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Short Communication

Transient reduction of visual distraction following electrical stimulation of the prefrontal cortex

Joshua D. Cosman *, Priyanka V. Atreya, Geoffrey F. Woodman

Department of Psychology, Center for Integrative and Cognitive Neuroscience, Vanderbilt Vision Research Center, Vanderbilt University, Nashville, TN, USA

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ABSTRACT

The ability to overcome distraction is critical to a number of goal-directed behaviors, but information that is not relevant to our goals often captures our attention and distracts us from the task at hand. Neuroimaging work has demonstrated that activity in specific regions of the lateral prefrontal cortex (PFC) is related to the suppression of distracting information, implicating PFC as a critical node in the goal-directed control network. In the current work we asked whether applying transcranial direct-current stimulation (tDCS) to PFC would influence the likelihood of attentional capture by salient, task-irrelevant visual information encountered during visual search. Our results showed that anodal stimulation, relative to sham or cathodal stimulation, led to a transient decrease in attentional capture lasting approximately 15 min after stimulation. This provides causal evidence that PFC is involved in goal-directed control over distraction, and provides a basis for using PFC stimulation as a causal tool to understand deficits in goal-directed control in both neurologically healthy and impaired populations.

1. Introduction

Overcoming distraction by salient information is key to effective goal-directed attentional control, and distractibility characterizes a number of neurological disorders. As a result, determining which brain structures are necessary for overcoming distraction is important for understanding and remediating deficits when they occur. A number of studies have implicated specific regions of the parietal and prefrontal cortices in the ability to exert top-down control over distracting information across a number of modalities (see Gazzaley & Nobre, 2012, for a review).

Of particular relevance to the current work, Leber (2010) demonstrated that the magnitude of pretrial activity in a specific region of prefrontal cortex, the middle frontal gyrus (MFG), predicted the likelihood that a salient distractor would capture attention during visual search, with increased pre-trial MFG activation leading to a decreased impact of a salient distractor on search performance (Leber, 2010). This suggests that the MFG is a critical node in the goal-directed attentional control network, serving to control access to limited capacity attentional mechanisms.

Here, we used a classic attentional capture task (Theeuwes, 1992) coupled with transcranial direct-current stimulation (tDCS) to examine whether it is possible to causally manipulate the magnitude of visual distraction by applying current centered over MFG. Briefly, low-amplitude application of tDCS leads to transient changes in the resting membrane potential of neurons under the site of stimulation, with anodal stimulation leading to a relative increase in resting membrane potentials and cathodal stimulation leading to a relative decrease (Bindman, Lippold, & Redfearn, 1964). Thus, if prefrontal cortex, and in particular MFG, is causally involved in goal-directed control over visual distraction, we would expect a transient decrease in attentional capture following anodal stimulation, and a transient increase in capture following cathodal stimulation, relative to sham stimulation.

2. Method

2.1. Participants

Eighteen volunteers with normal visual acuity and without color-blindness provided informed consent. Sample size was estimated on the basis of previous tDCS work in our lab showing effects of prefrontal stimulation and RT differences of a similar magnitude to those reported here (Reinhart & Woodman, 2014).

2.2. tDCS procedure

A within-subjects design was employed in which each subject acted as their own control across conditions, receiving cathodal,

* Corresponding author at: PMB 407817, 2301 Vanderbilt Place, Vanderbilt University, Nashville, TN 37240-7817, USA.

E-mail address: joshua.d.cosman@vanderbilt.edu (J.D. Cosman).

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anodal, or sham stimulation in different experimental sessions spaced 1–7 days (mean 3.2 days) apart, with stimulation type counterbalanced across days. The active electrodes (measuring 4.5 × 4.5 cm) were centered bilaterally at locations F3 and F4 of the standard 10–20 electrode system, a region corresponding to MFG (Herwig, Satrapi, & Schönfeldt-Lecuona, 2003). Reference electrodes (measuring 11.0 × 4.5 cm) were placed on the contralateral cheeks.

Placement over MFG was verified by modeling current flow at locations F3 and F4 using established methods (Fig. 2; Sadleir, Vannorsdall, Schretlen, & Gordon, 2010; Wagner et al., 2007). A realistic finite element model of the head was generated from the MNI T1-weighted MRI reference brain from the CURRY 6.0 multimodal neuroimaging software (Compumedics Neuroscan). Our forward computation using a finite element model was implemented in SCIRun (available as open source software: http://software.sci.utah.edu).

Participants were stimulated for 20 min at 1.0 mA in the anodal and cathodal conditions, and in the sham condition the stimulator was turned on at the beginning, middle, and end of the session for 30 s to simulate the feeling of the active conditions without delivering sustained current.

