Brain Research 1700 (2018) 109–117

Contents lists available at ScienceDirect

Brain Research

journal homepage: www.elsevier.com/locate/bres

Research report

Timing of mirror system activation when inferring the intentions of others

Eleanor J. Cole [a,b,*], Nick E. Barraclough [b]

[a] Department of Psychiatry & Behavioral Sciences, Stanford University, Palo Alto, CA 94305, USA
[b] Department of Psychology, University of York, Heslington, York YO10 5DD, UK

ARTICLE INFO

Article history:
Received 22 March 2018
Received in revised form 11 July 2018
Accepted 12 July 2018

Keywords:
Mirror neuron system
Mentalizing
Intentions
Transcranial magnetic stimulation (TMS)
Autistic traits

ABSTRACT

Neuroimaging studies have shown mirror system (MS) activation when participants infer internal states e.g. emotions, intentions or beliefs (known as 'mentalizing') from others' actions. However, the exact role of the MS in mentalizing tasks is unknown. Dysfunctional MS activation may underlie mentalizing deficits experienced by adults with autism spectrum disorder (ASD). This study investigated the timing of MS activity when inferring intentions in order to delineate between existing models of MS involvement. Single-pulse transcranial magnetic stimulation (TMS) was applied to the primary motor cortex at different time points during the observation of hand actions whilst participants inferred intentions (mentalizing task) and performed a non-mentalizing task. Electromyographic activity in the contralateral hand was used as an indirect measure of MS activity. Greater corticospinal activity was found during the mentalizing task than the non-mentalizing task, but only at the end of observed actions, suggesting late MS involvement in processing intentions. Enhanced corticospinal activity was not related to autistic traits or behavioural performance suggesting the MS has a more automatic role in processing others' intentions, irrespective of mentalizing ability. Our results extend current knowledge of MS activation when mentalizing, allowing initial delineation between different models of MS involvement in mentalizing.

1. Introduction

The mirror system (MS) is a network of brain areas, discovered in monkeys, that contain neurons that are active both when an individual performs an action and when they observe others performing similar actions (di Pellegrino et al., 1992; Rizzolatti et al., 1996). A similar system is thought to exist in the human, and the main components are considered to be the inferior frontal gyrus (IFG) and the inferior parietal lobe (IPL; Rizzolatti and Craighero, 2004; Rizzolatti and Sinigaglia, 2010). It is thought that the human MS plays an important role in interpreting others' actions (Gallese and Goldman, 1998; Rizzolatti and Craighero, 2004). In addition, when action kinematic information is available, it has been proposed that the MS is required in order to infer others' internal states (e.g. emotions, beliefs or intentions; collectively referred to as 'mentalizing'). Indeed, mentalizing tasks that have used stimuli which either include movies of human actions or portray human actions (through sets of still images or point-light displays), have tended to elicit MS activity (Brunet et al., 2000; Bucchioni et al., 2013; Centelles et al., 2011; Ciaramidaro et al., 2014; Enticott et al., 2013; Iacoboni et al., 2004). Although there is evidence that the MS is active when inferring others' internal states from their actions, the exact role of the MS in this task is debated.

There are a number of different theories regarding the involvement of the MS in inferring other's internal states from their actions: 1. The motor simulation theory states that MS activity alone, reflecting simulation of observed actions by the observer's own motor system, is sufficient to derive others' internal states (Rizzolatti and Sinigaglia, 2007); 2. A dual-process hypothesis has been proposed which suggests that internal state information embedded in action kinematics is subconsciously processed in the MS and this information is then passed on to a separate cortical system known as the 'mentalizing system' in order for make active inferences about the person's internal state (de Lange et al., 2008; Keysers and Gazzola, 2007; Spunt and Lieberman, 2012c; Uddin et al., 2007); 3. The 'mirroring-first' model implies that processing action kinematics in the MS is a vital prerequisite for inferring others' internal states but the MS is not involved in processing others' internal states itself (Hamilton and Marsh, 2013; Spunt et al., 2011).

* Corresponding author at: Department of Psychiatry & Behavioral Sciences, Stanford University, Palo Alto, CA 94305, USA.
E-mail address: ejc557@york.ac.uk (E.J. Cole).

https://doi.org/10.1016/j.brainres.2018.07.015
0006-8993/

A strict 'mirroring-first' model cannot account for the evidence which shows that MS activity is modulated by mentalizing (Brunet et al., 2000; Bucchioni et al., 2013; Centelles et al., 2011; Ciaramidaro et al., 2014; Enticott et al., 2013; Iacoboni et al., 2004). However, one possible source of this MS modulation could be feedback from the mentalizing system. The predictive coding theory suggests that when inferring aspects of someone's internal state from their actions, contextual ormation is processed prior to kinematic processing (Csibra and Gergely, 2007; Kilner et al., 2007). This contextual information is used to infer the internal state of the individual and therefore predict the outcome of upcoming actions. These predictions are then signalled to the MS and incoming sensory information is compared to predictions made. Discrepancies between predictions made and actual action outcomes are signalled in the form of 'prediction errors' and these are used to update future predictions (Kilner et al., 2009). Alexander and Brown's predicted response outcome model (Alexander and Brown, 2011) suggests that the medial pre-frontal cortex (mPFC), a core area of the mentalizing system, makes predictions about the outcomes of upcoming actions based on action context and prior experience. Therefore, the predictive coding model, in combination with the predicted response outcome model, suggests a potential fourth model of MS involvement: information regarding others' internal states is processed by the mentalizing system (mPFC) first based on contextual information before internal states are processed in the MS. Data from neuroimaging studies have provided evidence to support this model: action context and prior expectations about an upcoming action modulate activity in the mPFC (Alexander and Brown, 2011; Becchio et al., 2012; Chambon et al., 2017; Cooper et al., 2010; Ferdinand and Opitz, 2014; Fogelson et al., 2009; Forster and Brown, 2011; Jahn et al., 2014; Leue et al., 2015; Schiffer et al., 2014) and increased functional connectivity between the mPFC and the MS has been reported when inferring internal mental states from actions (Ciaramidaro et al., 2014; Spunt and Lieberman, 2012a,b). Additionally, action context has been shown to modulate MS activity (Amoruso et al., 2016a,b; Amoruso and Urgesi, 2016; Iacoboni et al., 2005), possibly via top-down connectivity from the mentalizing system to the MS.

