School of Psychology

The effect of transcranial direct current stimulation on judgement tasks

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Abstract

Transcranial direct current stimulation (tDCS) was used to investigate whether stimulating the right-dorsolateral prefrontal cortex (DLPFC) modulated performance on judgement and thinking tasks. Performance was improved by right-DLPFC offline stimulation in the 20-item Cognitive Reflection Test whilst controlling for cognitive ability (National Adult Reading Test; NART). The CRT scores were higher in open-minded thinking (AOT) individuals. These results are the first to show improvement in JDM tasks after tDCS stimulation, and support theoretical approaches proposing analytic thinking dispositions in overcoming intuitive responses.

Introduction

- Recent studies have shown that brain stimulation using tDCS affects performance in judgement and decision-making tasks for the enhancement of judgement and decision-making (JDM)[1,2].
- However, most of the effects in decision-making tasks were not reliable in contrast to sham stimulation[3].
- Here we test whether performance across judgement and decision-making tasks is modulated by anodal stimulation to the left- or right-dorsolateral prefrontal cortex (DLPFC), areas linked to increasing decision-making performance [4].
- We chose judgement and decision-making tasks from the heuristics-and-biases literature (e.g., Toplak, 2011 [5]).
- An additional focus were potential influences from individual differences:
  - Pennycook et al. (2012) found that religious belief was negatively associated with performance [6] on tasks tapping 'Type 2' reflective thinking.
  - Baron et al (2015) found that actively open-minded thinking was positively associated with performance [7] on tasks tapping 'Type 2' reflective thinking.

All tasks (order counterbalanced)

***Belief bias syllogisms*:**
Two premises (e.g., ALL ROSES NEED WATER and PLANTS NEED WATER) with a conclusion (e.g., THEREFORE, ROSES ARE PLANTS); respond by deciding if the syllogisms is valid or invalid. (Maximum: 2 x 8 no/conflict per session).

***Representativeness heuristics / base-rate neglect*:**
Measures Type 1 and Type 2 usage. Short questions with lures that are designed to initially illicit a Type 1 answer. (Maximum: 10 per session).

***Enhanced Cognitive Reflection Test (CRT)*:**
Measures Type 1 and Type 2 usage. Short questions with lures that are designed to initially illicit a Type 1 answer. (Maximum: 20 per session).

Questionnaires

Actively Open-minded Thinking (AOT [9]):
Measures open-mindedness in participants when making a decision and whether they are willing to consider new information or not. Respond on a scale from 1 (completely disagree) to 7 (completely agree).

Rational Experiential Inventory (REI [10]):
Measures cognitive styles (Type 1 or Type 2 usage). Respond on a scale from 1 (strongly disagree) to 5 (strongly agree).

Procedure

Figure 1. Experimental procedure. All judgement and decision-making tasks were counterbalanced and completed after the end of stimulation (offline).

Methods

- n = 54, between design (mean age = 24.63 ± 4.46 years; 29 females).

tDCS montage and parameters

- tDCS delivered using a battery-driven stimulator (NeuroElectrics, Barcelona)
- Two electrodes (anodal and reference) with a surface area of 25 cm^2.
- Electrode current intensity 1.5 mA & current density of 0.06 mA/cm^2.
- Stimulation duration of 20 minutes (15 seconds ramp-up).
- Stimulation: (i) right-DLPFC (anodal) – left-DLPFC (return), (ii) left-DLPFC (anodal) – right-DLPFC (return), or (iii) sham group. (see Figure 2)

