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Sources of mu activity and their functional connectivity in perceiving complexities in reciprocal social interactive motion: An exploratory study using the **'Namaste'** task

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ABSTRACT

Cognitive processes underlying reciprocal social interactions are understood by the mechanism of embodiment, which is closely related to the mirror neuron system. Electroencephalographic (EEG) mu activity is a neural marker of the mirror neuron system. This study investigated the mu activity, localization of its sources and functional connectivity, which was induced while watching reciprocal social interactive motion across various degrees of complexity. Eighteen healthy participants underwent high-resolution EEG recording using 256-channels while they watched a specifically designed, culture specific, video task that showed two persons interacting socially using body gestures. Task complexity was determined by (1) whether there was an identical gestural response or a non-identical one; (2) whether the participant watched two persons interacting or was virtually involved in the interaction. Source localization and functional connectivity analysis was conducted for mu activity across various tasks. We also correlated mu activity and functional connectivity measures with serum BDNF. We found that spectral densities in various brain sources of mu activity and their increased functional connectivity distinguished *identical and non-identical reciprocal* expression observations, while mu suppression alone did not discriminate various degrees of complexities. These findings might have important implications in the understanding of mechanisms underlying mirror neuron dysfunction in various psychiatric disorders.

1. Introduction

Humans are considered exquisitely social. Social behavior is determined by various receptive, appraisal and expressive capacities. While receptive capacities include perceptual functions like vision and hearing; cognitive and emotional processes are involved in the appraisal. And, social expression is mostly emotional and motor (both verbal and non-verbal). The cognitive and emotional appraisal on perceiving others' expressions is what is termed as 'social cognition'. More importantly, social cognition with its underlying psychobiological processes enables a human being to aptly interact socially. There has been a suggestion that the need to socially interact is a motivating factor in the evolution of skills that are explicitly human (Ramachandran, 2000). Moreover, deficits in social cognition and their neural correlates have been suggested as markers for various psychiatric disorders (Derntl and Habel, 2011). Especially in patients with schizophrenia, impairment in social processes have been shown to adversely affect functionality (Green et al., 2015).

Others' expressions during social interactions are termed 'social signals' (Frith and Frith, 2007). While unconscious processing of these signals in humans begins by the first year of life, a higher-level conscious processing starts by 18 months of age (Frith and Frith, 2007). In fact, social interaction plays a critical role in early brain development in humans (Blakemore, 2010). Animal models too have shown that protracted social isolation might induce ultra-structural changes in the brain regions and impaired myelination (Liu et al., 2012). Moreover, social interactions do have an influence on neuroplasticity in later life too in humans (Davidson and McEwen, 2012).

With neural and cognitive basis underlying social interaction, being proposed as the default mode for human social behavior (Hari et al., 2015), several modes of brain imaging investigation like electroencephalography (EEG), functional magnetic resonance imaging (fMRI), etc., have suggested the mirror neuron system to be the brain basis for social interactions (Hari and Kujala, 2009). Mirror neuron system and its role in social development have also been addressed (Vanderwert et al., 2013). Mirror neuron system

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has been shown to be dysfunctional in autism (Hamilton, 2013); where social development is centrally impaired (Volkmar et al., 1993). Besides, early hyperactivity of the brain derived neurotrophic factor (BDNF) has been causally linked to autism (Tsai, 2005). Furthermore, mirror neuron system and its impairments have been well established and linked to functional outcome in major psychiatric disorders like schizophrenia and bipolar affective disorder (Mehta et al., 2014; Kim et al., 2009). And interestingly, these disorders have been linked neuro-developmentally and shown to be associated with BDNF (Polyakova et al., 2015; Schmidt and Karoly Mirnics, 2015). Further, involvement of BDNF has been proposed as a major mechanism in understanding mirror neuron plasticity (Chen et al., 2008). BDNF has also been implicated in shaping the functioning of the neural circuits (like mirror neuron system) that regulate various social behaviors in healthy individuals as well (Feder et al., 2009).

Mirror neuron system and social connectedness; have been linked to each other by the mechanism of embodiment (Gallese, 2009). Embodiment is the sensorimotor simulation (of reenactment), which is triggered by perception of a stimulus, and is responsible for whether there is a resultant reciprocal expressive action or otherwise (Körner et al., 2015). Moreover, this mechanism, also referred to as 'mentalizing', (Frith and Frith, 2012) is claimed to have a strong coupling with the mirror neuron system during the imitative exchanges (Sperduti et al., 2014).

