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Modulation of selective attention by polarity-specific tDCS effects

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ABSTRACT

Selective attention relies on working memory to maintain an attention set of task priorities. Consequently, selective attention is more efficient when working memory resources are not depleted. However, there is some evidence that distractors are processed even when working memory load is low. We used tDCS to assess whether boosting the activity of the Dorsolateral Prefrontal Cortex (DLPFC), involved in selective attention and working memory, would reduce interference from emotional distractors. Findings showed that anodal tDCS over the DLPFC was not sufficient to reduce interference from angry distractors. In contrast, cathodal tDCS over the DLPFC reduced interference from happy distractors. These findings show that altering the DLPFC activity is not sufficient to establish top-down control and increase selective attention efficiency. Although, when the neural signal in the DLPFC is altered by cathodal tDCS, interference from emotional distractors is reduced, leading to an improved performance.

1. Introduction

Several theoretical views propose the prioritization of attentional selection of stimuli with high motivational significance (Öhman and Mineka, 2003; Vuilleumier and Huang, 2009). In this case, the amygdala biases the representation of emotional stimuli over competing ones by means of its feedback to sensory processing areas of the brain (i.e., Pessoa, 2009; Pourtois et al., 2013). When emotional stimuli are to be ignored, the extent to which attention is selectively allocated to task-relevant information depends on competition between two forces. One is the biasing effect of attentional control, in support of task-relevant information, and the other is emotion-mediated process (or processes), supporting task-irrelevant information. The demands on control processes for the suppression of task-irrelevant information is likely to be pronounced when distractors are emotional stimuli, because of the supposed enhancement of their signals from the neural circuitry centered on the amygdala. Under these conditions, boosting selective attention should reduce interference from task-irrelevant emotional stimuli.

According to well-established models of selective attention, mechanisms of top-down, frontal control are involved in prioritizing processing of task-relevant stimuli and minimizing interference from task-irrelevant distractor stimuli (i.e., Corbetta et al., 2008; Desimone and Duncan, 1995). In this context, selective attention relies on working memory to maintain templates to support task-relevant processing (i.e., Awh and Jonides, 2001). This is also a central aspect of Lavie's load theory (2005), which directly relates the efficiency of selective attention to the availability of working memory resources. Indeed, there is evidence showing that selective attention and working memory are supported by closely related neural mechanisms (Chun et al., 2011; Gazzaley and Nobre, 2012). In addition, behavioral and neurophysiological evidence shows reduced distractors processing when working memory resources are available and enhanced distractors processing when working memory resources are reduced by a concurrent load.

Specifically, de Fockert et al. (2001) used a picture–word interference task in which participants responded to names and ignored faces under low or high working memory (WM) load. They found that selective attention was less efficient, and distractors interference increased, when WM load was high. Similar findings have been reported in a variety of studies (see de Fockert, 2013 for a review). However, there is also some empirical evidence showing that distractors are processed even when working memory resources are available. For instance, Pecchinenda and Heil (2007) used a methodology similar to de Fockert et al. (2001) and replicated their findings with neutral stimuli. However, when emotional faces were used as distractors and positive and negative words were task-relevant (Experiment 3), distractors interference occurred under low *and* under high WM load. Similarly, Jongen and Jonkman (2011) used a picture–name interference task with neutral stimuli and varied WM load by asking participants to

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retain a string of 0, 2 or 4 letters (rather than digits). They found distractors interference on behavioral performance regardless of WM load.

More recently, Berggreen et al. (2012) used a visual search task with happy, angry, and neutral faces to assess the effects of load on attention toward task-relevant targets. WM load was manipulated by asking participants to count back in steps of 3 while performing the visual search task. Findings showed that the capture and maintenance of attention toward angry and happy faces presented in a visual search array was not affected by load. In contrast, Holmes et al. (2013) have provided evidence that WM load affects attention toward angry faces. They used a dot-probe task with pairs of faces (neutral and angry) and a WM load similar to that used in past studies (a series of digits in numerical or random order). Typical results reveal faster responses to probes presented at the location previously occupied by the task-irrelevant angry face (attentional bias for angry faces). Findings showed that high WM load enhanced the attentional bias toward angry distractor-faces. Unfortunately, only angry faces were used in this study, leaving open the question of whether this finding is specific to threat-related distractors or it is generalizable also to other emotional stimuli.

In summary, past studies have provided a complex picture and it is still unclear to what extent the efficiency of selective attention depends on working memory resources to reduce interference from distractors, particularly when they are emotional stimuli. To clarify this issue, in the present study we used a complementary strategy to that used in past studies. That is, in addition to assessing the effect of working memory load on selective attention, we also altered the neural activity of brain areas involved in working memory and selective attention.

