

# Gender differences in the human mirror system: a magnetoencephalography study

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The present study investigated whether the human mirror-neuron system exhibits gender differences. Neuromagnetic  $\mu$  (~20 Hz) oscillations were recorded over the right primary motor cortex, which reflect the mirror neuron activity, in 10 female and 10 male participants while they observed the videotaped hand actions and moving dot. In accordance with previous studies, all participants had  $\mu$  suppression during the observation of hand action, indicating activation of primary motor cortex. Interestingly, the

female participants displayed apparently stronger ( $P < 0.05$ ) suppression for the hand action than for the moving dot whereas the men showed the opposite ( $P < 0.05$ ). These findings have implications for the extreme male brain theory of autism and support the hypothesis of a dysfunctional mirror-neuron system in autism. *NeuroReport* 17:1115–1119 © 2006 Lippincott Williams & Wilkins.

**Keywords:** gender differences, magnetoencephalography, mirror-neuron system, primary motor cortex

## Introduction

The mirror-neuron system (MNS), the neurophysiological mechanism that matches action observation and execution in monkeys and in humans, plays a critical role in action understanding (e.g. [1–8]). This automatic perception–action link is also considered to be the basis of the emotional recognition and social sensitivity [9–11]. Moreover, at a population level, women perform better than men on the tasks of emotion recognition and social sensitivity (e.g. [12–15]). All of these previous studies seem to suggest that the MNS is likely to have gender differences. To date, however, there is no research that has tackled this issue.

The current experiment utilizes the ~20 Hz  $\mu$  rhythm from magnetoencephalography (MEG) measurements to assess whether the MNS operates differently in female and male individuals. The ~20 Hz  $\mu$  rhythm, as an indicator of the state of the precentral motor cortex, reflects the mirror neuron activity [5,16,17]. After an electrical stimulation of the median nerve at the wrist, this rhythm initially suppresses and then rebounds strongly 200–400 ms later. This poststimulus rebound, highly reproducible and robust, has been used as an indicator of the functional state of the primary motor cortex (MI) [5,16–18]. The rebound itself likely reflects cortical inhibition whereas its suppression represents cortical activation [19–21]. Besides, functional brain imaging studies (e.g. [6,22]) suggested that covert

hand mimicry induced by passive observation of hand action is predominantly governed by right hemispheric MNS. We thus explored the  $\mu$  rhythm of right MI to probe the gender differences of the MNS.

## Methods

### Participants

Ten women and 10 men, healthy volunteers aged between 20 and 32 years, participated in the study after having given written informed consent. The study was approved by the local Ethics Committee (Taipei Veterans General Hospital) and conducted in accordance with the Declaration of Helsinki. The participants did not differ in their age and education level. None of them had any history of substance abuse, major medical, psychiatric, or neurological disorder. All participants were prescreened to verify that they were heterosexual (self-reported as having only opposite-sex sexual desire and sexual experiences). They had normal or corrected-normal visual acuity and were right handed, according to the Edinburgh handedness inventory. Participants were naïve regarding the experimental goals.

### Experimental paradigm

The left median nerve was stimulated continuously over the wrist with 0.2 s constant-current pulses once every 3 s, with

stimulus intensities (4–7 mA in different participants, the mean of women and men as 5 and 6 mA, respectively) exceeding the motor threshold, to elicit the poststimulus rebounds of the  $\sim 20$  Hz *mu* rhythm during the following conditions: (i) *rest*, relaxing and fixing eyes to a cross; (ii) *hand*, attentively watching the colored video clip which depicted right hand manipulating a small three-dimensional object; (iii) *dot*, attentively observing the video clip which depicted a two-dimensional red light dot (1.5 cm diameter) moving randomly. Rest was set as the control. The displayed male hand with hairless and short nails rendered androgynous in absence of sexually arousing stimuli. Each condition was presented in two segments; the duration of each segment was 3 min. The order of the video clips (hand and dot) was randomized and balanced between women and men. The video clips were displayed 100 cm in front of each participant, and the hand subtended  $2\text{--}4^\circ$  of visual angle. Spontaneous cortical activity without median nerve stimuli was recorded while participants kept their eyes open for 1 min and closed for 1 min.

