



Mu desynchronization during observation and execution of facial expressions in 30-month-old children



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ABSTRACT

Simulation theories propose that observing another's facial expression activates sensorimotor representations involved in the execution of that expression, facilitating recognition processes. The mirror neuron system (MNS) is a potential mechanism underlying simulation of facial expressions, with like neural processes activated both during observation and performance. Research with monkeys and adult humans supports this proposal, but so far there have been no investigations of facial MNS activity early in human development. The current study used electroencephalography (EEG) to explore mu rhythm desynchronization, an index of MNS activity, in 30-month-old children as they observed videos of dynamic emotional and non-emotional facial expressions, as well as scrambled versions of the same videos. We found significant mu desynchronization in central regions during observation and execution of both emotional and non-emotional facial expressions, which was right-lateralized for emotional and bilateral for non-emotional expressions during observation. These findings support previous research suggesting movement simulation during observation of facial expressions, and are the first to provide evidence for sensorimotor activation during observation of facial expressions, consistent with a functioning facial MNS at an early stage of human development.

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1. Introduction

Facial expressions form an essential component of social interaction, providing us with a base from which we can understand other people's feelings, or infer their motivations and intentions. As such, accurate recognition and analysis of facial expressions is important for the facilitation of appropriate behaviour within an interaction, and contributes significantly to the success of a social exchange. Emotional facial expression processing is especially important during early development as young children acquire social and communicative skills. Before mastering language, infants understand others' emotions predominantly via the 'reading' of faces (Leppänen and Nelson, 2009), which continues to play a crucial role during social interactions throughout childhood and beyond. The facial expressions of caregivers convey a wealth of information to their offspring during face-to-face exchanges, for example fear or smiling in order to signal the danger or lack

thereof posed by a particular object or situation (Klinnert, 1984; Sorce et al., 1985). Furthermore, difficulty recognizing and understanding facial expressions has been associated with a range of adverse child outcomes, including impaired social functioning and behavioural problems (Izard et al., 2001; Leppänen and Hietanen, 2001; Trentacosta and Fine, 2010).

Simulation theories propose that observation of another person performing a facial expression activates the observer's sensorimotor representations implicated in producing that movement, which aids expression recognition (e.g. Adolphs, 2006). Neurophysiological findings in monkeys have provided the first evidence for such a neural mapping mechanism linking the perception of an action onto its cortical motor representation. These 'mirror neurons' were first discovered in the premotor cortex of the macaque monkey (Di Pellegrino et al., 1992), and are a class of neuron that fire both during the execution and observation of a similar action. Consequently, mirror neurons are widely thought to implement a mapping from an observed action to the observer's motor representation used to perform the same action (Rizzolatti and Craighero, 2004). Evidence from research using a variety of techniques (fMRI, TMS, EEG, depth-electrode recordings) now supports the existence of a homologous mirror neuron system (MNS) in human adults

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(Iacoboni and Dapretto, 2006; Molenberghs et al., 2012), including the inferior and superior parietal lobules, ventral premotor cortex, and inferior frontal gyrus (IFG), with the superior temporal sulcus (STS) providing the primary visual input. Accordingly, the concept of a human MNS has been suggested as a prospective biological mechanism underlying the perception of facial expressions as proposed by simulation theories, with the observation of another's action activating like neural processes in the observer as in the performer (Gallese and Sinigaglia, 2011).

Though much mirror neuron research has focused on the study of hand actions, a number of studies have also explored putative MNS involvement in the processing of facial expressions. Indeed, single cell recordings in the ventral premotor cortex of adult macaque monkeys have demonstrated the existence of mirror neurons for facial movements (Ferrari et al., 2003), and a number of fMRI studies with human adults have found common activation of brain areas associated with the MNS during observation, execution, and imitation of facial expressions (Carr et al., 2003; Dapretto et al., 2006; Engell and Haxby, 2007; Hennenlotter et al., 2005; Kircher et al., 2013; Lee et al., 2006; Likowski et al., 2012; Pohl et al., 2013; Van der Gaag et al., 2007). These human studies have demonstrated overlapping activation in response to both static and dynamic facial stimuli (e.g. Carr et al., 2003; Leslie et al., 2004).

Many facial expressions involve both motor and emotional components, and therefore it has been suggested that these aspects are processed by separate, but linked, mirror systems which work together to contribute to facial expression recognition (Van der Gaag et al., 2007). Observation, imitation, and execution of emotional and non-emotional facial expressions result in overlapping patterns of neural activation, with emotional facial expressions eliciting more activation in regions such as the amygdala, insula, and IFG (Carr et al., 2003; Kircher et al., 2013; Van der Gaag et al., 2007; Wicker et al., 2003). It has been proposed that the insula links the frontal component of the MNS with the limbic system, providing a mapping from an observed expression onto internal emotional representations (Dapretto et al., 2006; Rizzolatti et al., 2014).

