore, you were told that you would receive additional PPU, or money, if your performance increased by 10%, other participants did not receive this instruction. Upon completion everyone will be accredited with 1PPU, or €10. As we were primarily interested in the placebo effect, no real stimulation was used in this study, and all participants received placebo stimulation. To ensure we were measuring placebo effects it was necessary to deceive you, the participant, about the actual goal of the study.

Your right to withdraw from the study

Now that you are fully informed about the purpose of the study, you may still decide to withdraw from the study. There will be no penalties or consequences to you retracting your data, you are still eligible for any Sona systems credit. You do not have to provide any reason for your data retraction and can request this at any point in time. If you have any further questions, you can e-mail any of the researchers.

Data storage

Data will be stored according to the Utrecht University FSBS protocol.

Contact

If there remain any questions or you would like to retract any of your collected data you can send an e-mail to the following researchers:

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