### Recording

Cortical magnetic signals were recorded with a 306-channel whole-scalp neuromagnetometer (Neuromag Ltd., Helsinki, Finland), which contains 204 planar gradiometers and 102 magnetometers. The exact head position with respect to the sensor array was determined by measuring magnetic signals from four head indication coils placed on the scalp. The coil locations with respect to anatomical landmarks on the head were identified with a three-dimensional digitizer (Isotrak 3S10002, Polhemus Navigation Sciences, Colchester, Vermont, USA). The signals were recorded with a passband of 0.03–190 Hz and digitized at 0.6 kHz. Vertical and horizontal electrooculograms were monitored to reject all MEG epochs coinciding with blinks and excessive eye movements with an amplitude threshold of  $600\ \mu\text{V}$ . For evoked responses, about 90 artifact-free single responses were averaged on-line separately for each condition. The ongoing oscillatory neuromagnetic activity was recorded continuously, and the data were stored on an optical disk for later off-line analysis. Immediately after the MEG signal recording, each participant was required to conjecture the gender of the displayed hand.

### Data analysis

First, *t*-tests were calculated to compare the conjectural rate to the gender of the displayed hand between women and men. Second, the stimulus-related changes of the  $\sim 20$  Hz *mu* rhythm with temporal-frequency representation were quantified, with a method on the basis of Morlet wavelets (4D-Toolbox, <http://neuro.hut.fi/~tanzer/d4d/>). The analytic frequencies selected a range between 14 and 30 Hz. The analytic period of 3 s was started 1 s before the stimulus ( $-1$  to 2 s). The maximal  $\sim 20$  Hz poststimulus rebounds at each condition (rest, hand, and dot), in a time window from 300 to 2000 ms after median nerve stimulation, were chosen from the selected nine pairs of the sensors over right motor region. Then the normalized suppression of the maximal  $\sim 20$  Hz poststimulus rebound for hand and dot was calculated with the maximal  $\sim 20$  Hz poststimulus rebound for rest minus that for hand and dot, respectively, as percentages of the maximal  $\sim 20$  Hz poststimulus rebound for rest. Statistical analysis on the normalized suppression

was assessed by a two-way repeated-measures ANOVA using within-subject factor for the conditions (hand, dot) and between-subject factor for the genders (women, men), followed by post-hoc Tukey's tests.

