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Mu rhythm suppression during the imagination of observed action

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Abstract— **Mu wave suppression is thought to accompany the activation of the mirror neuron system which occurs when a human observes or imitates the behavior of others. Our investigation indicates a possible difference in mirror neuron system activation between passive and more active observation as suggested by mu wave activation levels. Participants were asked to observe four different videos each 80 s in duration. Each video was repeated once after a 30 s interval. The first video was of visual white noise and participants were instructed to passively observe the video. This was identified as the Baseline condition and served as a mu activation level baseline. The second video was of simple bouncing balls and the observer was again asked to passively observe the video (Ball condition). The third video was of a moving hand (Observation condition). The forth video was of the same moving hand and participants also imagined executing the observed hand movement (Imagination condition). As hypothesized, the Imagination condition activated the greatest level of mu suppression, while the Ball condition activated the lowest level of mu wave suppression. The Observation condition produced a slightly larger level of mu wave suppression than the Ball condition. This progressive increase in mu wave suppression supports the hypothesis that the activation of the mirror neuron system increases as the level of active observation increases.**

I. Introduction

The mirror neuron system (MNS) has been found to be active during perceived, imagined, and actual movement. This perception and appreciation of movement is thought to be a key element in imitation, which is itself thought to be an important component of communication and identification with others. Impaired mirror neuron functioning has been found in various studies of individuals with Autism Spectrum Disorders (ASD). Researchers have suggested that deficits in the ability to imitate, command of language, and empathy, as well as the theory of mind [1] developed by individuals with ASD, may in part be due to impaired MSN functioning [2~4]. Parsons et al employed positron emission tomography (PET) to ascertain the regions of the brain in which the MSN is localized to be the inferior premotor cortex (Brodmann's area 44) along with cerebellar, paretial, and frontal areas [5].

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Another method by which mirror neuron activity can be monitored exploits the difference in firing patterns of resting versus active sensorimotor neurons, with synchronous firing being present in the resting state, which produces large amplitude 8 to 13 Hertz oscillations known as mu waves observed by means of electroencephalography (EEG) [6].

Mu waves decrease in magnitude when sensorimotor neurons fire during movement [7, 8]. This suppression of mu waves also has been observed while the MNS was found to be active as a result of merely imagining a movement. Thus mu wave suppression has been taken to be an indicator of MNS activity [8]. In this study we established that typically developing adults can indeed increase mu wave suppression by imagining they are carrying out a hand movement they also are observing [9].

II. Method

A. Participants

Participants were 29 typically developing male adults, ranging in age from 18 to 22 years. All had normal hearing and normal, or corrected to normal, vision.

B. Stimulus

EEG data were collected during four conditions using three 80-s videos. In the three videos, both the ball and hand moved at a rate of 1 Hz.

- Baseline Condition (Video 1): Observing full-screen television static (white noise).
- Ball Condition (Video 2): Watching a video of two bouncing balls; two light gray balls on a black background moved vertically towards each other and touched in the middle of the screen and then moved apart to their initial starting positions. This motion was visually equivalent to the trajectory taken by the tips of the fingers and thumb in the hand video (below). The ball stimulus subtended 28 degrees of visual angle when touching in the middle of the screen and 58 at its maximal point of separation. (Figure 1)
- Observation Condition (Video 3): Watching a video of a moving hand. Subjects viewed a video of an experimenter opening and closing the right hand, and the hand subtended 58 degrees of visual angle when open and 28 degrees when closed. The hand was fresh color on a black background . (Figure 2)
- Imagination Condition (Video 4): Watching a video of a moving hand and imagining executing the observed hand movement at the same time. Subjects viewed the same video as in the Observation Condition and called up an image of executing the observed hand movement.

Figure 1. Video of two bouncing balls.

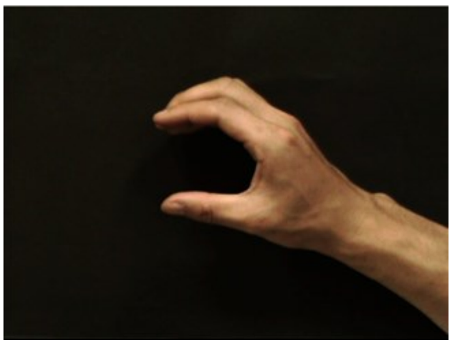

Figure 2. Video of moving the right hand.