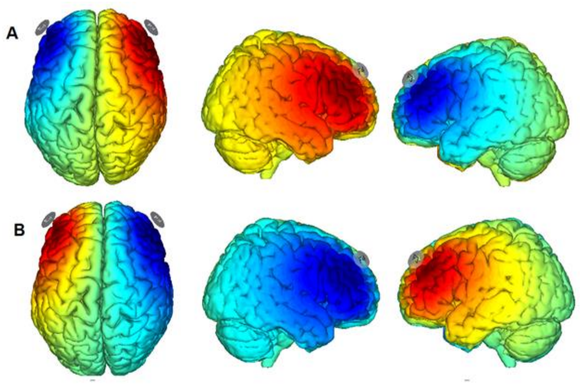

Figure 2. tDCS influence maps for electrode montages. Row A shows the right-DLPFC stimulation. Row b shows left-DLPFC stimulation. The increase in neural activity at the anodal electrode site is shown in red whilst blue denotes a decrease in neural activity at the reference electrode site, compared to sham.

Results – figures

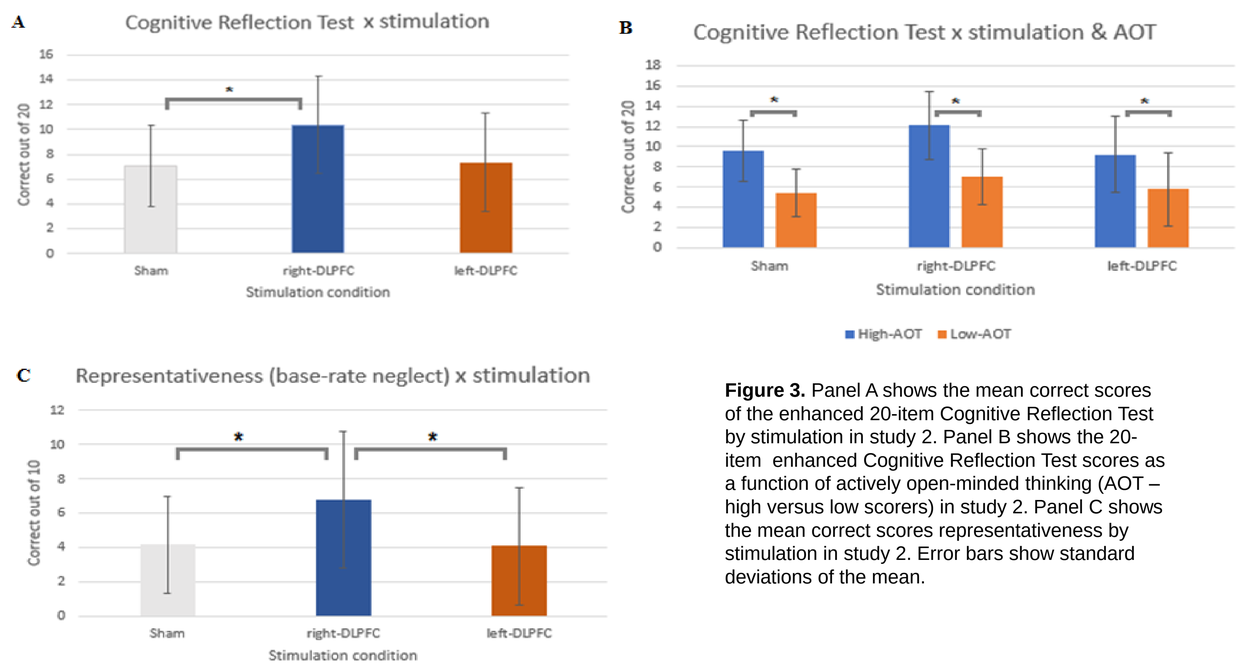

Figure 3. Panel A shows the mean correct scores of the enhanced 20-item Cognitive Reflection Test by stimulation in study 2. Panel B shows the 20-item enhanced Cognitive Reflection Test scores as a function of actively open-minded thinking (AOT – high versus low scorers) in study 2. Panel C shows the mean correct scores representativeness by stimulation in study 2. Error bars show standard deviations of the mean.

