BRAIN RESEARCH 1585 (2014) 108–119

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Research Report

Revisiting mu suppression in autism spectrum disorder

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ARTICLE INFO

Article history:
Accepted 13 August 2014
Available online 19 August 2014

Keywords:
Mu-suppression
EEG
Autism spectrum disorder
Action observation
Top-down inhibitory control

ABSTRACT

Two aspects of the EEG literature lead us to revisit mu suppression in Autism Spectrum Disorder (ASD). First and despite the fact that the mu rhythm can be functionally segregated in two discrete sub-bands, 8–10 Hz and 10–12/13 Hz, mu-suppression in ASD has been analyzed as a homogeneous phenomenon covering the 8–13 Hz frequency. Second and although alpha-like activity is usually found across the entire scalp, ASD studies of action observation have focused on the central electrodes (C3/C4). The present study was aimed at testing on the whole brain the hypothesis of a functional dissociation of mu and alpha responses to the observation of human actions in ASD according to bandwidths. Electroencephalographic (EEG) mu and alpha responses to execution and observation of hand gestures were recorded on the whole scalp in high functioning subjects with ASD and typical subjects. When two bandwidths of the alpha-mu 8–13 Hz were distinguished, a different mu response to observation appeared for subjects with ASD in the upper sub-band over the sensorimotor cortex, whilst the lower sub-band responded similarly in the two groups. Source reconstructions demonstrated that this effect was related to a joint mu-suppression deficit over the occipito-parietal regions and an increase over the frontal regions. These findings suggest peculiarities in top-down response modulation in ASD and question the claim of a global dysfunction of the MNS in autism. This research also advocates for the use of finer grained analyses at both spatial and spectral levels for future directions in neurophysiological accounts of autism.

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http://dx.doi.org/10.1016/j.brainres.2014.08.035
0006-8993/© 2014 Published by Elsevier B.V.

1. Introduction

Social impairments ranging from the simplest form of nonverbal interaction to sophisticated social cognition are decisive elements for the diagnosis of Autism Spectrum Disorder (American Psychiatric Association, 2013). The source of poor communication has been previously searched in psychological deficits of theory of mind (Baron-Cohen et al., 1985), imitation (Rogers and Pennington, 1991) or emotion sharing (Hobson, 1986). In the last decade, discovering which brain dysfunctions may account for such impairments has become a challenging topic for social neuroscience. The first studies used MEG (MagnetoEencephaloGraphy) to explore the activity of the MNS in Autism Spectrum Disorder (Avikainen et al., 1999; Nishitani et al., 2004). Then followed EEG and fMRI studies. A busy field of research explores the hypothesis that mirror neurons are 'broken" in persons with Autism Spectrum Disorder (ASD) Within this framework, fMRI studies started to compare the activation of the frontoparietal circuit during observation and action: should the mirror neurons be broken, action observation would then not cause the same firing effects as action execution (Gallese et al., 2012; Iacoboni and Dapretto, 2006; Rizzolatti et al., 2009; Williams et al., 2006). This would impede self-other mapping and understanding of others' action goals thus leading to imitation and interaction deficits (Gallese et al., 2012; Dapretto and Iacoboni, 2006; Oberman and Ramachandran, 2007; Williams et al., 2001).

Hamilton's (2013) meta-analysis demonstrates, however, that neuroimaging studies are far from providing clear support to this hypothesis. For instance, while several fMRI studies have reported weaker responses of the mirror neuron system (MNS) in ASD persons compared with typical controls during action observation and gestural imitation (Williams et al., 2006) or facial imitation (Dapretto et al., 2005), they are challenged by more recent studies that did not find such differences in emotional tasks (Bastiaansen et al., 2011; Grèzes et al., 2009; Schulte-Rüther et al., 2011) or imitation tasks (Dinstein et al., 2010; Marsh and Hamilton, 2011). It is worth stressing that the fMRI studies use heterogeneous methodology (see Rizzolatti and Sinigaglia, 2010, for a discussion of the methodology used) and procedures that are not supposed to tap only on MNS regions: for instance observing facial expressions would involve amygdala response while observing hand gestures would not.