All experimental conditions were conducted twice in order to exclude the influence of order-effects, and the order-effect was counterbalanced. Figure 3 shows the flow of the tasks.

All videos were presented on a 17-in. computer screen at a viewing distance of 96 cm with a visual angle of approximately 17°.

C. EEG procedure

EEG data were collected in an electromagnetically and acoustically shielded chamber, with the participant sitting in a comfortable chair. Disk electrodes were applied to the face above and below the eyes, and behind each ear (mastoids).

The computationally linked mastoids were used as reference electrodes. Data were collected from five electrodes attached to sc[illegible] International [illegible] 4).

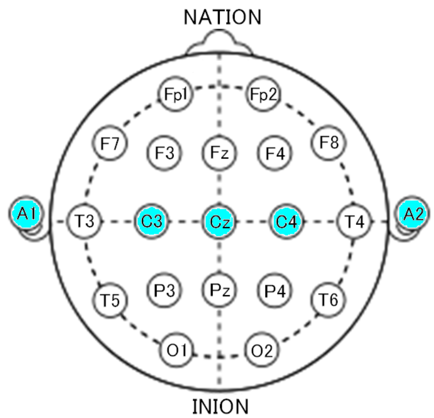

Figure 4. 10–20 method of electrode placement.

The impedances on all electrodes were measured and confirmed to be less than 10k both before and after testing.

The specifications of electrodes used in our experiment are as follows:

- electrode material: Ag/AgCl, Nihon Kohden Corp., Japan, NE-113A
- electrode geometry: discs
- size: 7mm in diameter
- used gel or paste, alcohol applied to cleanse skin, skin abrasion
- inter-electrode distance: 13 mm apart

The following combination analog/digital converter and amplifier was used to obtain EEG measurements. The model, resolving power, and sampling rate were as follows:

- converter/amplifier: Digitex Lab Co., Ltd., Japan, Polymate AP1532
- sampling rate: 500Hz
- AD–card: 32 ch, 16 bits
- EEG band pass filter: 0.1 – 30 Hz

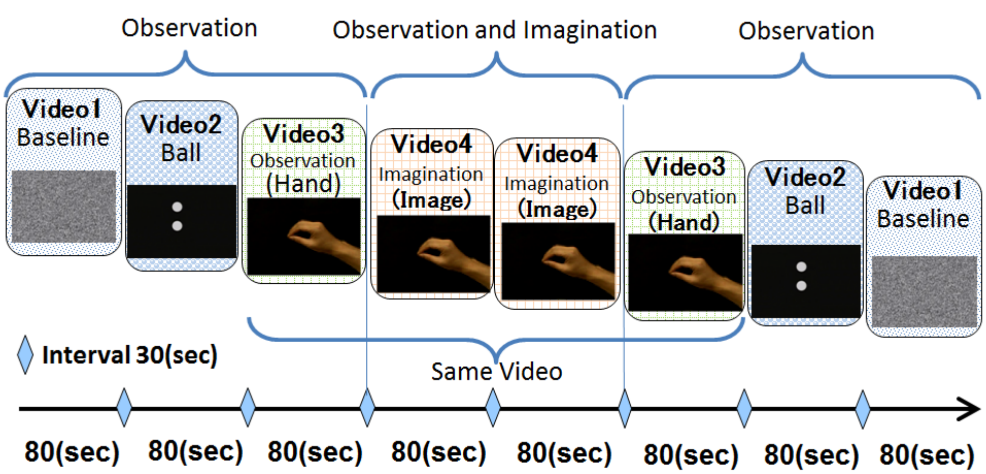

Figure 3. The flow of the tasks.