2.3. Stimuli and task

Directly following stimulation, participants performed an adapted version of the additional singleton task (Theeuwes, 1992). Search arrays were viewed on a black background and consisted of twelve items placed in a circle centered on fixation (Fig. 1); the items were equidistant from both each other (1°) and fixation (6°). Search items were either circles (0.90° radius) or squares (1.6° × 1.6°), and on each trial participants were asked to search for the item that differed in shape from the rest of the array, reporting the orientation of a line (1.1°) contained inside of it. On half of the trials, a color singleton distractor appeared at one of the non-target locations in the display (distractor present trials) and in the other half no color singleton appeared (distractor absent trials). All non-singleton items were drawn in light gray, and on distractor present trials the color singleton could randomly appear in red[1], green, blue, or yellow.

Displays were always presented for 3000 ms followed by an intertrial interval that lasted 1000–1500 ms, duration randomly jittered across trials, during which only the fixation point was visible. Participants were instructed to respond as quickly and accurately as possible. Participants were informed that the color singleton would never appear in the target location, and thus was a distractor that they should try to ignore. The task consisted of 3 blocks of 170 trials for a total of 510 trials.

3. Results

Mean reaction times and error rates for each stimulation condition across blocks are shown in Fig. 3. As can be seen in Fig. 4, our tDCS manipulation of prefrontal activity decreased the ability of the singleton distractors to slow responses to the less salient targets in the anodal condition, with this effect being maximal in the first block of trials and decreasing thereafter. An omnibus three-way ANOVA, with stimulation condition (anodal, cathodal, or sham), block (first, second, or third), and distractor presence (present vs. absent) as factors revealed a significant main effect of block, $F(2,34) = 41.3$, $p < .001$, $\eta_p^2 = .71$, and distractor presence, $F(2,34) = 215$, $p < .001$, $\eta_p^1 = .71$, and a significant three-way inter-

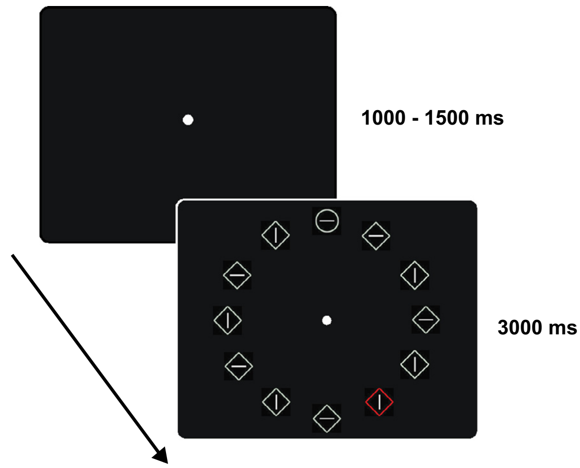

Fig. 1. Stimulus displays showing a distractor present trial.

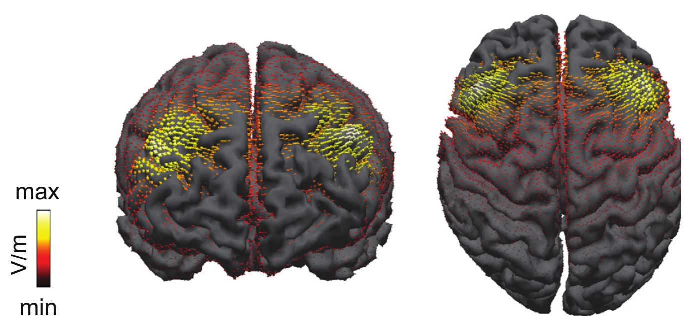

Fig. 2. tDCS current flow diagram showing the distribution of current during active stimulation.

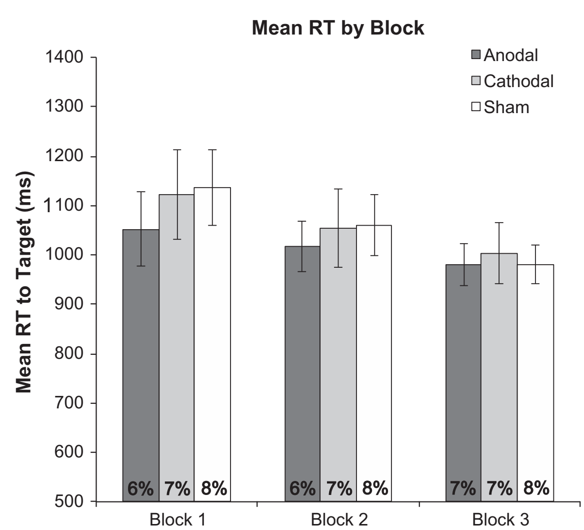

Fig. 3. Overall reaction times and error rates (base of graph) for each stimulation condition, by block. Error bars indicate 95% within-subjects confidence intervals (Morey, 2008).

action, $F(4,68) = 3.01$, $p = .02$, $\eta_p^2 = .15$, supporting the observation that the effects of stimulation and distractor presence depend on time following stimulation, as shown in previous work (Nitsche & Paulus, 2001). No other main effects or interactions were significant (Fs < .873, ps > .49). An identical analysis performed on accuracy data revealed only a marginally significant main effect of

[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.