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Research Report

# Oppositional transcranial direct current stimulation (tDCS) of parietal substrates of attention during encoding modulates episodic memory

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ABSTRACT

Effective learning requires that attentional resources be focused on target information and withheld from irrelevant events in the learner's surroundings. This requires engagement of the brain substrates of selective attention and the concurrent disengagement of brain substrates of orienting toward changes in the environment. In the present study, we attempted to modulate activation of cortical substrates of attention during learning by physiological intervention, using transcranial direct current stimulation (tDCS). To effect adversarial modulation, we applied anodal stimulation directed toward left intraparietal sulcus/superior parietal cortex (IPS/SPL; a substrate of selective attention) and cathodal stimulation directed toward right inferior parietal cortex (IPL; a substrate of orienting). Such stimulation during study of verbal materials led to superior subsequent recognition memory relative to the opposite polarity of stimulation. To our knowledge, this is the first application of direct current stimulation to parietal regions implicated in different forms of attention in an oppositional manner in order to modulate learning in a verbal recognition memory task. Additionally, these results may have practical implications for the development of interventions to benefit persons with various types of attentional deficits.



## 1. Introduction

Allocation of attention to specific aspects of our experience appears to be an important factor in determining whether resilient mnemonic representations of those aspects will be formed (Chun and Turk-Browne, 2007; Craik, 2001). Unattended percepts are far less likely to be remembered than attended information, and under certain circumstances may be totally absented from explicit memory (Bentin et al., 1995; Fisk and Schneider, 1984; Yi and Chun, 2005). Furthermore, dividing attention between two concurrent tasks during encoding impairs declarative memory for studied information (Anderson and Craik, 1974; Baddeley et al., 1984; Craik et al., 1996; Femandes and Moscovitch, 2000). In contrast, attending to specific features of a perceived object leads to better subsequent memory for that feature (Uncapher and Wagner, 2009). The neuronal basis of this effect seems to be that hippocampal encoding mechanisms are sensitive to attentional modulation of cortical activity (Uncapher and Rugg, 2009).

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Attention is not a single entity. In recent years, compelling evidence has accumulated for the existence of several attention systems, with separable brain substrates, functions, and even different key neurotransmitters (Fan and Posner, 2008; Raz, 2004; Tsal et al., 2005). The ventral attentional network that supports orienting, including the temporo-parietal junction (TPJ), inferior parietal lobe, and ventral prefrontal cortex, appears to be primarily concerned with detecting change in the environment (Behrmann et al., 2004; Corbetta and Shulman, 2002; Corbetta et al., 2008). Damage to this system, especially right hemisphere lesions, yields hemi-neglect and extinction deficits, reflecting loss of awareness of the appearance of perceptual objects. In contrast, the dorsal attentional network, including superior parietal cortex and the frontal eye fields, appears to support top-down focus of attention on selected spatial, object, or feature characteristics that are chosen for enhanced processing (Corbetta and Shulman, 2002; Corbetta et al., 2008).

Under ecological conditions, our ongoing sensory experience represents a dynamic interchange between the latter two attentional systems — the ventral network pulling in the direction of orienting toward change or salience of the overall environment, and the dorsal system directing our limited resources toward specific pre-selected goal-relevant information (Corbetta and Shulman, 2002). The effects of activation of the ventral and dorsal systems on encoding have been highlighted in a recent meta-analysis of functional neuroimaging studies of parietal cortex using the subsequent memory paradigm (Uncapher and Wagner, 2009). The authors show that the vast majority of positive subsequent memory effects are observed in dorsal parietal areas associated with selective attention, while all negative subsequent memory effects localize to ventral parietal areas associated with orienting, including TPJ and angular gyrus (Uncapher and Wagner, 2009). The competition between these two systems is mediated by the executive attention system. When executive function is impaired, as occurs in diverse situations including ADHD, schizophrenia, and frontal lobe damage, attentional allocation is sub-optimal, and ongoing cognitive performance is impaired (Alvarez and Emory, 2006; Barkley, 1997; Velligan and Bow-Thomas, 1999). Currently, pharmacological interventions such as methylphenidate (O'Driscoll et al., 2005) are the methods of choice for assisting people with executive deficits (as well as providing controversial enhancement of attentional focus of healthy individuals). Might other effective methods exist for the modulation of attention in favor of the selective processes that support learning and success in other cognitive tasks?

