Non-invasive brain stimulation targeting the right fusiform gyrus selectively increases working memory for faces

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Abstract
The human extrastriate cortex contains a region critically involved in face detection and memory, the right fusiform gyrus. The present study evaluated whether transcranial direct current stimulation (tDCS) targeting this anatomical region would selectively influence memory for faces versus non-face objects (houses). Anodal tDCS targeted the right fusiform gyrus (Brodmann’s Area 37), with the anode at electrode site PO10, and cathode at FP2. Two stimulation conditions were compared in a repeated-measures design: 0.5 mA versus 1.5 mA intensity; a separate control group received no stimulation. Participants completed a working memory task for face and house stimuli, varying in memory load from 1 to 4 items. Individual differences measures assessed trait-based differences in facial recognition skills. Results showed 1.5 mA intensity stimulation (versus 0.5 mA and control) increased performance at high memory loads, but only with faces. Lower overall working memory capacity predicted a positive impact of tDCS. Results provide support for the notion of functional specialization of the right fusiform regions for maintaining face (but not non-face object) stimuli in working memory, and further suggest that low intensity electrical stimulation of this region may enhance demanding face working memory performance particularly in those with relatively poor baseline working memory skills.

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1. Introduction
The ability to detect and remember faces is critical to human social functioning, allowing us to know when people are present, recognize a familiar face, and identify known individuals (Kanwisher & Yovel, 2006). These processes involve a network of interrelated brain regions including at least the inferior occipital gyrus, superior temporal sulcus, and lateral fusiform gyrus (Haxby, Hoffman, & Gobbini, 2002). The most consistently implicated region in this network is the right fusiform gyrus, a portion of which has been termed the “fusiform face area” (FFA) by Kanwisher and colleagues (Kanwisher, McDermott, & Chun, 1997). Though subject to debate (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Kanwisher & Yovel, 2006) this region is thought to serve as a specialized module for face perception, responding maximally to the perception of face stimuli relative to non-face objects such as houses (Haxby et al., 1999), cars (Grill-Spector, Knouf, & Kanwisher, 2004), or flowers (McCarthy, Puce, Gore, & Allison, 1997).

One popular method for examining the specialized ability for individuals to process and maintain faces is to engage them in a working memory task with varying load (e.g., maintaining 1–4 faces), and varying stimulus domains (e.g., maintaining faces versus houses) (Druzgal & D’Esposito, 2001, 2003; Gazzaley, Rissman, & D’Esposito, 2004; Ranganath, DeGutis, & D’Esposito, 2004). Overall, research has demonstrated parametrically increasing right fusiform gyrus activity (with fMRI) as working memory set size increases from 1 to 4 faces (Druzgal & D’Esposito, 2003), and much greater responses in this region to faces than houses (Yovel & Kanwisher, 2006). Thus, the right fusiform gyrus appears to be involved in the processing and maintenance of faces during a working memory task. Transcranial direct current stimulation (tDCS) provides a unique opportunity to explore causal relationships between right fusiform gyrus activity and working memory for faces, by selectively modulating brain activity in this region and measuring the impact the processing and maintenance of faces versus non-face objects.

Transcranial direct current stimulation (tDCS) involves non-invasively applying low intensity electrical current to brain regions

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by way of electrodes positioned on the surface of the scalp (Brunoni et al., 2012). In most studies, between 1.0 and 2.0 mA intensity direct current (DC) is administered by positioning electrodes in a manner intended to target brain regions of interest with anodal or cathodal polarity stimulation (Jacobson, Koslowsky, & Lavidor, 2012). A unidirectional flow of charge emanates from a single anode, propagates through cortical tissue, and returns via a single cathode; as anodal current propagates through the cortex, it produces neuronal membrane depolarization (Purpura & McMurtry, 1965), increases neuronal firing rates (Nitsche & Paulus, 2000, 2001), and increases functional brain connectivity in task-related networks (Peña-Gómez et al., 2012). Though tDCS has been used extensively in the behavioral, cognitive, clinical, and affective sciences literature (Jacobson et al., 2012; Price, McAdams, Grossman, & Hamilton, 2015; Shiozawa et al., 2014), very few studies have examined its influence on face processing or memory. In two of them, anodal tDCS was applied over the dorsolateral prefrontal cortex (Lafontaine, Theoret, Gosselin, & Lippe, 2013) or occipito-temporal cortex (which includes the FFA, the occipital face area (OFA), and superior temporal sulcus (Yang et al., 2014)), and outcomes were measured via event-related potentials (ERPs). In the first experiment, the authors found enhanced N170 repetition suppression, indicating faster face recognition with right hemisphere anodal stimulation. In the second experiment, the authors found anodal or cathodal stimulation to influence the N170 waveform during a face orientation task, an effect maximal over the right hemisphere. In a more recent study, Renzi and colleagues (Renzi et al., 2015) used anodal OFA stimulation and found reduced performance on a task involving the detection and discrimination of faces and non-face objects; right fusiform gyrus stimulation was not examined (see also (Barbieri, Negrini, Nitsche, & Rivolta, 2015)). Thus, existing research regarding putative tDCS influences on face processing and memory is equivocal, using varied stimulation targets and outcome measures, and finding mixed results.

