Transcranial direct current stimulation to prefrontal cortex alters blood flow and functional connectivity in reward networks

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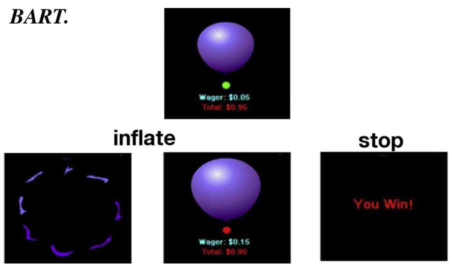
Introduction

Transcranial direct current stimulation (tDCS) over prefrontal cortex (PFC) has been shown to have cognitive effects, notably on risk-taking and impulsivity. However, no investigators have imaged the hemodynamic effects of tDCS over PFC. We examined the effects of tDCS over dorsolateral prefrontal cortex (DLPFC), a region activated during decision under risk (Rao et al., 2008) that alters risk preference when stimulated (Fecteau et al., 2007).

Methods

17 participants were scanned before and after tDCS with arterial spin-labeling (ASL) perfusion fMRI during rest, and standard BOLD fMRI during performance of the Balloon Analog Risk Task (BART; Lejuez et al., 2002). 9 participants received real stimulation and 8 received sham.

BART.

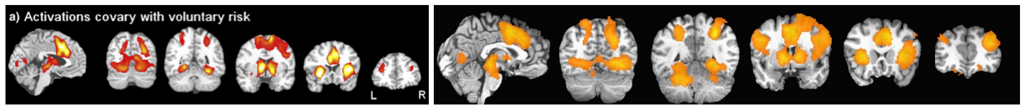


We did not detect any differences in behavior between sham and stimulated subjects, or interactions with task timing (pre- vs. post-stimulation).

tDCS. Non-sham participants were stimulated with two 5x5-cm electrodes at 1.5 mA for 15 minutes. The anode was placed over right DLPFC (electrode F4 in the International 10-20 System) and the cathode over left DLPFC (F3), following Fecteau et al. (2007).

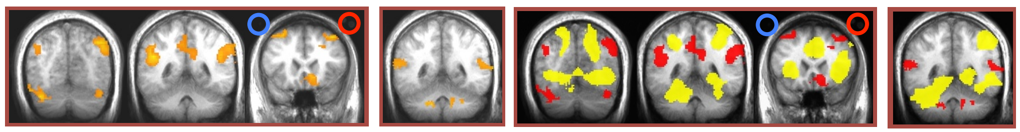
Imaging. Images were analyzed in AFNI. ASL images were blurred with a 12-mm FWHM Gaussian kernel. Relative cerebral blood flow (rCBF) was calculated according to Wang et al. (2003). BOLD images were blurred with a 10-mm FWHM Gaussian kernel and normalized to percent signal change. Voxel time courses were analyzed via multiple regression with three predictors: One for wins, one for losses, and one varying parametrically with risk.

1. Replication of previous work



BOLD response to parametric risk from Rao et al. (2008, left) and current study (right).

2. Effects on task-related BOLD signal.

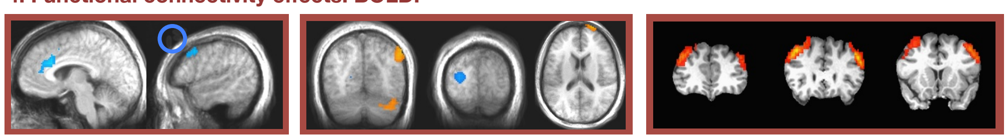


a–c: Inferior parietal lobule, cerebellum/fusiform, posterior cingulate, and DLPFC bilaterally, as well as right orbitofrontal cortex, show increased response to risk. **d**: Bilateral superior temporal gyrus and cerebellum show increased response to wins. **2e–h:** BART network from [1] (yellow), tDCS effects (red), and overlap (green). The anode's site is marked in red, the cathode's in blue.

3. Effects on resting rCBF.

Right precuneus, bilateral lingual gyrus, right middle temporal gyrus, left DLPFC, left premotor cortex, and right frontal pole show increased rCBF; right fusiform gyrus shows decreased rCBF.

4. Functional connectivity effects: BOLD.



a–b: Functional connectivity (FC) to **left DLPFC** is decreased in left ACC and left premotor cortex. **c–e:** FC to **right DLPFC** is increased in right inferior parietal lobule, right cerebellum/fusiform, and right frontal pole and decreased in left middle occipital gyrus. **f–h:** DLPFC ROIs used for FC.

BOLD images are thresholded at $p<0.005$ and minimum cluster size of 254; CBF images are thresholded at $p<0.002$ and minimum cluster size of 232. Simulations determined that clusters this large occurred randomly with $p<0.05$ given the statistical thresholds, voxel grids, and smoothing kernels. Each image shows the result of the same contrast: Stimulated subjects post-stimulation against all other conditions.

Functional connectivity. We assessed functional connectivity to the left and right DLPFC, which we designated the 30 voxels (in the BOLD images) or 21 voxels (in the ASL images) closest to the electrode site. Electrode sites for the BOLD images are visualized in 4f–h. Time courses of no interest were extracted from equivalently sized regions in the white matter and white matter and ventricles, as well as the mean intracranial signal. In the case of the BOLD images, the task regressors were also entered as regressors of no interest. Group analysis was performed on the *z*-transformed correlation coefficients.

Discussion

- Prefrontal tDCS affects hemodynamic activity and functional connectivity in regions distal to the stimulation site.
- Both anode and cathode increase task-related activity at the stimulation site (corroborating research in motor cortex; Lang et al., 2005).
- tDCS effects on task-related BOLD are near the BART network but nonoverlapping. (Perhaps the tDCS effect is drowned out by the BART effect?)
- Like Rao et al. (2008), we observe greater involvement of right than left DLPFC in risk- and win-related BOLD. This may indicate that the behavioral effect of tDCS is selectively driven by the anode (but see Fecteau et al., 2007).
- Parietal and fusiform regions are equally active during risky decisions and mere perception of risk (Rao et al., 2008). Modulation of these areas may affect decision-making by biasing *perception of* rather than *preference for* risk. Note also that tDCS increases FC between DLPFC and right parietal and fusiform regions.

References

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