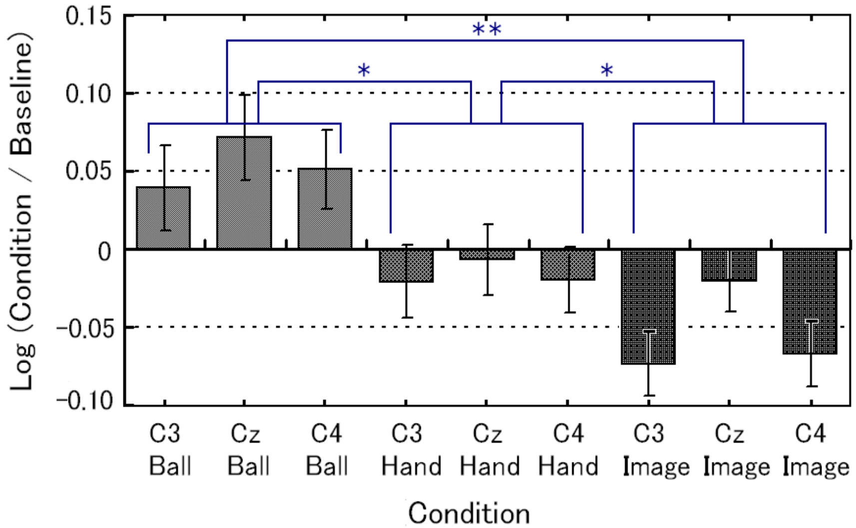

Figure 5. *Bars represent the mean log ratio of power in the mu frequency (8–13 Hz) during the Ball condition (light gray), Observation condition (medium gray), and Imagination condition (dark gray) over the power in the Baseline condition for scalp locations C3, CZ, and C4. Error bars represent the standard error of the mean. For all values, a mean log ratio greater than zero indicates mu enhancement; a mean log ratio less than zero indicates mu suppression. Significant suppression is indicated by asterisks, *P <0.05, **P < 0.01.*

Data were analyzed only if there was a sufficiently clean amount with no movement or eye blink artifacts. For each clean segment, the integrated power in the 8–13 Hz range was computed using a Fast Fourier Transform.

Data were segmented into epochs of 2 s beginning at the start of the segment. Fast Fourier Transforms were performed on the epoched data (1024 points)

Mu suppression was calculated by forming a ratio of the power during the experimental conditions relative to the power in the baseline condition.

We calculated the ratio of the power during the Ball condition, the Observation condition and the Imagination condition relative to the power during the Baseline condition. A ratio was used to control for variability in absolute mu power as a result of individual differences such as scalp thickness and electrode impedance, as opposed to mirror neuron activity.

An experimental condition × electrodes scalp position ANOVA was used. ANOVAs were used to compare the log suppression values of each condition to zero, using the Bonferroni correction for multiple comparisons.

Although data were obtained from three electrodes across the scalp, mu rhythm is defined as oscillations measured over the sensorimotor cortex, thus only data from electrode sites C3, Cz and C4 are presented.

III. Results

Powers in the mu frequency at scalp locations corresponding to sensorimotor cortex (C3, Cz, and C4) in the Ball, Observation and Imagination conditions were compared to power in the Baseline (visual white noise) condition by forming the log ratio of the power in these conditions for both groups (Figure 5). An experimental condition × electrodes position ANOVA was used. The results revealed a significant main effect of condition ($F(2, 56) = 12.64$, $p < 0.01$). Pair-wise comparisons revealed a linear trend with the imagining hand movement condition showing the greatest amount of suppression (M = −0.05) followed by the observing hand movement condition (M = −0.02), with the observing balls condition showing the least amount of suppression (M = 0.05).

Neither a significant electrodes scalp position × condition interaction, nor a significant main effect of electrodes scalp position was found.

IV. Discussion

The results of the present study found increases in mirror neuron system activation with simultaneous imagining and observing a hand movement. Continuously, we investigate whether the inhibition of mu waves occurs when children and adults diagnosed with ASD imagine and observe the hand motion.

The EEG quantification of the impact of imagination upon mu wave activity creates the potential for this apparatus to serve in a Brain Machine Interface capacity, in which bio-feedback can be provided to subjects being trained to develop imaginative capacities.

Effective training and development of the capacity to imagine in people diagnosed with ASD holds the promise of therapeutic benefit.

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