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Review

Motor network activation during human action observation and imagery: Mu rhythm EEG evidence on typical and atypical neurodevelopment

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ABSTRACT

The mental simulation theory suggests activation of the motor network during imagery and observation of human movements, similarly to the activation during action execution and is proposed to be mediated by the mirror neuron system. This activation can be measured by several technologies such as electroencephalography, magnetoencephalography, functional magnetic resonance imaging and positron emission tomography. It is proposed that motor network activation and therefore increased cortical excitability of primary motor cortex occur due to premotor mirror neuron system inputs. This mechanism has been demonstrated as important for planning actions and seems relevant for anticipating others actions and for empathy establishing as well as for language development. In this review we focused on studies relative to electroencephalography data of motor neural network activation during movement observation and imagery in typical and atypical development.

Contents

1. Introduction – motor imagery and observation

Action recognition is fundamental for the comprehension of other's attitudes and for social behavior (Buccino, Binkofski, & Riggio, 2004). It is suggested that observed actions are processed in an active perception manner in which the

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comprehension during observation is elaborated throw the interconnection of sensory and motor modules (Pulvermüller & Fadiga, 2010). Thus, recognition of several actions performed by another individual occurs due to the transposition of the observed action to the observer own motor repertoire (Buccino et al., 2004).

The relationship between observation and execution is quite narrow and the motor repertoire has significant relevance for movement perception and comprehension. In contrast, the sensory inputs are important for the control of actions (Guenther, Ghosh, & Tourville, 2006). It has been proposed that motor areas recruitment, called by some authors as motor resonance, has an active role on perception (not merely a passive epiphenomenon of perception).

In turn, motor imagery consists in imagining sensory and motor inputs. It can be defined as a process linked to perception in the absence of a real external stimulus (Annet, 1995; Farah, 1984; Kosslyn, Ganis, & Thompson, 2001). The generation of a motor imagery is based on proprioception and visual imagery. Furthermore, according to Decety and Grèzes (2006), the production of a mental imagery presents evolutionary adaptive advantages since it allows one to plan actions and also anticipate and comprehend other's actions (Decety & Grèzes, 2006).

The mental simulation theory claims that the motor neural network is activated both during movement imagery and execution of this motor representations (Jeannerod, 2001), analogously to action observation and execution. This process of motor activation seems mediated by a neural system called the mirror neuron system (MNS) (Rizzolatti, 2005; Rizzolatti, Fogassi, & Gallese, 2001).

Mirror neurons are a particular type of neurons that fire both when an individual performs an action or observes another individual performing a similar action and when exposed to words related to an action (e.g. kick) resulting on the activation of neural structures related to its execution (Hauk & Pulvermüller, 2004). This process demonstrates a multimodal integration of auditory, visual and motor systems (Le Bel, Pineda, & Sharma, 2009; Rizzolatti, 2005). Although initially discovered in the F5 area of the monkey premotor cortex, there is strong evidence suggesting the existence of a comparable system in the homologue region of human premotor cortex (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995).

According to Rizzolatti et al. (2001) this system seems to unify a variety of phenomena in the same neural mechanism. That response goes beyond elementary behaviors, such as response facilitation, also playing a critical role in superior cognitive functions such as learning through imitation, action comprehension and language development.

Furthermore, Gallese and Goldman (1998) argue on the role of the MNS over the general ability of comprehend the mental state of another individual (e.g. perceptions, aims, believes and expectations) and also raise the hypothesis that by mechanisms of internalization of the observed actions, mirror neurons may compose part of a system able to module action planning via its motor imagery (Gallese & Goldman, 1998).

It is though that observation and imagery represent a subtle stage of action execution underlined by cortical areas typically involved in motor planning and execution such as supplementary motor area (SMA), premotor cortex and primary motor cortex (M1) (Jeannerod, 2001). Particularly, the premotor cortex seems deeply involved to three processes, (i) motor execution, (ii) motor observation (Rizzolatti & Craighero, 2004) and (iii) motor imagery (Michelon, Vettel, & Zacks, 2006).

In this review, we aimed to discuss the use of EEG to further comprehend the motor neural network activation in humans. We focused on Mu rhythm data during human motor imagery and observation tasks. Particularly, we present and discuss these mechanisms in both typical and atypical neurodevelopmental with a special focus in autism spectrum disorder.

2. Neuroimaging during motor imagery and observation tasks

The use of different technological approaches in neuroscience during the last decade render a deeper knowledge of several neural processes. Concerning to this paper topic, they enable the study of multimodal interaction (Huettel, Song, & McCarthy, 2004) through neural activity measures that support the comprehension relative to action observation and motor imagery along with the impact of these activities in posterior motor performance.

Several techniques such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET), electroencephalography (EEG) and mangnetoencephalography (MEG) converge and confirm the motor network activation during movement observation and imagery and further, argue in favor of the involvement of the MNS.

FMRI data show contralateral activation of M1 and SMA during observation, imagery and performance of hand rotation Michelon et al. (2006) and sequences of digit movements (Decety, Kawashima, Gulyás, & Roland, 1992). There is also evidence of posterior parietal cortex (PPC) involvement, which seems crucial to maintain an internal representation of the state/position of the effector limb, necessary to adjust action performance playing a role on unifying neural activity information related to the trajectory and aim of the movement (Decety & Grèzes, 2006; Mulliken & Andersen, 2009; Harris et al., 2000).

Moreover, fMRI studies report selective activation of both M1 and posterior superior temporal sulcus (STS) during observation of human movement (Saygin, Wilson, Hagler, Bates, & Sereno, 2004). There is also evidence of higher activity of premotor areas during observation of well-known actions when compared to unfamiliar ones suggesting a perceptual effect of expertise in motor activation (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Cross, Hamilton, & Grafton, 2006). The visual (observation) and motor (performance) familiarity of stimuli show an important effect, being the motor practice the most significant (Calvo-Merino, Ehrenberg, Leung, & Haggard, 2010; Calvo-Merino et al., 2006). Furthermore, Calvo-Merino et al. (2010) proposed that visual perception of biological actions might involve mechanisms of stimuli configuration process, which is also modulated by the observer expertise.