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TRANSCRANIAL ALTERNATING CURRENT STIMULATION TO THE INFERIOR PARIETAL LOBE DECREASES MU SUPPRESSION TO EGOCENTRIC, BUT NOT ALLOCENTRIC HAND MOVEMENTS

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Abstract—Egocentric vs. allocentric perspective during observation of hand movements has been related to self-other differentiation such that movements observed from an egocentric viewpoint have been considered as self-related while movements observed from an allocentric viewpoint have been considered as belonging to someone else. Correlational studies have generally found that egocentric perspective induces greater neurophysiological responses and larger behavioral effects compared to an allocentric perspective. However, recent studies question previous findings by reporting greater (μ) suppression and greater transcranial magnetic stimulation (TMS)-induced motor-evoked potentials (MEPs) during observation of allocentric compared to egocentric movements. Furthermore, self-other differentiation has been generally related to activity within the inferior parietal lobe (IPL), but direct evidence for a causal and functional role of IPL in self-other differentiation is lacking. The current study was therefore designed to investigate the influence that IPL exerts on self-other differentiation. To this aim, we measured the impact of individually adjusted alpha-tuned transcranial alternating current stimulation (tACS) applied over IPL on μ-suppression during hands movement observation from an egocentric and allocentric perspective. Electroencephalography (EEG) was recorded during movement observation before and immediately after tACS. Results demonstrated that tACS decreased μ-reactivity over sensorimotor (but not visual) regions for egocentric (but not allocentric) movement observation providing direct evidence for a causal involvement of IPL in the observation of self- but not other-related hand movement.

Key words: EEG, tACS, self-other differentiation, perspectives, IPL.

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Abbreviations: ANCOVA, analysis of covariance; EEG, electroencephalography; IAF, individual alpha frequency; IFG, inferior frontal gyrus; IPL, inferior parietal lobe; MEPs, motor-evoked potentials; tACS, transcranial alternating current stimulation; TMS, transcranial magnetic stimulation.

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INTRODUCTION

Neuroimaging studies investigating the neural basis of self-recognition and self-other differentiation have consistently pointed to the involvement of the inferior parietal lobule (IPL) and the inferior frontal gyrus (IFG) (Ruby and Decety, 2001; Chaminade and Decety, 2002; Decety et al., 2002; Farrer and Frith, 2002; Farrer et al., 2003; Uddin et al., 2006; Kaplan et al., 2008). However, neuropsychological literature suggests that the pivotal role is rather played by the IPL. For example, individuals with schizophrenia experiencing the passivity phenomenon (the belief that one's thoughts or actions are being controlled by someone else) demonstrate IPL hyperactivity (Spence et al., 1997), while lesions to the IPL have been associated with impaired ability to imitate (Goldenberg, 1995; Goldenberg and Karnath, 2006) and with disruption of body schema and corporeal awareness (Berlucchi and Aglioti, 1997). Additionally, disruptive brain stimulation to areas within the IPL (right angular gyrus and temporo-parietal junction) results in the out-of-body phenomenon (Blanke et al., 2002; Blanke et al., 2005) and impaired performance on a self-other discrimination task (Uddin et al., 2006).

Self-other relations have frequently been studied by means of perspectives or viewpoints (e.g. Vogt et al., 2003; David et al., 2006; Jackson et al., 2006; Frenkel-Toledo et al., 2013). Typically, these studies reason that the observation of a movement presented as if the observer is conducting the movement (egocentric) is more self-related than the observation of the movement observed as if facing another agent conducting the movement (allocentric). Hence the neurophysiological response during the observation of egocentric movements is a correlate of self-related actions, while the response to an allocentric movement is related to actions conducted by others (e.g. Gallagher and Meltzoff, 1996; Decety and Chaminade, 2003; Meltzoff and Decety, 2003). Typically, correlational studies investigating perspectives as an indication of self-other differentiation have shown that egocentric stimuli induce greater neurophysiological and behavioral responses compared to allocentric stimuli. For example, it has been observed: greater cortical activity in the sensory-motor cortex (Jackson et al., 2006), greater visuomotor interference (Vogt et al., 2003; Bortoletto et al., 2013) and larger motor-evoked potentials (MEPs) as induced by transcranial magnetic stimulation (TMS) during the observation of egocentric movements (Maeda et al., 2002). However, these correlational reports have not always been consistent; Alaerts and colleagues (2009) reported that MEPs are not necessarily larger for egocentric movements per se; rather, MEPs are larger for an egocentric right hand and for an allocentric left hand. No difference in MEPs between perspectives has also been reported by Burgess and colleagues (2013). Furthermore, greater suppression in the electroencephalography (EEG) μ-rhythm (Frenkel-Toledo et al., 2013) and larger TMS-induced MEPs (Fitzgibbon et al., 2014) has been reported during observation of allocentric hand movements compared to egocentric. In addition to these inconsistencies, causal assessment of the neurophysiological underpinning of self-other differentiation for egocentric vs. allocentric perspective is currently lacking.