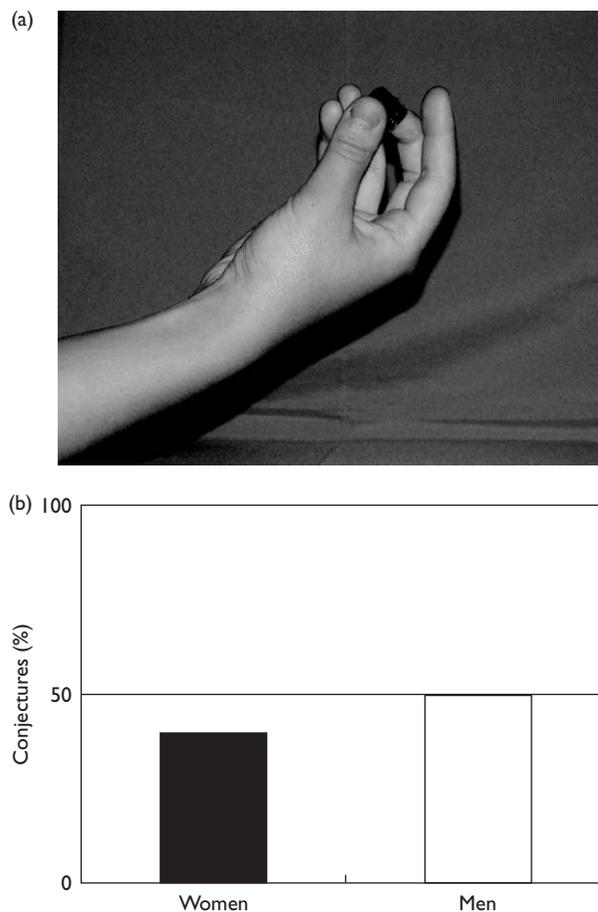
## Results

### Conjecture

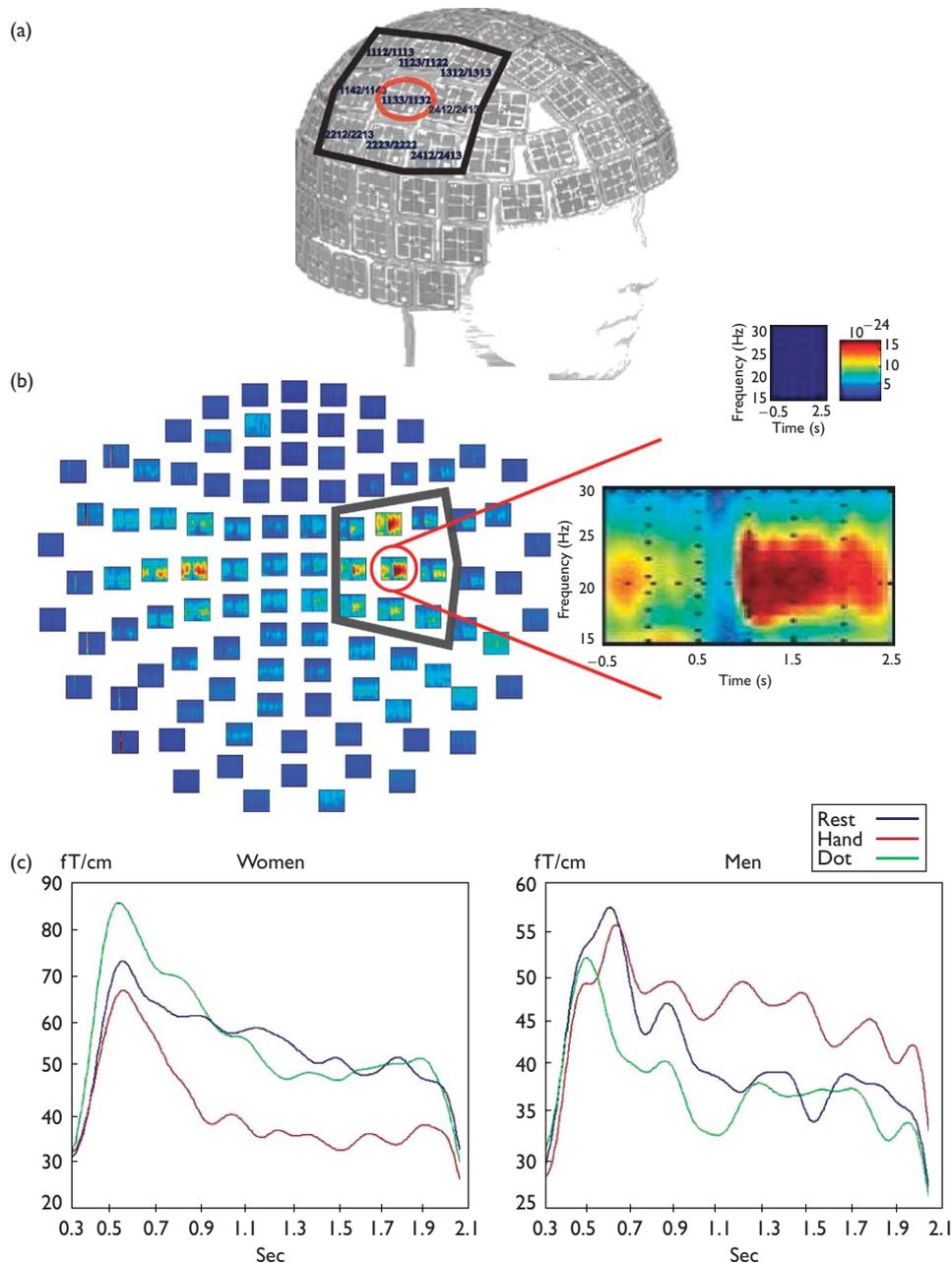
The conjectural rate about the hand gender did not differ significantly ( $P = 0.673$ ) between women and men. Only up to half of all participants could correctly guess to ensure the display of the androgynous hand (Fig. 1).

