Sex differences in spinal excitability during observation of bipedal locomotion

Yawei Cheng[a], Jean Decety[g], Ching-Po Lin[b], Jen-Chuen Hsieh[d], Daisy Hung[c,f] and Ovid J.L. Tzeng[c,e]

[a]Department of Physical Medicine and Rehabilitation, Taipei City Hospital, [b]Brain Connectivity Laboratory, Institute of Neuroscience, [c]Cognitive Neuropsychology Laboratory, National Yang-Ming University, [d]Laboratory of Integrated Brain Research, Department of Medical Research and Education, Taipei Veterans General Hospital, [e]Institute of Linguistics, Academia Sinica, Taipei, [f]Institute of Cognitive Neuroscience, College of Science, National Central University, Taoyuan, Taiwan and [g]Department of Psychology and Center for Cognitive and Social Neuroscience, The University of Chicago, Chicago, Illinois, USA

Correspondence to Yawei Cheng, MD, PhD, Department of Physical Medicine and Rehabilitation, Taipei City Hospital, 145 Zheng Zhou Road, Taipei 103, Taiwan
Tel: +886 2 25553000; fax: +886 2 25595510; e-mail: yaweicheng@gmail.com

Received 25 January 2007; accepted 2 February 2007

This study investigated whether there are sex differences in the spinal excitability of the human mirror–neuron system. We measured the modulation of spinal excitability, elicited by Hoffmann reflex in the left plantar flexor muscle (soleus), when women and men participants observed videos of bipedal heel-stepping (plantar dorsiflexion), standing still, and bipedal toe-stepping (plantar flexion). Men and women were similarly divided in their sex judgments of the observed legs. Our results indicate that whereas both men and women mimicked spinal excitability to the observed bipedal step, only women participants produced stronger modulation of spinal excitability. These findings demonstrate that the human mirror–neuron system exhibits sex differences in spinal excitability. *NeuroReport* 18:887–890 © 2007 Lippincott Williams & Wilkins.

Keywords: bipedal, Hoffmann reflex, mirror–neuron system, sex, spinal

Introduction

Mirror neurons, originally discovered in area F5 of the monkey premotor cortex, discharge when a monkey performs an action and when a monkey observes another monkey or a human performing a similar action [1]. The mirror–neuron system, a basic sensory-motor neurophysiologic mechanism that automatically aligns our behaviors with those of our partners, presumably plays a role in action understanding (e.g. Refs. [2,3]) and facilitating communication [4,5]. This automatic perception–action resonance is considered to be the basis of the emotional recognition and social sensitivity [6,7]. Psychologically, women generally perform better than men on the tasks of emotion recognition and social sensitivity (e.g. Refs. [8,9]). Furthermore, one recent neuromagnetic study demonstrated sex differences of the human mirror–neuron system [10]. In that study, female participants' observation of hand action produced stronger activations in the primary motor cortex than did viewing a moving dot. Such findings suggest that women seem to have more motor resonance to action observation than men.

Considering that the spinal cord, as well as the primary motor cortex, constitutes the corticospinal track, the current experiment adopted the amplitude modulation (AM) of Hoffmann (H) reflex during the observation of bipedal step as the spinal excitability to assess whether the mirror–neuron system operates differently across female and male participants. Direct evidence of spinal excitability in the human mirror neuron system was drawn from previous H-reflex studies. Notably, Baldissera and colleagues (2001) [11] reported an AM of H-reflex in forearm finger flexor muscles during the observation of hand actions. Our previous study [12] also disclosed the AM of H-reflex in plantar flexor muscles (soleus) during the observation of bipedal step. It is thus possible to track the modulation of spinal excitability to investigate if the human mirror–neuron system exhibits sex differences.

Methods

Participants

Fifty healthy participants (25 women) between 20 and 30 years old were enrolled in the study after giving written informed consent. The study was approved by the local Ethics committee (Taipei City Hospital, Taipei, Taiwan) and conducted in accordance with the Declaration of Helsinki. The female and male participants did not differ in terms of age ($P=0.85$) or educational level ($P=1.00$). They were prescreened to verify that they were heterosexual (self-reported as having only opposite-sex sexual desire and sexual experiences). All of them were right-handed dominant, according to the Edinburgh handedness inventory; and right foot dominant, as determined by the preferred foot for kicking a ball [13]. They had no history of neurological, psychiatric, or medical disorders. The participants lay comfortably prone on a physical examination bed with their eyes at about 50 cm distance from a 14-inch LCD screen. Their feet were hung over with the lateral malleolus approximately at the posterior rim of the bed.

