Changes in mu rhythm during action observation and execution in adults with Down syndrome: Implications for action representation

Naznin Virji-Babul[a,b,*], Alexander Moiseev[a], Teresa Cheung[a], Daniel Weeks[b], Douglas Cheyne[c], Urs Ribary[a,b]

[a] Down Syndrome Research Foundation, MEG Laboratory, Burnaby, British Columbia, Canada
[b] Department of Psychology, Simon Fraser University, Burnaby, British Columbia, Canada
[c] Program in Neurosciences and Mental Health, Hospital for Sick Children Toronto, Ontario, Canada

ARTICLE INFO

ABSTRACT

The human mirror neuron system is thought to be the underlying basis of perception–action coupling involved in imitation and action understanding. In order to examine this issue we examined the recruitment of the mirror neuron system, as reflected in mu rhythm suppression in a population of adults with Down syndrome (DS) with known strengths in imitation but with impairments in perceptual-motor coupling. Ten healthy adults and 10 age-matched adults with (DS) participated in the study. Subjects were asked to make self-paced movements (execution), and view movements made by the experimenter (observation). The action consisted of reaching with the dominant hand to grasp and lift a cup. Cortical responses were recorded with a whole head magnetoencephalography (MEG) system. Both groups demonstrated significant attenuation of the mu rhythm in bilateral sensorimotor areas when executing the action. Typical adults also demonstrated significant mu suppression in bilateral sensorimotor areas during observation of the action. In contrast, when observing the movement, adults with DS showed a significantly reduced overall attenuation of mu activity with a distinct laterality in the pattern of mu suppression. These results suggest that there is a dysfunction in the execution/observation matching system in adults with DS and has implications for the functional role of the human mirror neuron system.

© 2008 Elsevier Ireland Ltd. All rights reserved.

The ability to understand the actions of another person and to imitate the same actions is a central component of human social cognition. The neurophysiologcal basis of the perceptual-motor coupling involved in these behaviours has received much attention since the discovery of mirror neurons in the monkey. Reports that visuomotor neurons in areas F5 and PF in the macaque monkey respond to both the observation and execution of an action [9,10] have led to the hypothesis that action understanding may be achieved by mapping the visual representation of the observed action onto the observer's motor representation for the same actions [20]. Indirect evidence from neuroimaging experiments suggest a similar network involved in action understanding in the human brain, including the superior temporal sulcus, the inferior parietal lobe, and inferior frontal gyrus [13]. This mirror neuron system is thought to have a crucial role in action understanding and imitation [19].

Although imitation and action understanding have generally been considered together in the current mirror neuron system interpretation, they are quite distinct behaviours that have somewhat different functions. Imitation of another person's movements is critical when learning a new motor skill and may require a more detailed internal representation of limb dynamics. In inferring intentions, it may be more crucial to extract information about the general goal of action with less emphasis on the fundamental properties of the motion itself. Thus, while both involve some aspect of matching between the actions of others and the actions of the self, there may not be a single neural system mediating these behaviours. In order to tease out the difference between these two behaviours, we studied a population of adults with Down syndrome (DS).

Down syndrome (DS) is a genetic condition resulting from the presence of an additional whole or part copy of chromosome 21. The consequence is a disruption of many aspects of cognitive and sensorimotor development. DS presents a unique etiology in that the developmental process is complex and variable with unequal skill development in different domains of function. Of particular interest is that individuals with DS generally show a particular pattern of social and perceptual-motor characteristics that may be useful in understanding the neural control of action

* Corresponding author at: Down Syndrome Research Foundation, 1409 Sperling Avenue, Burnaby, British Columbia, Canada. Tel.: +1 604 444 3773; fax: +1 604 431 9248.
E-mail address: naznin@dsrf.org (N. Virji-Babul).

representation. Specifically, individuals with DS have long been known to have strengths in imitation of limb gestures [6]. In fact, their ability to imitate action is reportedly better than that of control individuals matched for mental age [26]. Recently Bunn et al. [3] conducted a detailed investigation of how children with DS perform on subtests of apraxia battery that required imitating representational and nonrepresentational gestures. The subtests included both transitive and nontransitive gestures. They found that participants with DS performed as well as control participants on all subtests that involved imitation of gestures.