EEG studies examine the same hypothesis with a focus on rolandic rhythm also called mu rhythm. Indeed mu rhythm, recorded over the sensorimotor cortex at a frequency range varying from 7–11 Hz for some authors (Willemse et al., 2010; Lachat et al., 2012) to 8–13 Hz for others (Pineda, 2005), is suppressed during both execution and observation of action. It has been suggested that mu suppression is an index of MNS recruitment and reflects downstream modulation of motor cortex by prefrontal mirror neurons (Cochin et al., 2001; Muthukumaraswamy et al., 2004; Oberman et al., 2005; Pineda, 2005). However, Arnstein and colleagues have provided a more restricted picture of the links between EEG and fMRI–BOLD signals. By recording simultaneously the two neuroimaging signals during action execution and observation, they have shown that inferior parietal, dorsal premotor and primary somatosensory cortices are directly involved in mu suppression while Brodmann (BA) 44 area is only indirectly correlated with mu modulation (Arnstein et al., 2011). In this line, a study of the effects of brain damage on action execution and observation has revealed that the magnitude of mu suppression correlated significantly with lesion extent in right parietal regions but not in the inferior frontal gyrus (IFG) (Frenkel-Toledo et al., 2014). The results of these two studies suggest that mirror neurons in BA44 are not the prime source of mu suppression; however, transcranial magnetic stimulation (TMS) studies found the IFG involved in perception-action coupling during the perception of biological and non biological actions (Newman-Norlund et al., 2010; Keuken et al., 2011). Therefore, further research is needed to clarify conflicting results in studies testing the broken mirror hypothesis with different techniques. Moreover, from seven EEG studies using Oberman design of execution and observation of hand movements, four reported an absence of mu suppression (Bernier et al., 2007; Oberman et al., 2005, 2007, 2008) though limited to gestures of unfamiliar persons), while three others found no significant differences between action execution and observation (Bernier et al., 2013 for hand movements but not facial movements (Fan et al., 2010; Raymaekers et al., 2009). Studies of children with ASD show the same inconsistencies (Martineau et al., 2008 find no mu suppression during action observation while Ruysschaert et al., 2014 find similar central mu suppression in ASD and typical children).

Such conflicting EEG and fMRI evidence of a dysfunctioning MNS in autism lead several social neuroscientists to move beyond mirror neurons in our understanding of the social brain and to explore the hypothesis of a complementary role of the Mentalizing System (or TOM system). For example, Uddin et al. (2007) have suggested that the MST would enable physical simulation of actions and action goals, while the mentalizing system (including Cortical Midline Structures and Temporo-Parietal Junction) would allow simulation of mental states or evaluative simulation. Our Psycho Physiological Interaction (PPI) analysis has revealed a significant functional coupling of the MNS with the mentalizing system during imitative interaction (Sperduti et al., 2014). As regards EEG studies, Pineda and Hecht (2009) have looked at mu suppression during two kinds of ToM tasks and found mu insensitive to incorrect social cognitive inferences; they concluded that additional mechanisms are needed to make mental attributions of intentions. A way to take into account this conclusion is to change a focus limited until now to central electrodes and to look at different functions of the alpha-mu rhythm according to distinct bandwidths.

In favor of a change in focus, it is worth considering that EEG studies have restricted their exploration of the 8–13 Hz rhythm modulation to the sensorimotor regions (i.e., mu rhythms), whereas research in neurotypical subjects has shown that observational tasks produce changes in 8–13 Hz oscillations over scalp regions other than the central regions (i.e., alpha rhythms). In particular, alpha suppression to visual stimuli may reflect cortical activation whereas alpha power increase may reflect inhibitory and top-down regulatory processes (e.g., Bazanova and Vernon, 2013; Cooper et al., 2003; Klimesch et al., 2007; Klimesch, 2012; Perry et al., 2011).