Stimuli

Participants were requested to attentively watch the videos. The video presentation (DCR TRV70K, SONY) included a randomized sequence of three segments (video duration, 5 s) representing (a) standing still, 'stand'; (b) bipedal toe-stepping, 'toe'; and (c) bipedal heel-stepping, 'heel'. Stand was used as a control. Toe and heel presented movements during which the soleus muscle acts as an agonist and antagonist, respectively. The actor in the video representation was young, right-handed and right-foot dominant. The displayed male legs appeared thin and had very little observable hair to render them androgynous. The actors walked bare-footed on a plain surface at a comfortable speed. Each video clip depicted bilateral lower legs from just above the knees and was filmed from the left side in lateral view. No other body part was shown. The lateral view was selected because it showed the entire calf muscle and feet more fully than an anterior or posterior view. Participants were naive with the actor in the video.

H-reflex recordings

Constant current pulses (duration 0.5 ms) were delivered (DANTEC, Skovlunde, Denmark) to evoke the monosynaptic soleus H-reflex on the left leg. The bipolar surface-stimulating electrode was positioned over the posterior tibial nerve near the popliteal crease's center under constant fixation. The recording electrode was positioned on the soleus muscle, halfway between the midpoint of the popliteal fossa and upper border of the medial malleolus. The reference electrode was placed in the same line 5 cm distal to the active electrode, and the ground electrode was placed between the stimulating and reference electrodes. The stimulating electrodes were correctly positioned by inspecting muscle twitch stimulation. The stimulation frequency was around 1 Hz to avoid the habituation phenomenon [14]. The stimulus intensity was increased until maximal H-reflex amplitude and minimum motor response (M wave) were reached, while the participant lay prone facing the black screen. The mean amplitude of five elicited H-reflexes in this condition was the 'baseline'. Given this stimulus intensity at the baseline, the computer elicited the test H-reflex responses on the left leg immediately after the commencement of each video representation. During video presentation, participants were requested to keep a still position and to watch attentively the stimuli presented on the screen. To assess the absence of any spontaneous electromyography (EMG) activity during video presentation, pretrigger background EMG (5 s) was acquired before H-reflex stimulation. No EMG activity was found in the rectified background traces.

Behavioral task

The behavior task was divided into two parts to ensure the displayed leg appeared androgynous. First, another 40 volunteers (20 women) were requested to grade their conjectural response of the videoed leg's sex using a 7-point scale [definitely clear male/female characteristics (3 vs. −3), probably some male/female characteristics (2 vs. −2), possibly slight male/female characteristics (1 vs. −1), and uncertain gender identity (0)]. Second, immediately after H-reflex recordings, the participants were asked to conjecture whether the observed legs were those of a man or a woman.

Data analysis

During each video presentation, five H-reflexes were elicited from the left leg. Peak-to-peak amplitudes of the H-reflex were measured. Afterwards, the AM of H-reflex at each condition was defined as the difference (in μV) by subtracting the averaged H-reflex amplitude from the baseline.

Results

Behavior

The graded conjectural response of the volunteers about the sex of the videotaped leg showed 0 ± 1.2 in average. The participants involved in H-reflex recordings were mostly split, with 64% of the female participants and 60% of the males identifying the legs as male. Their conjectural rate about the sex of the leg did not differ significantly ($P=0.29$) between the female and male participants. The behavioral results confirmed that the legs appeared androgynous.

H-reflex

The female and male participants differed neither in the baseline (women vs. men: 2.48 ± 0.4 vs. 2.64 ± 0.3 mV; $P=0.52$) nor in the stimulus intensity (15.1 ± 1.2 vs. 14.8 ± 2.1 mA; $P=0.89$). Figure 1 illustrates the H-reflex and M-wave during the baseline, heel, stand, and toe in one

