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Research report

Effects of repetitive transcranial magnetic stimulation (rTMS) on attribution of movement to ambiguous stimuli and EEG mu suppression

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ABSTRACT

Recent research suggests that attributing human movement to ambiguous and static Rorschach stimuli (M responses) is associated with EEG mu suppression, and that disrupting the left inferior gyrus (LIFG; a putative area implicated in mirroring activity) decreases the tendency to see human movement when exposed to the Rorschach ambiguous stimuli. The current study aimed to test whether disrupting the LIFG via repetitive transcranial stimulation (rTMS) would decrease both the number of human movement attributions and EEG mu suppression. Each participant was exposed to the Rorschach stimuli twice, i.e., during a baseline condition (without rTMS but with EEG recording) and soon after rTMS (TMS condition with EEG recording). Experimental group ($N = 15$) was stimulated over the LIFG, while the control group ($N = 13$) was stimulated over the Vertex. As expected, disrupting the LIFG but not Vertex, decreased the number of M attributions provided by the participants exposed to the Rorschach stimuli, with a significant interaction effect. Unexpectedly, however, rTMS did not significantly influence EEG mu suppression.

1. Introduction

Mirror neurons are a particular class of cortical cells, originally discovered in area F5 of the monkey premotor cortex, which fire both when the monkey performs an action and when it observes another individual performing the same action (di Pellegrino et al., 1992; Gallese et al., 1996; Rizzolatti et al., 1996; Cook et al., 2014). A similar neurological network likely exists in humans, although there is some debate as to where the mirror neurons are located (Molenberghs et al., 2009, 2012). In general, the evidence supporting the presence of a human mirror neuron system (MNS) is mainly indirect (Dinstein et al., 2007;Hickok, 2009;Lingnau et al., 2009;Rizzolatti and Craighero, 2004). Functionally, the MNS is hypothesized to represent the neurological substrate of a mirror-matching mechanism that allows individuals to quickly and pre-rationally understand the actions performed by others (for a review, see Pineda, 2005; Rizzolatti and Craighero, 2004; Gallese et al., 2011). Previous neurophysiological experiments have shown that when individuals observe an action performed by another agent their motor cortex becomes active, in the absence of any visible motor activity, as a function of learning (Heyes, 2011). In fact, studies by Fadiga et al. (1995), and Strafella and Paus (2000)demonstrated that observation of complex actions, such as grasping and writing, provided changes in corticospinal excitability. Furthermore, when observing other acting individuals and their expressive and intense meaning, an embodied interpersonal link automatically and implicitly occurs (Gallese, 2009). Therefore, some researchers (Gallese et al., 2004; Rizzolatti and Craighero, 2004; Oberman et al., 2005; Iacoboni, 2009; Rizzolatti et al., 2001) have suggested that the MNS may provide the neurophysiological substrate for higher cognitive human functions such as action understanding, perspective taking, and empathy.

Although several studies on MNS properties investigated the specificity of the changes in motor corticospinal excitability during the observation of an action by using video clips with overt actions, the motor simulation process can likewise be induced by the observation of static images of actions, e.g., in works of art (Proverbio et al., 2009; Sbriscia-Fioretti et al., 2013; Yao et al., 2007). An event related potential (ERP) study reported a direct relation between the observation of static images and the activation of the cortical motor system (Proverbio et al., 2009). More specifically, during the presentation of pictures representing human actions with different degrees of dynamism, a higher motor cortical activation occurred for observation of pictures with more

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dynamic actions than for observation of pictures representing less dynamic actions. Along the same lines, an EEG study (Yao et al., 2007) evaluated the extent to which mirroring activity occurred during the observation of modern abstract artwork by Lucio Fontana, using event-related sensory-motor alpha desynchronization (ERD) as index of motor simulation. Consistent with Proverbio et al.'s (2009) findings, when compared to the observation of the other type of images, the observation of Fontana artworks was associated with a significantly stronger ERD.

Furthermore, by using single and paired-pulse TMS, Battaglia et al. (2011) reported that (a) the observation of an action in an artistic representation activated the corticomotor system and (b) the mental rehearsal of observation of a painting induced a similar degree of corticomotor activation. Likewise, a recent study on implied motion (Concerto et al., 2015) showed that observation of a static image pulled out from a video depicting movement increased Motor Evoked Potentials (MEP) size and decreased the short-interval intracortical inhibition (SICI), which suggests that observation of highly dynamic images may implicate an overall facilitation in primary motor cortex. Also in line with these findings, Sbriscia-Fioretti et al. (2013) reported that activation of sensorimotor cortical circuits during the exposure to the static works art by Franz Kline was related to an increased ERP mean amplitude. These results were interpreted by the authors as indicative of an embodied simulation of the artist's actions in the production of the artwork.