Various psychological and cognitive aspects, underlying 'gestures' and 'facial mimicry' have been understood with the mechanism of embodiment (Dijkstra and Post, 2015). Now, gestures and mimicry are intrinsic domains of reciprocal social expression. Reciprocity in expression—both verbal and non-verbal, in response to social signals is yet another important component of social expression that determines the overall social behavior. Mainly, there can be two types of reciprocal social expressions—*identical and non-identical*. Example for a verbal *identical reciprocal expression* is saying 'hello' in response to a 'hello'; and responding 'you are welcome' to a 'thanks' is an example for a verbal *non-identical reciprocal expression*. Culture has a tremendous influence on these social signals and reciprocal expressions. Beyond verbal signals, which have an obvious influence of vernacular language, non-verbal signals and expressions like posture and motor gestures have a noticeable influence of culture. Human experiences and skills have a strong influence of culture and it has also been proposed that the embodied simulation is dependent on previous experiences and skills (Körner et al., 2015). Hence, culturally influenced reciprocal social expressive actions can be used to understand role of mirror neurons, embodied simulation and social interactions.

In India, greeting 'namaste' or 'pranam' by holding both palms together with slight bending forward of the trunk and neck is a social signal that generates a non-verbal *identical* reciprocal motion response. Greeting 'namaste' with further bending and attempting to touch the feet of the person in front to seek blessings generates a non-verbal *non-identical* reciprocal motion response of mid-flexing both elbows and extending hands with palms facing down upon the 'seeker'. Moreover, the kind of appraisal while watching two persons greeting 'namaste' (as a third person) may be distinct from the kind when one is directly involved in the interaction (second person); similarly for 'namaste' + seeking blessing. We hypothesize that the cognitive load in all these different social settings is variable, with some being simple and some complex.

With this literature backup, the present study aimed to investigate the role of brain sources (and their connectivity) of cortical EEG oscillations in the mu frequency range, a marker of mirror neuron system, induced by a varying cognitive load of reciprocal expressive motions within a social interaction. The study also aimed to correlate the brain connectivity measures and serum BDNF, a peripheral marker of neural development and plasticity.

2. Methods

The study was conducted after the approval by the Institute's Ethics Committee. Written informed consent was taken from all the participants before enrolling them for the study.

Eighteen healthy participants (mean age-30.06 $\pm$ 3.75 years, all men, all right handed, all Hindus) were recruited. Mean education was 15.78 $\pm$ 3.00 years and 66.7% of them were employed and 33.3% were students by occupation. 55.6% belonged to middle socioeconomic status and 66.7% resided in a rural habitat. All participants had normal or corrected vision. The participants were screened on the General Health Questionnaire-12 (Golderberg and Williams, 1988). All participants were naive to the purpose of the study.

2.1. EEG recording

All participants underwent an EEG recording. Recording was carried out between 0900 and 1200 hours at the KS Mani Centre for Cognitive Neurosciences, CIP. Participants were advised to avoid use of tea, coffee or nicotine for at least one hour before recording. EEG was acquired on the Geodesic EEG System 400 (Electrical Geodesics, Inc., Eugene, Oregon, USA) system with 256 EEG channel Geodesic Sensor Nets; sensors placed according to the international 10-10 system of electrode placement (Fig. 1). Eye movement potentials were monitored using right and left electro-oculogram (EOG) channels. Electrode impedance was kept $< 50 k\Omega$. EEG was filtered (time constant—0.1 s, high frequency filter—120 Hz) and digitized (sampling rate—250 Hz) using Net Station 5.2 software (Electrical Geodesics, Inc., Eugene, Oregon, USA).

2.2. The 'Namaste' task

The participants were made to sit in a sound attenuated room. An 18″ HD monitor was placed in front of them at a distance of 96 cm, at an appropriate height; and was the only source of illumination in the room.

Four color video clips, 6 s each were used.

- *Task 1 (Grade A (simple)/3*rd *person observer)*: the two actors in the video greeted each other by folding their hands (namaste) and bending slightly forward toward each other.
- *Task 2 (Grade A (simple)/2*nd *person observer):* one of the actors greeted 'namaste' toward the screen as if greeting the participant.
- *Task 3 (Grade B (complex)/3*rd *person observer):* the actors in the video folded hands toward each other similar to 1st video clip. Then actor-1 further bent forward as if to touch actor-2's feet and seek blessing while the later placed his hands over actor-1's head.
- *Task 4 (Grade B (complex)/2*nd *person observer):* similar to the 2nd video clip with one of the actors folding hands and bending forward as if to seek blessing from the subject.

Each of these clips was repeated 20 times; total duration for each task lasting 2 min was prepared. Each task was shown alternating with visual white noise (VWN) video of 1 min on the computer screen (Fig. 2); the whole recording lasted 12 min.

The movements involved in these tasks were bilaterally symmetrical. Such movements were chosen to evoke analogous modulation of EEG activity in both hemispheres.