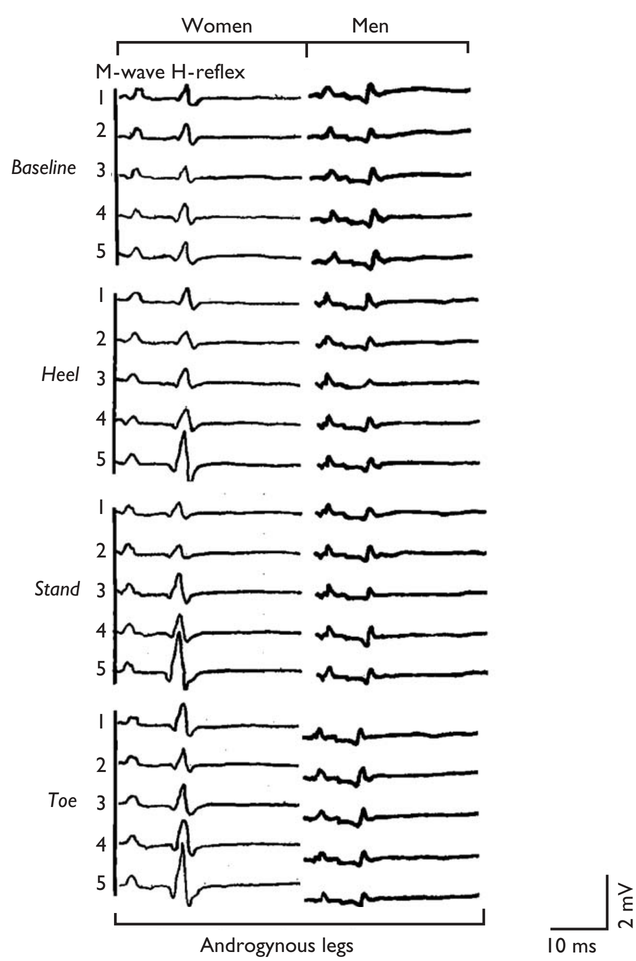

Fig. 1 The M-wave and H-reflex response in one female and one male participant during baseline and viewing heel, stand and toe.

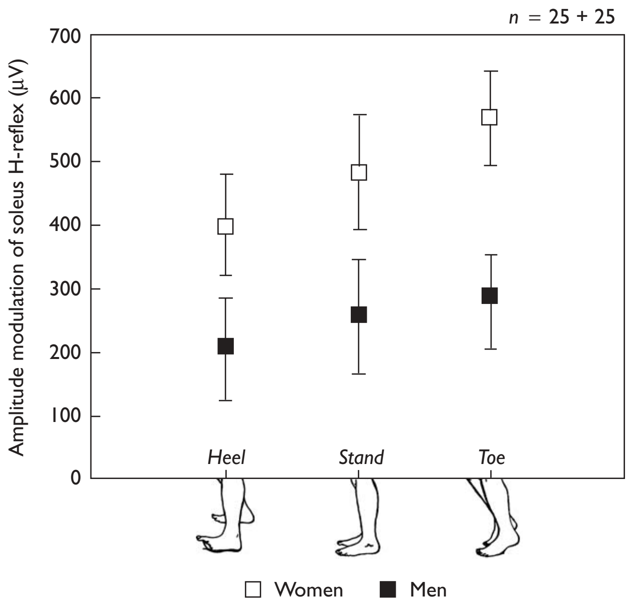

Fig. 2 Spinal excitability of left soleus H-reflex when watching bipedal step in the model of androgynous-appearing legs. No matter observing which kind of bipedal step, female participants (□) have significantly stronger amplitude modulation of H-reflex ($P = 0.024$) than males (■). Additionally, their spinal excitability mimics the observed bipedal step, that is, the amplitude modulation of soleus H-reflex during their observation increases from heel, stand, to toe. Heel, bipedal heel-stepping; stand, standing still; toe, bipedal toe-stepping. Error bars indicate SEM.