Though tDCS has not yet been applied in the context of working memory for face stimuli, or for specifically targeting the right fusiform gyrus, an extensive literature examines the impact of tDCS on working memory task performance. Indeed one of the most reliable results in the tDCS literature is an enhancement of verbal n-back task performance with tDCS targeting the left dorsolateral prefrontal cortex (DLPFC) (Berrylhill, Peterson, Jones, & Stephens, 2014; Brunoni & Vanderhasselt, 2014). For instance, Ohn and colleagues (Ohn et al., 2015) used anodal stimulation and found lower performance on the task, indicating a decreased working memory performance (Martin, Liu, Alonzo, Martinez-Aran, & Amsterdam, 2014). For instance, recent research shows that tDCS of right medial temporal lobe regions only improves navigation performance for individuals with relatively poor spatial sense of direction (Brunyé, Holmes, et al., 2014), and tDCS of DLPFC only improved arithmetic performance for individuals with high mathematics anxiety (Sarkar, Dowker, & Cohen Kadosh, 2014). It is unknown how individual differences in working memory ability may modulate the influence of tDCS on face working memory task performance. Finally, we incorporate a mixed experimental design that controls for perceived cutaneous sensation and reduces the potential for experimental demand characteristics influencing arousal and task performance (Brunyé, Cantelon, Holmes, Taylor, & Mahoney, 2014).

While performing the working memory task (i.e., online), participants received either 0.5 mA or 1.5 mA active anodal tDCS, in a repeated-measures (crossover) design. We chose this design based on a review of recent literature. First, there is compelling evidence that online stimulation influences cognitive task performance either similarly to (Axelrod, Rees, Lavidor, Bar, & Corballis, 2015; Wirth et al., 2011), or more than (Martin, Liu, Alonso, & Loi, 2014), offline tDCS. Second, an anodal-excitatory effect is reliably obtained in cognitive literature (Jacobson et al., 2012), and we chose 1.5 mA because it reliably influences cortical excitability (Dymond, Coger, & Serafetinides, 1975) and cognitive task performance (Ditye, Jacobson, Walsh, & Lavidor, 2012; Javadi, Cheng, & Walsh, 2012); furthermore, the influence of tDCS does not necessarily scale with increased intensity to 2.0 mA (Batsikadze, Moliadze, Paulus, Kuo, & Nitsche, 2013). Finally, we chose to use a low intensity stimulation control condition (0.5 mA) rather than sham due to recent research demonstrating cutaneous sensation differences in sham versus active stimulation conditions, and unintentional participant awareness of condition-based differences (Brunyé, Cantelon, et al., 2014). A 0.5 mA low intensity control condition reduces otherwise large differences in perceived sensation between active and sham conditions, without influencing cognitive task performance relative to sham (Brunyé, Cantelon, et al., 2014; Nitsche & Paulus, 2000). In fact, to our knowledge only one sleep-related study suggests an influence of 0.5 mA stimulation on any cognitive, behavioral, or physiological measures (Marshall, Mölle, Hallensleid, & Born, 2004). To ensure no discernable influence of 0.5 mA stimulation on task performance, we also collected control data from a separate group of participants who received no stimulation.

We expect that tDCS targeting the right fusiform gyrus will influence performance on the working memory task; given the putative face-selective role of this region, we also expected this effect to be specific to faces, and not extend to houses. This effect may also emerge only at relatively high memory set sizes, given possible ceiling performance at low memory loads (Druzelg & &
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