We hypothesized that one such possible method might be the electrical stimulation of cortical areas supporting the relevant attentional systems. Transcranial direct current stimulation (tDCS) is a non-invasive brain stimulation technique which utilizes persistent direct current injection into the brain. Current is passed between a positively charged anode and a negatively charged cathode. Because flow of current is directional, anodal and cathodal stimulation may have different effects on brain activity. In a pioneer study, Nitsche and Paulus (2000) found that anodal stimulation increases human motor cortex excitability, while cathodal stimulation decreases it, both during stimulation and for a few minutes thereafter. In the wake of that spearhead study, tDCS effects on cognitive functions have been broadly investigated. Most studies found the anodal facilitation effect reported by Nitsche and Paulus (2000): Flöel et al. (2008); Iyer et al. (2005); Kincses et al. (2004); Sparing et al. (2008); and Stone and Tesche (2009). Some of them also reported the cathodal inhibition effect (Berryhill et al., 2010; Knoch et al., 2008; Loui et al., 2010, but see Flöel et al., 2008; Iyer et al., 2005; Priori et al., 2008, who did not find inhibitory cathodal effect).

Application of anodal tDCS has been shown to be effective in improving a number of types of learning. Flöel et al. (2008) applied tDCS over the posterior part of the left peri-sylvian area and found an improvement in associative language learning, Kincses et al. (2004) applied tDCS over the prefrontal cortex and found an improvement in probabilistic classification learning, and Vries et al. (2010) applied tDCS over Broca's region and found an improvement in artificial grammar implicit learning. The effects of tDCS have also been reported for motor learning. For example, Antal et al. (2004) applied tDCS over visual areas and found an improvement in visuo-motor learning, and Nitsche et al. (2003) applied tDCS over primary motor cortex and found an improvement in implicit motor learning. Other cognitive functions can be improved by tDCS as well. Iyer et al. (2005) applied tDCS over left prefrontal cortex and found an improvement in verbal fluency, and Ross et al. (2010) applied tDCS over right anterior temporal lobe and found an improvement in person naming. Notably, it has recently been demonstrated that repeated application of tDCS in the context of cognitive processes may lead to long-lasting beneficial modulation (Cohen-Kadosh et al., 2010).

One particular aspect of tDCS is especially intriguing in view of its possible relation to the dynamic competition between orienting and selective attentional systems postulated above. As noted, it is sometimes found that while anodal stimulation improves cognitive function dependent on underlying cortex, cathodal stimulation may impair such processes (Nitsche and Paulus, 2000). Accordingly, in the current study we engaged in what might be termed 'adversarial modulation': we conducted simultaneous anodal stimulation of left intraparietal sulcus/superior parietal lobe (IPS/SPL; a substrate of selective attention) and cathodal stimulation of right inferior parietal lobe (IPL; a substrate of orienting). We thus attempted to modulate attention during learning in favor of selection processes, in the hope of benefitting subsequent episodic memory for that information. The choice of right IPL as the primary locus of attentional orienting was specific, supported by a host of lesion and functional imaging studies that attest to a much stronger role in orienting of right hemisphere than left hemisphere (Corbetta et al., 2008; Downar et al., 2000). However, IPS/SPL involvement in selective attention is more bi-laterally distributed (Corbetta et al., 2008). Because the effects of tDCS are not very spatially precise, we chose to stimulate left IPS/SPL in order to improve the separation between the two loci of stimulation.

Based on the above literature, we hypothesized that participants undergoing tDCS in the Cathodal R-IPL/Anodal L-IPS/SPL condition during encoding of verbal material would subsequently demonstrate better recognition than in the opposite condition of stimulation. Furthermore, we predicted that recognized stimuli would be more vividly remembered as a