female and one male participant. For the whole group of 25 women and 25 men, we ran a two-way mixed analysis of variance with the sex of the participant (female vs. male) as a between-participant factor and bipedal stepping type (heel, stand, toe) as a within-participant factor. Using the H-reflex AM as the dependent variable, female participants showed 400 ± 80, 484 ± 90, and 568 ± 73 μV; male participants displayed 205 ± 80, 256 ± 90, 279 ± 73 μV during heel, stand and toe. Overall, women modulated stronger spinal excitability than men [$F(1,48) = 5.45$, $P = 0.02$]. In addition, Fig. 2 illustrates H-reflex AM mimicking the observed bipedal step, irrespective of the sex of the participants. That is, although the actual contraction of soleus muscle increases from heel, stand, to toe, the soleus H-reflex AM during their observation increased accordingly [$F(2,96) = 3.26$, $P = 0.04$]. The interaction of the bipedal stepping type and participant's sex, however, did not reach significance ($P = 0.57$). Post-hoc Tukey's Honestly Significant Difference tests revealed that the gender effect was mainly driven by significant differences for the *toe* between female and male participants ($P = 0.01$) instead of the stand ($P = 0.07$) and the heel ($P = 0.09$). The main effect of bipedal step mainly arose from the toe relative to the heel of the women' observation ($P = 0.03$). Besides, the comparison of the perceived sex differences (same sex vs. opposite sex) did not reach significance within either participant sex group (women, $P = 0.32$; men, $P = 0.43$).

Discussion

The current study found sex differences in the modulation of spinal excitability during the observation of bipedal step. These findings support the existence of sex differences in the spinal excitability of the human mirror–neuron system. In accordance with our previous study [12], the modulation of spinal excitability mimicked the seen bipedal step. Interestingly, female participants appeared to resonate with stronger spinal excitability than men when watching the bipedal step.

The main effect of sex noted here might result from nonspecifically physiologic as well as empathic sex differences. This study, however, has controlled the physiologic factors to a degree. The female and male participants were of similar age and educational level. Neither the guess of the sex of the displayed leg, the baseline, the stimulus intensity of H-reflex, nor the perceived sex differences (same sex vs. opposite sex) differed significantly between women and men.

The known sex differences in empathy may account for this sex difference of spinal excitability during the observation of bipedal step. Empathy is considered as the capacity to understand and respond to the unique affective experiences of another person [7]. One crucial aspect of empathy relies on the unconscious affective sharing between self and other [6,7]. This sharing stems from the perception–action coupling (the mirror neuron system), which automatically induces the observer to resonate with the emotional state of another individual, with the observer emulating the motor representations and associated automatic and somatic responses that stem from the observed target [6]. A number of the scholars have recently suggested that the mirror–neuron system is the seat of empathy (e.g. Refs. [15–17]). The mirror–neuron system that matches observation and execution of motor actions could give rise to shared representations, which subsequently constitutes one important aspect of empathy. Furthermore, it has been acknowledged that women show superiority in empathy [9,18]. Women appear to perform better at reading others' facial and body actions while communicating, and score higher on tests of emotional recognition (e.g. [8,9,19,20]). Therefore, the sex differences in spinal excitability of the mirror–neuron system noted here, depicting stronger spinal excitability to the observed bipedal step in female than in male participants, might arise from sex differences in empathy.

Furthermore, the current findings in the sex differences of spinal excitability accord well with previous brain imaging and neurophysiologic studies. Using functional brain imaging, women displayed stronger activation in inferior frontal cortex during emotional speech perception than men [21]. Using steady-state visual evoked potentials, women showed widespread frontal latency reductions, predominantly right side, associated with the processing of unpleasant images but men did not [22]. Using magnetoencephalography, women produced stronger activation of primary motor cortex for viewing hand action relative to a moving dot, whereas men did the opposite [10]. Using EMG, women awakened stronger activities of facial corrugator (frowning) and zygomatic (smiling) muscles when viewing angry and happy faces, respectively, than men [23]. In this context, the current results in spinal excitability provide another evidence to support gender differences in corticospinal excitability of the human mirror–neuron system.

Accordingly, the discrepancy between the present and Baldissera and co-workers [11] results could be due to the dynamics of the human mirror–neuron system. The spinal excitability mimics the observed bipedal step, whereas the spinal excitability was opposite to the observed hand action [11,12]. Here, women displayed more mimicking spinal excitability to the watched bipedal step than men. Behaviorally, women resonate with more head rotation in conversation than men [24]. Thus, we postulated that the wide range of spinal excitability of the human mirror–neuron system might represent the likelihood of an observed action being repeated by the observer [12,25]. Whether the spinal excitability can be modulated by the identity of the observer's and observed sex is a matter for further study.

Conclusion

For women, more than for men, the observation of bipedal step could modulate the spinal excitability of the mirror–neuron system. In agreement with speculations of sex differences in empathizing, the present findings are also in line with findings from previous brain imaging and neurophysiologic studies.