Despite the work on the MNS providing important information concerning a common neural substrate for emotion observation and execution, its focus exclusively on adult participants leaves open the question of whether such a mechanism is functional from a much earlier age, which would support the hypothesized presence of a simulative process for emotion understanding in the developing brain (Decety and Meyer, 2008). Non-invasive techniques such as EEG are required for studying MNS activity in more challenging populations such as young children and infants. The mu rhythm (8–13 Hz in adults) recorded over the central electrodes, has been identified as an index of MNS activity (Muthukumaraswamy et al., 2004; Pineda, 2008) because it is thought to be generated in the sensorimotor cortex, is modulated during both action execution and observation, and its activity covaries with BOLD activity in MNS regions during simultaneous EEG and fMRI acquisition (Arnstein et al., 2011). In infancy and early childhood, the mu frequency range is lower than in adults, gradually increasing over time (Marshall et al., 2002). The 6–9 Hz range has been identified as functionally analogous to the adult 8–13 Hz band in early development (Stroganova et al., 1999; Stroganova and Orekhova, 2007), and is considered appropriate for use with children up to 4 years of age (Marshall et al., 2002). As recommended by Cuevas et al. (2014), from here on we refer to mu 'desynchronization' where power is significantly decreased from a baseline period, and 'suppression' where mu power is significantly different between conditions or regions but not necessarily lower than baseline.

In human adults, the mu rhythm is sensitive to observation and mental imagery of orofacial movements (Muthukumaraswamy et al., 2006; Pfurtscheller et al., 2006; Spiegler et al., 2004), and

the few studies that have investigated adult mu activity during observation of emotional facial expressions suggest MNS simulation of facial movements (Cooper et al., 2013; Moore et al., 2012). Interestingly, hemispheric differences in mu activity have been found in during observation of positive and negative facial expressions (Moore et al., 2012), which is in keeping with other research demonstrating the dominance of the right hemisphere for face and emotion processing (Adolphs, 2002; Borod et al., 1998; Killgore and Yurgelun-Todd, 2007). Borod et al., 1998; Killgore and Yurgelun-Todd, 2007).

Around 8–14 months of age, human infants already demonstrate changes in mu rhythm power during observation of hand actions (Marshall and Meltzoff, 2014; Marshall et al., 2011; Nyström et al., 2011; Southgate et al., 2010), but despite the importance of face-face interactions during early childhood (Trevarthen and Aitken, 2001), mu responses to facial expressions in very young populations have not yet been explored. Ferrari and colleagues (Ferrari et al., 2012; Vanderwert et al., 2015) found evidence for MNS involvement during observation and execution of facial gestures in newborn macaque monkeys, with desynchronization demonstrated in the 5–6 Hz EEG rhythm during observation of live human facial gesture performance. This suggests that a functioning MNS could also be present soon after birth in humans, and may play a role in facial expression processing from an early stage in development. Therefore conducting similar studies with younger human populations is now critical in order to address this question.

In the present study, mu rhythm desynchronization in 30-month-olds was explored in response to observation of videos in which adults performed both dynamic emotional and non-emotional facial expressions. While the age group included in this study is particularly difficult for EEG research, it is of importance because of the extensive emotional and social developments that occur during this period (Brownell and Kopp, 2007; Denham, 1998). Children of this age become increasingly adept at reading others' mental states and emotions (Bartsch and Wellman, 1995; Phillips et al., 2002), and, for example, begin to display more empathic behaviour towards parents (Zahn-Waxler, 1992), and sometimes peers (Nichols et al., 2009; Spinrad and Stifter, 2006). Therefore 30 months constitutes an appropriate age to first explore potential involvement of the sensorimotor system during observation of facial expressions at an early stage in human development. Based on previous studies of hand action observation with young populations and adult EEG studies of facial expressions, we expected to see mu desynchronization during both observation and execution of facial expressions. In keeping with best practices suggested for mu rhythm research with young children (Cuevas et al., 2014), we used dynamic stimuli that included a pre-movement static neutral expression, as well as videos of facial expressions in which the face was scrambled. This enabled comparison of mu power changes relative to a baseline period and a control condition, which allowed us to determine whether any observed effects were simply due to observation of a (the static baseline) face or a face-like stimulus performing meaningless movements (the scrambled condition). Trials in which participants spontaneously produced facial expressions were coded offline and excluded from the main observation analysis. These trials were then analysed separately in lieu of an execution condition.

2. Methods

2.1. Participants

28 healthy children (15 male, 13 females) aged approximately 30 months took part in this study, which was approved by the University of Reading Research Ethics Committee (21.05.13). Par-

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