In the present study, we compared EEG μ-suppression during observation of moving hands from both egocentric and allocentric perspectives subsequent to transcranial alternating current stimulation (tACS) to the IPL in order to investigate the functional relationship between μ-suppression and self-other differentiation. The rationale for this approach is that tACS interferes with ongoing oscillations non-invasively (Antal and Paulus, 2013) and has been shown to affect behavioral performance corresponding to the neuronal network or specific oscillation targeted (e.g. Miniussi et al., 2012; Cecere et al., 2015). The μ-rhythm is generated in the sensorimotor cortex and it is known that suppression in μ reflects activation of motor-related processes (Hari et al., 1998; Rossi et al., 2002; Cheyne et al., 2003). μ-suppression during observation of movement correlates with cortical activity in the IPL and IFG (e.g. Arnstein et al., 2011; Braadbaart et al., 2013; Babiloni et al., 2016), and therefore, tACS to the IPL enables a causal investigation of μ-rhythms during observation of egocentric and allocentric perspectives. Given that previous work has demonstrated reduced μ-suppression subsequent to stimulation to the IPL and IFG (Keuken et al., 2011; Puzzo et al., 2013), we predicted offline tACS over IPL to have a comparable impact. Two alternative hypotheses were made: (1) if IPL is specifically attuned to self-related stimuli (e.g. Uddin et al., 2006; Kaplan et al., 2008) then we expect tACS to selectively reduce μ-suppression during observation of egocentric (but not allocentric) movements; (2) if IPL is reactive to both self- and other-related stimuli alike (e.g. Spence et al., 1997; Goldenberg and Karnath, 2006) then we predict reduced μ-suppression following IPL stimulation regardless of perspective.

EXPERIMENTAL PROCEDURES

Participant selection

In total, 21 participants (10 females) were screened in relation to their suitability for tACS using the TMS safety screening questionnaire (TASS: Keel et al., 2001) and reported not suffering any known mental or neuropsychiatric conditions. Participants' age ranged between 18 and 35 (mean age = 23.71 SD = 4.69) and were randomly allocated to either active tACS or sham stimulation. All participants were right handed, signed the informed consent form, and were paid GB £10 for their time. The local ethics committee (Department of Psychology, University of Essex) granted ethical approval.

Stimuli

Participants observed video presentations of a female actor opening and closing her left or right hand (one at the time) at a rate of 1 Hz. These videos were based on stimuli used by several others (e.g. Oberman et al., 2005; Bernier et al., 2007; Raymaekers et al., 2009; Puzzo et al., 2011), but adapted to include both left and right hand. Two hands were included rather than one in light of Alaerts and colleagues (2009) finding that the effect of perspective may depend on the observed hand (left vs. right). The hands were visibly Caucasian skin colored, presented against a black background, and shown from the egocentric and allocentric perspective. Images of these perspectives are presented in Fig. 1 below.

Hand movement sequences were constructed using Motion 5 (Apple Inc. version 5.1.2) video editing program. Videos included 5 sequences of various combinations of the left and right hand opening and closing. Each movement lasted 1 s $\times$ 5 movements = 5 s.

A schematic example of a hand movement sequence is presented in Fig. 2 below.

Procedure

Participants completed an informed consent form and were fitted with electrodes to record eye movements and reference signal. Skin surface underlying electrodes for recording eye movements and reference signal were lightly abraded to reduce impedance of electrode-to-skin contact. Next, a 64-channel quick-cap (Compumedics, Neuroscan) was fitted for the EEG. Resting EEG was recorded for two minutes with eyes-open, before completing Croft and Barry's (2000) eye-movement calibration protocol. Subsequently, individual alpha frequency (IAF) was defined based on individual peaks in alpha. In order to establish IAF, the resting period was epoched to 1024 data points and subsequently the time domain data were transferred into power values in the frequency domain using fast Fourier transformation (FFT). IAF was defined based on each individual's most commonly occurring peak frequency between 8 and 12 Hz over parietal and occipital electrodes (P3, P1, Pz, P2, P4, O1, Oz, O2). The occipital and parietal sites were chosen based on the rationale that alpha oscillations are strongest over these areas, and due to numerous previous studies also using these electrodes to define IAF (e.g. Klimesch, 1999; Puzzo et al., 2013; Grandy et al.,

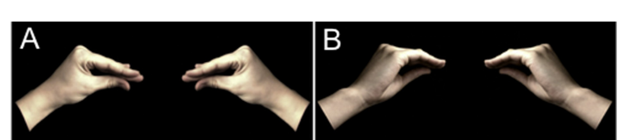

Fig. 1. Graphical representation of hands from egocentric (A) and allocentric (B) perspective.