Understanding *when* MS activity is modulated by mentalizing may help delineate the possible roles of the MS in the mentalizing process. Previous studies have shown that the early kinematics of actions vary depending on the actor's underlying intentions and intentions can be predicted from this information before the outcomes of the actions have been revealed (Manera et al., 2011; Sartori et al., 2011). Both the motor simulation theory and dual-process hypothesis suggest that when inferring intentions from actions, MS activity should be observed early during action observation whilst kinematic differences reflecting the actor's intention are available and processed. In contrast, the predictive coding framework suggests that predicted intentions of others are first processed in the mentalizing system and, therefore, mentalizing-induced modulation of MS activity would be observed later following top-down signalling of action predictions. Finally, the strict 'mirroring-first' model would suggest that MS activity shows little modulation by the process of mentalizing.

Previous studies have used transcranial magnetic stimulation (TMS) to investigate the timing of MS modulation due to the high temporal resolution of this technique (Amoruso et al., 2016b; Barchiesi and Cattaneo, 2013; Bardi et al., 2015; Candidi et al., 2014). Single TMS pulses can be applied at different time points during action observation in order to provide an indirect measure of MS activity at different stages of an action. For example, Alaerts and colleagues found that the weight of objects being acted upon influenced MS activity during early stages of action observation even before the objects had been grasped (Alaerts et al., 2012). These results suggest that the MS represents predictions about upcoming actions based on properties of the objects being acted upon as well as the kinematics of the goal directed action. In contrast, Amoruso and colleagues found that when participants were inferring the goals of observed actions, action context only modulated MS activity during later stages of the actions (Amoruso et al., 2016a,b). This shows that the MS is not involved in early processing of action context when making predictions about the goals of observed actions. Collectively, these data suggest that different factors modulate MS activity at different time points during action observation. In the current study, we used single-pulse TMS in order to determine when mentalizing modulates MS activity in order to help delineate the role of the MS when inferring the intentions of others' from their actions.

Determining the role of the MS in inferring others' intentions from actions is of potential importance in understanding autism spectrum disorder (ASD) which is associated with difficulties inferring the intentions of others (Happé, 1994; Kana et al., 2014; Moran et al., 2011). The 'broken mirror' theory proposes that these individuals exhibit atypical MS activity (Iacoboni and Dapretto, 2006; Oberman and Ramachandran, 2007; Ramachandran and Oberman, 2006), and this underlies difficulties these individuals experience in inferring the internal states of others, and consequently contribute to the social interaction deficits associated with ASD (American Psychiatric Association, 2013). ASD is a spectrum disorder, meaning that individuals within the non-clinical population exhibit differing degrees of autistic traits (Robinson et al., 2011). Individuals with relatively high levels of autistic traits without a diagnosis, have been shown to display reduced abilities to infer the internal states of others (Baron-Cohen et al., 2001; Gökçen et al., 2014, 2016) and atypical MS activity (Cooper et al., 2013; Lepage et al., 2010; Puzzo et al., 2009). Collectively, these data suggest that the level of autistic traits displayed may correlate with MS functioning and abilities to infer intentions. In this study we, therefore, evaluated the degree of autistic traits displayed by participants in order to examine whether this factor influenced the level of MS activity displayed when inferring others' intentions.

The present study aimed to investigate MS activity at different time points during three different tasks in order to delineate between previously proposed models of the role of the MS in inferring intentions from actions. Single-pulse TMS was applied at different time points during action observation whilst participants inferred the actors' intentions (Mentalizing task), whilst participants observed actions that did not depict the actors' intentions and participants were not required to mentalize (Action task), and whilst participants observed actions that reflected the actors' intentions but participants were not required to mentalize (Either task). If the motor simulation theory explains the role of the MS in mentalizing, early MS modulation would be observed during the Mentalizing task, and MS activity during this task should correlate with ability to infer intentions. If the dual-process hypothesis explains the role of the MS in mentalizing, early MS modulation would be observed during both the Mentalizing and the Either task, but MS activation should not correlate with behavioural performance. If intentional information is processed by an alternative cortical system first (e.g. the mentalizing system) then MS modulation would be expected only at later stages of the observed actions during the mentalizing task. Finally, the mirroring-first model would predict equivalent levels of MS activity across all tasks throughout action observation as the MS should not specifically be involved in deriving intentions. Autism quotient (AQ) scores were also measured for all participants in order to perform an exploratory analysis examining whether the level of autistic traits participants displayed correlated with the degree of mentalizing-induced MS modulation. Individuals with higher levels of autistic traits were expected to exhibit lower levels of MS modulation (cf. Dapretto et al., 2006).