1.1. Mu suppression, ambiguous Rorschach stimuli, and movement attributions

Based on these previous studies indicating that the MNS might be engaged by exposure to static artworks or designs, it has been recently suggested that exposure to ambiguous Rorschach inkblots might be sufficient to activate MNS activity, even in the absence of evident, visual indicators of movement, as far as the observer experiences a "feeling of movement." More specifically, using EEG mu suppression as a proxy biomarker for mirror neuron activation, Giromini et al. (2010), Pineda et al. (2011), and Porcelli et al. (2013) showed that EEG mu suppression occurred concomitantly with the participants perceiving/feeling human movement while exposed to ambiguous, Rorschach inkblot stimuli. Interestingly, the presumed embodied simulation produced by the Rorschach cards seemed to occur very early, suggesting that the "feeling of movement" was induced at a preconscious level, before the participants had time to formulate their Rorschach attributions, i.e., prior to reporting that they saw human movement or M responses in the inkblot designs (Pineda et al., 2011). The authors interpreted these findings as indicative of the existence of a link between EEG mu suppression, embodied simulation, and attribution of human movement to ambiguous stimuli.

According to various Rorschach experts (e.g.; Klopfer and Kelley, 1942; Piotrowski, 1957; Rorschach, 1921), seeing human movement in the ambiguous stimuli (e.g., "this inkblot reminds me of two people playing paddy-cake" or "here I see a person dancing flamenco"), would rely on an ongoing identification mechanism. Other Rorschach determinants (i.e., form, color, and shading) may reflect distinct perceptual features recognized directly from the actual characteristics of the inkblots, while human movement responses (or M responses) are added to the stimulus field, presumably as a result of imagined activity (Exner, 2003). Several studies support the validity of the M responses as linked to an identification mechanism (e.g., Meyer et al., 2002; Viglione et al., 2012; Mihura et al., 2012; Giromini et al., 2016). The inter-rater reliability of the M response also is excellent (Cicchetti, 1994), indicating that two independent raters, blind to each other's evaluation, code for the presence or absence of M responses reliably, with intraclass correlation coefficients (ICC) ranging from 0.96 to 0.97 (Meyer et al., 2002; Mihura et al., 2012; Pignolo et al., 2017; Viglione and Taylor, 2003; Viglione et al., 2012).

Important to our goal, about two years ago, Ando' et al. (2015) reported that disrupting the left inferior frontal gyrus (LIFG), a putative area of the mirror neuron system (Keuken et al., 2011; Pobric and Hamilton, 2006), via repetitive Transcranial Magnetic Stimulation (rTMS) decreased significantly the number of human movement attributions (or M responses) to the Rorschach ambiguous stimuli. According to the authors, this finding would be in line with Giromini et al.'s (2010) findings that the LIFG plays a key role in MNS functioning. Also in line with the hypothesis that the LIFG and MNS are involved in the attribution of M responses to the ambiguous Rorschach stimuli, Giromini et al. (2017a,b) recently reported on an fMRI study, in which M responses were associated with increased activity in a MNS region of interest that included a small portion of the LIFG.

1.2. The current study

Giromini and colleagues (Giromini et al., 2010; Pineda et al., 2011; Porcelli et al., 2013) discussed their EEG findings as supportive of a link between mirroring activity and attribution of human movement to spontaneous Rorschach stimuli (M responses). Ando' et al. (2015) also proposed, based on rTMS results, a relationship between the LIFG, the MNS, and the production of M responses. However, none of these studies demonstrated that disrupting the LIFG would affect *both* the production of M responses to the Rorschach *and* its presumably associated biometric, mu rhythm suppression. Hence, the aforementioned inferences concerning the existence of a link between MNS-related areas (such as the LIFG), mu suppression, and attribution of human movement to ambiguous stimuli, currently remain indirect.

The present study aimed at filling this gap in the literature, by testing the effects of rTMS over LIFG on Rorschach responses and EEG mu suppression. More specifically, we administered a subset of Rorschach inkblot stimuli to a student population twice, i.e., during a baseline condition and soon after rTMS. As for the rTMS condition, the experimental group was stimulated over the LIFG, the control group was stimulated over the Vertex. Compared to Ando' et al.'s (2015) study, our investigation also overcomes a technical limitation, i.e., while the earlier study did not implement a neuronavigation system (p. 138), the current study did.

2. Results

2.1. rTMS effects on human movement responses

As reported in Table 1 and Fig. 1, disrupting the LIFG, but not Vertex, decreased the number of M codes produced by the participants during exposure to the Rorschach stimuli. In fact, a mixed 2 (between-subjects factor, site: LIFG vs. vertex) by 2 (within-subjects factor, condition: baseline vs. rTMS) ANOVA reported a statistically significant interaction effect, [$F\ (1,\ 26) = 24.60$, $p < .001$, *Partial* $\eta^2 = 0.486$]. Importantly, within the control group, the baseline and rTMS (vertex) conditions provided a strikingly similar number of M codes [t (12) = −0.693, $p = .502$, $d = -0.12$]; but, within the experimental group, the number of M codes after rTMS (LIFG) was significantly lower than at the baseline condition [$t\ (14) = 5.77$, $p < .001$, $d = 1.47$].

2.1.1. Additional analyses

Given that the LIFG includes Broca's area (BA 44, corresponding to F7 of the 10–20 EEG system) (Nishitani and Hari, 2000), we