Interestingly, this strength in imitation behaviour is usually accompanied by impairments in perceptual-motor control. A number of studies have reported impairments in perceptual-motor coupling in a number of tasks including catching [12] reaching and grasping [4] and obstacle crossing during locomotion [22]. Recently, Virji-Babul et al. [23] reported that children with DS also show difficulties in interpreting the actions of others, as represented by point light displays of motion. Interestingly, these impairments were not limited to the perception of action but included impairments in the ability to assess the intentions of other people's actions related to emotions. Thus, this de-coupling between imitative and perceptual-motor skills in individuals with DS provides a unique perspective from which to understand the nature of the mirror neuron system.

One index of mirror neuron activity that has been extensively studied in humans is mu (8–13 Hz) suppression. At rest, neurons in the sensorimotor area fire synchronously resulting in large amplitude EEG oscillations in mu frequency band. When subjects perform an action, imagine movement or observe movements, these neurons fire asynchronously decreasing the power of the mu band [5,15,17,18]. It has been hypothesized that the mu rhythms reflect downstream modulation of primary sensorimotor areas by mirror neuron activity, representing a critical information processing function translating perception into action [18].

The aim of the present study was to characterize the pattern of mu rhythm modulation in the sensorimotor areas during action observation and execution in individuals with DS. Given previous reports on the impairments in perceptual-motor coupling in DS, we hypothesized that adults with DS would demonstrate reduced mu rhythm suppression during action observation.

Ten healthy adult participants (4 men and 6 women) aged 20–40 years and 10 adults with Down syndrome (4 men and 6 women) aged 20–40 years participated in this study. None of the control subjects had a previous history of neurological or visual disorder. Informed consent was obtained from each subject after full explanation of the study. This study was approved both by the Simon Fraser University Research Ethics Board and the Down Syndrome Research Foundation Research Ethics Committee. All participants were right handed with the exception of one female participant with DS.

Participants were seated in an electromagnetically shielded room (Vaccumschmeltz). Cortical responses were recorded with a 151 channel whole head MEG system (VSM MedTech). Signals were sampled at a rate of 600 Hz with a bandwidth of DC to 150 Hz and third order gradiometer noise cancellation. Data were collected under three conditions: rest, execution and observation.

In the rest condition participants were asked to sit quietly with hands on their lap and eyes open. Timing of events associated with the performed and observed movements were measured using two non-magnetic response pads (Lumitouch, Burnaby, B.C.) with highly sensitive buttons (four on each pad) placed adjacent to each other on a wooden board in front of the participant. For the movement task, participants began by resting their right hand on the buttons of one pad and made self paced movements to reach with their dominant hand and grasp and lift a cup that was placed on the buttons of the second button box (Fig. 1). The participants

Fig. 1. Two experimental conditions: execution—participant reaches to grasp the cup and observation—participant observes experimenter reaching and grasping the cup.

were asked to lift the cup approximately 2–3 inches off the box and return it to the same position and finally return to their initial hand position. This provided trigger signals that were recorded along with the MEG data indicating the onset of reaching (hand motion), onset of lifting (hand/object motion), placement of the cup on the pad (termination of object motion) and time of return of the moving hand (termination of hand motion). In the observation condition participants sat with their hands in their lap and passively observed the experimenter performing the same action in an identical way, ensuring that timing of reaching and lifting events was highly similar across the two conditions. Vision of the participant's own hands during the observation condition was obstructed by a cloth or blanket. In addition, the experimenter was seated on the subject's dominant side so that the subject viewed the action from the same perspective as during the execution condition. The experimenter's hand and reaching arm was positioned on the table so that it was visible to the participant throughout the session from rest to the completion of the movement. Each reach and grasp trial lasted approximately 3 s with approximately 2–3 s inter trial interval between trials. The average number of trials ranged between 80 and 100 in each condition.

All epochs of MEG activity were manually inspected for artifacts exceeding ±2 picoTesla (pT). Between 75 and 85% of trials were retained for each subject. Epochs extending from 200 ms prior to 1.5 s after movement onset were selected and analyzed. Fast Fourier transforms (FFT) were performed using Brain Electrical Source Analysis (BESA) 5.0 (MEGIS Software GmbH). A source montage was used to transform the MEG activity obtained from all the 151 channels into estimated contributions of a set of 15