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Exploring associations between gaze patterns and putative human mirror neuron system activity

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The human mirror neuron system (MNS) is hypothesized to be crucial to social cognition. Given that key MNS-input regions such as the superior temporal sulcus are involved in biological motion processing, and mirror neuron activity in monkeys has been shown to vary with visual attention, aberrant MNS function may be partly attributable to atypical visual input. To examine the relationship between gaze pattern and interpersonal motor resonance (IMR; an index of putative MNS activity), healthy right-handed participants aged 18–40 (n = 26) viewed videos of transitive grasping actions or static hands, whilst the left primary motor cortex received transcranial magnetic stimulation. Motor-evoked potentials recorded in contralateral hand muscles were used to determine IMR. Participants also underwent eyetracking analysis to assess gaze patterns whilst viewing the same videos. No relationship was observed between predictive gaze and IMR. However, IMR was positively associated with fixation counts in areas of biological motion in the videos, and negatively associated with object areas. These findings are discussed with reference to visual influences on the MNS, and the possibility that MNS atypicalities might be influenced by visual processes such as aberrant gaze pattern.

Keywords: transcranial magnetic stimulation, mirror neurons, motor resonance, autism, gaze pattern, predictive gaze

Introduction

Discovered serendipitously whilst recording single motor neurons in macaques, mirror neurons are cells that fire both when an action is performed, and when that same action is observed (Di Pellegrino et al., 1992). Homologous neurons and mechanisms have been inferred in humans via a range of techniques, with the inferior parietal lobule (IPL) and the inferior frontal gyrus (IFG) typically implicated. These structures, along with the superior temporal sulcus (STS), are together referred to as the parietofrontal mirror neuron system (MNS; Iacoboni and Mazziotta, 2007). Some assert that the MNS is responsible for, or implicated in, social cognitive processes such as action/goal/intention understanding (Gallese et al., 2013), imitation (Williams et al., 2001), empathy (Iacoboni and Mazziotta, 2007), and theory of mind (Perkins et al., 2010). Others have challenged these claims (Dinstein et al., 2008; Hickok, 2009).

These potential links between the MNS and social cognition have led to hypotheses such as the broken mirror theory of autism spectrum disorder (ASD). This posits that if MNS function is impaired, this might lead to a decreased ability to understand and/or imitate what we observe, which would in turn contribute to the social and mentalising deficits characteristic of ASD.
(Ramachandran and Oberman, 2006). Relevant results in this regard are inconsistent, however. One possible explanation for such inconsistency is that MNS dysfunction may be secondary, influenced by factors such as atypical visual processing. The MNS necessarily receives input from occipital and temporal regions involved in visual processing. It has been suggested that abnormalities of the STS (a region inputting to the MNS and involved in integrating visual biological motion cues), for example, may provide a neural basis for aberrant social cognitive performance (Dakin and Frith, 2005; Hickok, 2013). More generally, MNS activity (both in the immediate and longer term) in the broader population is likely to be influenced by the quality of visual input, which is in turn shaped by factors such as gaze variables and early visual processing.

Two relevant gaze variables in this regard are gaze pattern (the number and duration of fixations in particular areas of a visual scene) and predictive gaze (PG; eye movements that proactively arrive at a visual target before a moving stimulus does). Given that mirror neurons are most active in response to observing transitive actions (Rizzolatti and Craighero, 2004), it could be hypothesized that gaze patterns that attend relatively strongly to the biological motion aspect of a transitive action (rather than the object being acted upon) would be more likely to promote greater MNS activity. Regarding PG, Flanagan and Johansson (2003) found similar PG profiles when participants observed and when they performed the same action. They inferred that observers implement eye motor programs directed by their own motor representations of the performance of that action. This inference has been supported by others and hypothesized to be related to MNS activity (Falck-Ytter et al., 2006; Elnser et al., 2013).

Whilst this proposed influence of such gaze variables on MNS activity may seem straightforward, the relationship has not been empirically examined in humans as far as the authors are aware. One study did explore this relationship in monkeys, however. Maranesi et al. (2013) recorded premotor cortex mirror neuron activity (via microelectrodes) and eye position in macaque monkeys during the observation of grasping actions. Most neurons recorded discharged more strongly when the monkey was looking directly at the action, and discharged earlier and more strongly when the gaze was proactive rather than reactive. The authors therefore concluded that mirror neuron activity was related to gaze behavior.

Direct electrode recordings of mirror neurons are generally not possible in humans. One paradigm used to putatively measure MNS activity employs transcranial magnetic stimulation (TMS) during the observation of transitive actions. TMS is a non-invasive means of stimulating the cortex via pulsed magnetic fields. When applied to the ‘hand region’ of the primary motor cortex, TMS can be used to elicit a motor evoked potential (MEP) in contralateral hand muscle which can be measured by electromyography (EMG). The observation of another’s hand movement during such TMS application results in a facilitated (i.e., increased) MEP (Fadiga et al., 1995; Theoret et al., 2005). In this context, MEPS are regarded as a measure of interpersonal motor resonance (IMR), a concept alluding to the activity of one’s motor/sensorimotor system whilst viewing another’s motor actions (Uithol et al., 2011). IMR is in turn an index of putative MNS activity.

The current study utilized this TMS paradigm to investigate the human mirror neuron response, whilst eye tracking recordings were also taken to investigate aspects of gaze and visual processing during action observation. PG times [(time of hand or object arrival at target) – (time of first fixation on target after the first fixation on arriving hand or object)] and fixations in areas of interests (AOIs) were measured, with the latter focusing on hand movement areas versus object areas. It was hypothesized that IMR would be positively associated with PG times and fixation counts in hand AOIs, and negatively associated with fixation counts in object AOIs.

Materials and Methods

Participants

As per approval conditions of the Alfred Ethics Committee and the Monash University Human Research Ethics Committee, participants were recruited via advertisements distributed throughout the Alfred Hospital and Monash University managed sites. Participants were 36 healthy adults aged 18–40 years (M = 27.6, SD = 6.0, 18 females; Figure 1).

Written informed consent was obtained, and participants were reimbursed $20 for the full study (both TMS and eyetracking) or $10 for the test–retest component (eyetracking only). Participants were without hand contact lenses, and reported having no neurological, psychiatric, or ocular condition or syndrome. Participants were also screened to ensure they met TMS safety criteria (Rossi et al., 2009).

Materials

The Edinburgh Handedness Inventory (EHI) is a 10-item index of a person’s left or right hand dominance in everyday activities, such as writing or using cutlery (Oldfield, 1971). It is the most widely used such measure (Fazio et al., 2011), and possesses strong psychometric properties (McFarland and Anderson, 1980). Scores range from −100 to +100, with scores of +40 or above categorizing the person as right handed.

Procedure

Full Study (TMS and Eyetracking)

Participants in the full study completed the EHI, and forms related to TMS screening criteria and demographic information. TMS and eyetracking components were conducted separately, in a counterbalanced manner (see Figure 1).

TMS component

As done previously (Enticott et al., 2012b), IMR was measured by delivering single TMS pulses to the primary motor cortex of the left hemisphere and recording, via EMG, the MEP of the contralateral first dorsal interosseous (FDI) and abductor digitii minimi (ADM) muscles during the observation of short video clips. Videos displayed either a static right hand (baseline condition), or right handed object-grasping actions. Such transitive actions are understood to promote mirror neuron