Results

A multivariate analysis of variance (MANOVA) to examine effects of stimulation (right-DLPFC, left-DLPFC or sham) and Actively Open-minded Thinking (AOT; high or low) and cognitive ability (National Adult Reading Test; NART) on the enhanced Cognitive Reflection Test (CRT), representativeness, logic index, and belief index scores. Follow-up ANOVAs used where indicated.

Enhanced Cognitive Reflective Test:
- Main effect of **stimulation** on accuracy F(2,47) = 4.16, p = .02, partial η^2 = .15 (see Figure 3A)
- *Pairwise comparisons:* Difference between right-DLPFC stimulation & sham (p = .03).
- Trend towards difference between right-DLPFC stimulation & left-DLPFC stimulation (p = .07)
- No difference left-DLPFC stimulation & sham *(p = .92).*

- Main effect of **AOT** on accuracy F(2,47) = 8.32, p = .01, partial η^2 = .15
- *Pairwise comparison:* difference between low-AOT & high-AOT (p = .01) (see Figure 3B)

- *Covariate:* main effect of **cognitive ability** on accuracy F(2,47) = 27.56, p = .01, partial η^2 = .37

- *Stimulation x AOT:* No interaction F(2,47) = 0.53, p = .58, partial η^2 = 02

Representativeness:
- Main effect of **stimulation** on accuracy F(2,47) = 4.68, p = .01, partial η^2 = .16
- *Pairwise comparisons:* Difference between right-DLPFC stimulation & sham (p = .02)
- Difference between right-DLPFC stimulation and left-DLPF stimulation (p = .04)
- No difference between left-DLPFC stimulation & sham (p = 1) (see Figure 3C)

- No main effect of **AOT** on accuracy F(2,47) = 1.13, p = .30, partial η^2 = .02

- *Covariate:* main effect of **cognitive ability** on accuracy F(2,47) = 6.16, p = .01, partial η^2 = .11

- *Stimulation x AOT:* No interaction F(2,47) = 2.40, p = .10, partial η^2 = 10

Logic index (from belief bias – larger indices indicate greater logic):
- No main effect of **stimulation** F(2,47) = 1.07, p = .35, partial η^2 = .04
- No main effect of **AOT** F(2,47) = 1.60, p = .21, partial η^2 = .03
- *Covariate:* No main effect of **cognitive ability** F(2,47) = 2.03, p = .16, partial η^2 = .16
- *Stimulation x AOT:* No interaction F(2,47) = 1.60, p = .21, partial η^2 = 06

Belief index (from belief bias – larger indices indicate greater belief bias):
- No main effect of stimulation on **belief index** F(2,47) = 0.58, p = .56, partial η^2 = .02
- No main effect of **AOT** F(2,47) = 0.01, p = .93, partial η^2 = 02
- *Covariate:* No main effect of **cognitive ability** F(2,47) = 0.40, p = .52, partial η^2 = 01
- *Stimulation x AOT:* No interaction F(2,47) = 0.93, p = .40, partial η^2 = 01

Logic index and belief index calculated with the following equations [11]:

Logic index = VB + VU – IB – IU

Belief index = VB + IB – VU – IU

VB = valid-believable
VU = valid-unbelievable
IB = Invalid-believable
IU = Invalid-unbelievable

	Stimulation conditions mean (Standard Deviation)		
Task / variable	**Right-DLPFC**	**Left-DLPFC**	**Sham**
Enhanced CRT	10.38 (3.94)*	7.33 (3.97)	7.05 (3.28)
Representativeness	6.77 (3.96)*	4.11 (3.42)	4.16 (2.83)
Logic index	1.05 (2.12)	1.55 (1.94)	2.00 (1.81)
Belief index	2.61 (1.57)	2.11 (1.27)	2.00 (1.18)
Interaction index	-2.50 (1.46)	-1.00 (2.08)	-1.77 (1.35)

Note. An asterisk (*) signifies a significant effect of stimulation in follow-up analysis of variances (ANOVAs), p < .05. Abbreviations: DLPFC – dorsolateral prefrontal cortex, CRT – Cognitive Reflection Test.