Acknowledgements

This study was sponsored by National Science Council (NSC95-2752-H-010001PAE). We thank three anonymous reviewers from their valued comments and suggestions.

References

1. di Pellegrino G, Fadiga L, Fogassi L, Gallese V, Rizzolatti G. Understanding motor events: a neurophysiological study. *Exp Brain Res* 1992; **91**:176–180.
2. Fadiga L, Fogassi L, Pavesi G, Rizzolatti G. Motor facilitation during action observation: a magnetic stimulation study. *J Neurophysiol* 1995; **73**:2608–2611.
3. Rizzolatti G, Fogassi L, Gallese V. Neurophysiological mechanisms underlying the understanding and imitation of action. *Nat Rev Neurosci* 2001; **2**:664–670.
4. Rizzolatti G, Arbib MA. Language within our grasp. *Trends Neurosci* 1998; **21**:188–194.
5. Rizzolatti G, Craighero L. The mirror–neuron system. *Annu Rev Neurosci* 2004; **27**:169–192.
6. Preston SD, de Waal FBM. Empathy: its ultimate and proximate bases. *Behav Brain Sci* 2002; **25**:1–72.
7. Decety J, Jackson PL. The functional architecture of human empathy. *Behav Cogn Neurosci Rev* 2004; **3**:71–100.
8. Hall JA. *Nonverbal sex differences*. Baltimore: Johns Hopkins University Press; 1984.
9. Baron-Cohen S, Knickmeyer R, Belmonte MK. Sex differences in the brain: implications for explaining autism. *Science* 2005; **310**:819–823.
10. Cheng YW, Tzeng OJL, Decety J, Imada T, Hsieh JC. Gender differences in the human mirror system: a magnetoencephalography study. *Neuroreport* 2006; **17**:1115–1119.
11. Baldissera F, Cavallari P, Craighero L, Fadiga L. Modulation of spinal excitability during observation of hand actions in humans. *Eur J Neurosci* 2001; **13**:190–194.
12. Cheng YW, Tzeng OJL, Hung D, Decety J, Hsieh JC. Modulation of spinal excitability during observation of bipedal locomotion. *Neuroreport* 2005; **16**:1711–1714.
13. Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 1971; **9**:97–113.
14. Oh SJ. *Clinical electromyography: nerve conduction studies*. Baltimore: William & Wilkins; 1993.
15. Gallese V, Goldman A. Mirror neurons and the simulation theory of mind-reading. *Trends Cogn Sci* 1998; **2**:493–501.
16. Decety J, Sommerville JA. Shared representations between self and others: a social cognitive neuroscience view. *Trends Cogn Sci* 2003; **7**:527–533.
17. Jackson PL, Meltzoff AN, Decety J. How do we perceive the pain of others? A window into the neural processes involved in empathy. *NeuroImage* 2005; **24**:771–779.
18. Seifritz E, Esposito F, Neuhoff JG, Lüthi A, Mustovic H, Dammann G, *et al*. Differential sex-independent amygdala response to infant crying and laughing in parents versus nonparents. *Biol Psychiat* 2003; **54**:1367–1375.
19. Geary DC. *Male, Female: the evolution of human sex differences*. Washington, DC: American Psychological Association; 1998.
20. McClure EB. A meta-analytic review of sex differences in facial expression processing and their development in infants, children, and adolescents. *Psychol Bull* 2000; **126**:424–453.
21. Schirmer A, Zysset S, Kotz SA, Cramon DY. Gender differences in the activation of inferior frontal cortex during emotional speech perception. *NeuroImage* 2004; **21**:1114–1123.
22. Kemp AH, Silberstein RB, Armstrong SM, Nathan PJ. Gender differences in the cortical electrophysiological processing of visual emotional stimuli. *NeuoImage* 2004; **16**:632–646.
23. Dimberg U, Lundquist LO. Gender differences in facial reactions to facial expressions. *Biol Psychol* 1990; **30**:151–159.
24. Rotondo JL, Boker SM. Behavioral synchronization in human conversational interaction. In: Stamenov M, Gallese V, editors. *Mirror neurons and the evolution of brain and language*. Philadelphia: John Benjamin's Press; 2002. pp. 151–162.
25. Morrison I. Mirror neurons and cultural transmission. In: Stamenov M, Gallese V, editors. *Mirror neurons and the evolution of brain and language*. Philadelphia: John Benjamin's Press; 2002. pp. 333–340.