### Magnetoencephalography

The temporal evolution of the  $\sim 20$  Hz poststimulus rebound at a pair of sensors over the right motor cortex, contralateral to the left median nerve stimulated, appears differently, which is demonstrated in one of the female and male participants (Fig. 2). During rest, the  $\sim 20$  Hz rhythm strongly rebounded after the median nerve stimulation, usually starting at about 300 ms and reaching its maximal level within 700 ms after the stimulus. During the hand condition, both female and male participants suppressed this  $\sim 20$  Hz poststimulus rebound to some degree, indicating



**Fig. 1** (a) Snapshot of the videotaped hand action. (b) Conjectures at the observed hand gender between the male ( $\square$ ) and female ( $\blacksquare$ ) participants. Forty percent of the women and 50% of the men identified the hand as male ( $P > 0.05$ ), which confirmed that the hand appeared rather androgynous.



**Fig. 2** Temporal evolution of the  $\sim 20$  Hz  $\mu$  rhythm. (a) A three-dimensional view of the head with the locus of the selected sensors. (b) Time-frequency spectrum of all magnetoencephalographic sensors and plot from a pair of selected sensors. (c) Poststimulus  $\sim 20$  Hz rebound in one female and one male participant at the three conditions (rest, blue; hand, red; dot, green). During the rest condition, the  $\sim 20$  Hz  $\mu$  rhythm strongly rebounded after the median nerve stimulation, usually starting at about 300 ms and reaching its maximal level within 700 ms after the stimulus. During the dot relative to the hand condition, the male participant showed prominent  $\mu$  suppression whereas the female participant displayed the opposite.

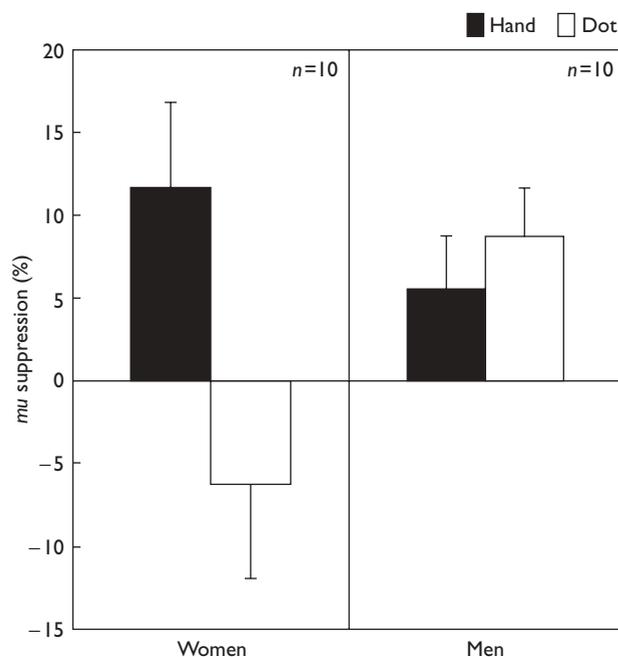
right MI activation. During the dot relative to the hand condition, the male participant, however, showed prominent  $\mu$  suppression whereas the female participant displayed the opposite.