Table 1. Descriptive values for all judgement and decision-making tasks and variables. Belief bias syllogism data is represented be the logic, belief and interaction indices. Logic index is the difference between acceptance of valid and invalid conclusions. Belief index is the difference between acceptance of believable and unbelievable conclusions. Interaction indices is the degree to which belief bias is greater for invalid than valid items.

Conclusion

Anodal stimulation of the right-DLPFC had a main effect of improving accuracy on the longer-form, enhanced 20-item CRT, compared to sham and left-DLPFC stimulation. Individual differences in thinking disposition (here religiosity and AOT) had an overall effect on reflection tasks across stimulation conditions. These results cannot be explained by differences in cognitive abilities, and support theoretical models claiming that cognitive style is a predictor of performance in judgement tasks in which a pre-potent response has to be inhibited (CRT, Representativeness), and that stress the role of analytic thinking in overcoming stereotypical responses in decision-making [12]. Future research may determine whether the positive effects on performance from anodal tDCS are linked to processes improvements in task shifting related to divergent thinking [13].

References

[1] Votinov, M., Aso, T., Koganemaru, S., Fukuyama, H. & Mima, T. (2013). Transcranial direct current stimulation changes human endowment effect. *Neuroscience Research, 76, 251-256.*
[2] Cheng, G. & Lee, T. (2015). Altering risky decision-making: influence of impulsivity on the neuromodulation of prefrontal cortex. *Social Neuroscience, 11(4), 353-364.*
[3] Edgcumbe, D., Thoma, V., Mutz, J., Rivolta, D., Nitsche, M. & Fu. C. (2017) Under review
[4] Ye, H., Chen., S., Huang., D., Wang., S. & Luo. J. (2015). Modulating activity in the prefrontal cortex changes decision-making for risky gains and losses: a transcranial direct current stimulation study. *Behavioural Brain Research, 286, 17-21.*
[5] Toplak, M., West, R. & Stanovich, K. (2011). The Cognitive Reflection Test as a predictor of performance on heuristics-and-biases tasks. *Memory & Cognition, 39(7), 1275-1290.*
[6] Pennycook, G., Cheyne, J., Seli, P., Koehler, D. & Fugelsang, J. (2012). Analytic cognitive style predicts religious and paranormal belief. *Cognition, 123(3), 335-346.*
[7] Baron, J., Scott, S., Fincher, K. & Metz, E. (2015). Why does the Cognitive Reflection Test (sometimes) predict utilitarian moral judgment (and other things)? *Journal of Applied Research in Memory and Cognition, 4, 265-284.*
[8] Frederick, S. (2005). Cognitive reflection and decision making. *The Journal of Economic Perspectives, 19(4), 25-42.*
[9] Haran, U., Ritov, I & Mellers, B. (2013). The role of actively open-minded thinking in information acquisition, accuracy, and calibration. *Judgment and Decision Making, 8(3), 188-201*
[10] Epstein, S., Pacini, R., Denes-Raj., V. & Heier, H. (1996). Individual differences in intuitive-experiential and analytical-rational thinking styles. *Journal of Personality and Social Psychology, 71(2), 390-406.*
[11] Strupple, E., Ball, L., Evans, J. & Kamal-Smith, E. (2011). When logic and belief collide: Individual differences in reasoning times support a selective processing mode. *Journal of Cognitive Psychology, 23(8), 931-941.*
[12] Stanovich, K. (2009). Distinguishing the reflective, algorithmic, and autonomous minds: Is it time for a tri-process theory. *In two minds Dual processes and beyond, Oxford University Press: London, (Ed) pp 55-88.*
[13] Leite J, Carvalho S, Fregni F, Gonalves .F. Task-specific effects of tDCS-induced cortical excitability changes on cognitive and motor sequence set shifting performance. PLoS ONE. 2011; 6:e24140.10.1371/journal.pone.0024140