Studies using fMRI have linked selective attention to the activity of the dorsolateral prefrontal cortex (DLPFC) and in particular to maintaining an attentional set of task priorities (i.e., Hadland et al., 2001; MacDonald and Angus, 2000). This means that the DLPFC is involved in top-down attentional control and working memory components (see Banich, 2009; Katsuki and Costantinidis, 2012 for reviews). Indeed, ERPs evidence shows that the DLPFC (electrodes sites F3 and F4) is the neural source for the biasing signal that prioritizes attentional selection of relevant information over irrelevant one (Liesefeld et al., 2014). Stimulation of the DLPFC with transcranial direct current stimulation (tDCS) improves performance on working memory tasks (e.g., Boggio et al., 2006, 2009) and tDCS over the left DLPFC improves performance at a Stenberg task, when participants had to distinguish between distractors and word-items from the memory set. This evidence is taken to indicate that anodal DLPFC stimulation primes the relationship between stimuli and their behavioral relevance (Gladwin et al., 2012). Similarly, anodal tDCS over the right DLPFC improves spatial working memory span at a Corsi tapping task (Wu et al., 2014). A recent meta-analysis that analyzed 12 tDCS studies of the N-back task, which is considered to be a valid index for working memory, revealed that anodal stimulation of the DLPFC improved reaction times at the task but not accuracy (Brunoni and Vanderhasselt, 2014). In addition, it has been found that anodal tDCS to the left DLPFC is associated with an enhanced working memory performance both in depressed patients and control subjects (Wolkenstein and Plewnia, 2013). The researchers used a delayed response working memory task with pictures of varying content (emotional vs. neutral) presented during the delay period. However, for control (healthy) subjects, emotional valence was not affected by stimulation. Another indication to the role of the left DLPFC in control processes was reported by Peña-Gómez et al. (2011) who found that anodal, but not cathodal, tDCS over the left DLPFC reduced the perceived degree of emotional valence for negative stimuli. The interpretation was that this reduction was possibly due to an enhancement of cognitive control of emotional expression. In contrast, Nitsche et al. (2012) found that anodal tDCS of the prefrontal cortex improved emotion processing in healthy subjects, but did not influence subjective emotional state. Notwithstanding this evidence, to what extent the activity of the DLPFC is crucial in biasing attentional selection toward task-relevant information and away from emotional distractors is not yet clear and any causal links between the activity of the DLPFC and selective attention might be best explored via brain stimulation. To the best of our knowledge, there are no previous studies that have investigated the effects of altering DLPFC activity via tDCS on working memory and visual selective attention with emotional distractors.

tDCS is a non invasive brain stimulation technique involving the application of a mild electrical stimulation to the scalp. Typically, for the motor cortex, anodal stimulation is associated with an increase in cortical excitability, whereas cathodal stimulation is associated with a decrease in excitability (Stagg and Nitsche, 2011). Based on these findings, tDCS effects of enhancing anodal and inhibiting cathodal patterns were expected also in the cognitive domain. Although, there is much evidence supporting the facilitative effects of the anode (Hsu et al., 2011; Floel et al., 2008; Boggio et al., 2007; Fregni et al., 2005), the cathodal effects are less consistently documented in the cognitive domain (Jacobson et al., 2011). While there is some support for the expected inhibitory effects of cathodal stimulation (Hsu et al., 2011; Ladeira et al., 2011), there are some studies that have reported a null effect (Fregni et al., 2005) or even an opposite one (Dockery et al., 2009; Antal et al., 2004). We reasoned that, by potentiating the activity of the DLPFC, involved in working memory and selective attention, we may enhance the biasing signal to prioritize target over distractor processing, thus improving visual selective attention. This should result in reduced distractors interference when anodal tDCS is applied over the left DLPFC. With cathodal stimulation, we predicted impaired selective attention.

2. Method

2.1. Experimental design

We used a $3 \times 2 \times 2 \times 2$ mixed-factorial experimental design where tDCS was the between-subjects factor (3 groups: Anodal, Cathodal and Sham), WM load (2: Low, High), Distractor-Face (2: Angry, Happy), and Target-Valence (2: Negative, Positive) were varied within-subject.

2.2. Participants

A total of 43 (33 females, 10 males), healthy young participants completed the study and they were randomly assigned to 1 of 3 groups. There were 15 participants in the Anodal group (12 females, 3 males; mean age 24.6 years, SD=4.1), 14 participants in the Cathodal group (10 females, 4 males; mean age 21.4 years, SD=1.3), and 14 participants in the Sham group (11 females, 3 males; mean age 21.5 years, SD=2.4).

All participants completed a brief questionnaire and fulfilled the following inclusion criteria: healthy, with normal/corrected to normal vision, native Italian speakers. The exclusion criteria were: having suffered – or first degree relative suffering – from an epileptic seizure, having suffered or being diagnosed with neurological or psychotic disorders, having suffered head injuries or trauma, having head metallic implants or metal fragments, using psychoactive medications, being pregnant, having a sensitive skin. All participants gave their written informed consent, which was obtained according to the Declaration of Helsinki (1991). The