When the normalized suppression of the maximal 20 Hz post-stimulus rebound was quantified, women had the mean  $\pm$  SEM as  $11.6 \pm 5.1\%$  in the hand and as  $6.3 \pm 5.7\%$  in the dot. For men, the mean  $\pm$  SEM was  $5.6 \pm 3.2\%$  and  $8.8 \pm 2.8\%$ , respectively. The statistical results did not show a major effect in the gender itself ( $F_{1,18} = 0.767$ ,  $P = 0.393$ ), but in the condition itself ( $F_{1,18} = 4.521$ ,  $P = 0.048$ ) and their interaction ( $F_{1,18} = 9.331$ ,  $P = 0.007$ ). To probe the significant

interaction, the post-hoc Tukey's tests found that women had significantly stronger ( $P = 0.027$ ) suppression for the hand than for the dot and men showed the opposite ( $P = 0.037$ ) (Fig. 3).

## Discussion

The current study demonstrates gender differences in right MI activation during the observation of hand action relative to the observation of moving dot. These findings lend support to the existence of gender differences in the human MNS. In accordance with previous reports [5], the maximal



**Fig. 3** Gender differences in the normalized suppression (mean  $\pm$  SEM%) of the  $\sim$ 20 Hz poststimulus rebound during the hand (■) and dot (□). Female participants had stronger suppression to the hand relative to the dot ( $P < 0.05$ ). Male participants, by contrast, showed stronger suppression to the dot relative to the hand ( $P < 0.05$ ).

$\sim$ 20 Hz poststimulus rebound significantly differed among the rest, hand, and dot conditions (Fig. 2). Interestingly, there was a noteworthy major effect in the interaction of the condition (hand, dot) and the gender. Women had stronger *mu* suppression, that is, MI activation, during the hand than during the dot whereas men showed the opposite (Fig. 3).

The significant interaction between the conditions and the genders may in part result from the different strategy of the participants (women versus men) during the observation of moving dot. Men might treat this stimulus as an 'object' to trigger the canonical neurons of the premotor cortex, but women did not. One MEG study by Hari *et al.* [5] reported that the viewing of a moving dot did suppress the  $\sim$ 20 Hz poststimulus rebounds, but the suppression was weaker than that observed during action viewing. Here it was found that such suppression was modulated by the participant's gender. Moreover, the present findings might reflect partially the opposite-gender response, that is, female participants responded stronger to the displayed male hand, although the equivalent conjectural rate between the genders was controlled to ensure the male hand rendered androgynous. To address this issue, we need a further study with the displayed female hand.

Importantly, this study used MEG measures to demonstrate gender differences of the human MNS. Female participants showed stronger  $\sim$ 20 Hz *mu* suppression, as an indicator of MI activation, when watching hand action, whereas men displayed stronger ones when observing a moving dot. That is, when individuals observe an action done by another individual, motor cortex in female participants cortex becomes more active than in male participants. The perception-action mechanism, which automatically prompts the observer to resonate with the

emotional state of another individual with the observer emulating the motor representations [10], is considered to be a crucial aspect of empathy [11]. The neuromagnetic gender differences of the MNS noted here appear in accordance with psychological and cognitive gender dimorphism, that is, women are stronger empathizers and men are stronger systemizers in the general population [12–15]. Interestingly, William and colleagues [23] speculated that consequent developmental failures of the MNS could lead to impaired self-other representations and imitation. This, in turn, could lead to impaired social and communication abilities, such as empathy and language, as in autism [23]. Previous studies using electroencephalogram and MEG had demonstrated that autists have abnormal function of the MNS with no *mu* suppression to the observed hand movements [24,25]. Here, using MEG revealed that healthy male participants had less *mu* suppression to the watched hand action relative to the moving dot. Considering that the extreme male brain theory of autism posits that autism represents an extreme of the male brain pattern with impaired empathizing and enhanced systemizing [14,15], the present findings point out the normal male MNS pattern on MEG to support the hypothesis of a dysfunctional MNS in autism.

### Conclusion

The human MNS exhibits gender differences as reflected by the neuromagnetic *mu* rhythm to the observation of hand action versus a moving dot.

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