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Research article

Modulation of Hoffmann reflex excitability during action observation of walking with and without motor imagery

Naotsugu Kaneko[a], Yohei Masugi[a,b], Noboru Usuda[a], Hikaru Yokoyama[a,c], Kimitaka Nakazawa[a,*]

[a] Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo, Komaba, Meguro-ku, Tokyo, Japan
[b] Institute of Sports Medicine and Science, Tokyo International University, Matoba, Kawagoe-shi, Saitama, Japan
[c] JapanSociety for the Promotion of Science, Chiyoda-ku, Tokyo, Japan

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ABSTRACT

Action observation (AO) and motor imagery (MI) are used for motor impairment rehabilitation after neurological disorders, such as spinal cord injuries or strokes. Clinical studies have reported that rehabilitation using AO and MI is effective in restoring motor function. Our previous study showed a difference in the modulation of corticospinal excitability only during action observation (AO) of walking and AO of walking combined with motor imagery (AO + MI). However, it is unclear whether AO and AO + MI can modulate spinal reflex excitability as well as corticospinal excitability. Thus, the purpose of this study was to investigate the modulation of the Hoffmann reflex (H-reflex) during AO and AO + MI.

We measured H-reflex in the soleus muscle under the following conditions: (1) control, (2) AO, and (3) AO + MI. Posterior tibial nerve electrical stimulation, which induces H-reflex, was applied at the following four walking phases: 1) mid-stance, 2) terminal-stance, 3) early-swing, and 4) terminal-swing. Our results showed that AO + MI significantly increases H-reflex over AO alone, regardless of phase and that AO significantly modulates H-reflex depending on the observed phase. These findings suggested that spinal reflex excitability can be modulated during AO and AO + MI and that neural effects are different in AO and AO + MI.

1. Introduction

Action observation (AO) and motor imagery(MI) are used for motor impairment rehabilitation after neurological disorders, such as spinal cord injuries or strokes. Clinical studies have reported that rehabilitation using AO and MI has been effective in restoring motor function. For example, Park and Hwangbo [1] reported that in patients with hemiparesis after stroke, gait training with AO results in higher walking speeds than gait training without AO. Further, Dickstein et al. [2] reported that in an individual with hemiparesis after stroke, training with MI of gait increased gait speed by 23% and decreased double-support time by 13% over training without MI. Recently, evidence for the neural mechanisms of AO and MI has been reported in neuroimaging and electrophysiological studies. For example, AO [3,4] and MI [5,6] increased the amplitudes of motor evoked potentials (MEPs) elicited by transcranial magnetic stimulation (TMS) in muscles related to movement observed and imagined. Further, AO [7–9] and MI [10,11] increased the amplitudes of Hoffmann reflex (H-reflex) induced by stimulation of group Ia afferents. These results showed that AO and MI without physical movement can modulate neural systems, such as corticospinal tracts and spinal reflex circuits.

It has been demonstrated that corticospinal excitability can be modulated by AO and MI of not only upper-limb movement, but also of walking [12,13]. Our recent study reported that AO of walking combined with MI (AO + MI) increased MEPs in lower-limb muscles over AO alone [13]. These results were consistent with the results of previous studies, which found that AO + MI increased MEPs more than either AO or MI alone [14,15]. These results suggest that AO + MI strongly enhances corticospinal excitability. On the other hand, it is unknown whether AO + MI can also modulate spinal reflex excitability.

Spinal reflex excitability is known to be modulated during walking in a phase-dependent manner. For example, H-reflex amplitudes during walking are larger in the stance phase than in the swing phase [16]. This phase-dependent modulation results from both somatosensory inputs and descending inputs from higher nervous centers during walking. Using the passive movement paradigm, previous studies have investigated the effects of somatosensory inputs on the H-reflex during walking [17–19]. Kamibayashi et al. [18] showed that the H-reflex is

* Corresponding author at: Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo, 3-8-1 Komaba, Meguro-ku, Tokyo 153-8902, Japan.
E-mail address: nakazawa@idaten.c.u-tokyo.ac.jp (K. Nakazawa).

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strongly modulated by movement-related afferent inputs induced by robot-assisted stepping. However, it is unclear if AO and MI of walking without somatosensory inputs modulate the H-reflex depending on walking phases and if there are any differences in the effects of AO and AO + MI of walking on the H-reflex. To clarify these research questions, we aimed to: 1) compare the modulation of the H-reflex during AO alone and AO + MI of walking; and 2) investigate if H-reflex modulation depends on the walking phase during AO and AO + MI of walking.

2. Material and methods

2.1. Participants

Eleven healthy males aged 22–32 years (mean 25.2 ± 3.0 years) with no history of neurological disorders participated in the present study after providing informed consent. All experimental procedures were approved by the local ethics committee of the University of Tokyo. This study was performed in accordance with the Declaration of Helsinki (1964).

2.2. Experimental protocols

Participants were each seated on a comfortable chair placed 1 m away from a 32-inch screen (697.7 × 392.3 mm, Multisync V321, NEC, Tokyo, Japan). Both presentation of videos and timing of electrical stimulation were controlled using a custom LabVIEW program (National Instruments Inc., Austin, TX, USA). Two 7-second videos with a frame rate of 30 fps, one portraying walking and the other a fixation cross, were used. The walking video showed a man walking on the floor for 10 steps, including heel contact of the right foot.

This study investigated the following three conditions: 1) control; 2) AO; and 3) AO + MI (Fig. 1a). In the control condition, the participants were asked to look at the center of the fixation cross that was presented at the center of the monitor. The control conditions, which occurred immediately before the AO condition and the AO + MI condition, were labeled “control of AO” and “control of AO + MI,” respectively. In the AO condition, the walking video was presented on the monitor, and the participants were asked to observe the man's legs and to not imagine anything. In the AO + MI condition, the same walking video was presented on the monitor, and the participants were asked to observe the man's legs and to imagine that they were walking like the man in the movie. In all conditions, the participants were given the same instructions. They were asked to relax their bodies and concentrate on each task during the recording.

Each experiment consisted of 3 sets. Each set consisted of 4 blocks of 12 trials and was followed by a break of at least 2 min to prevent any decrease in concentration. In each set, the trials for the first and third blocks were performed for the control condition and the trials for the second and fourth blocks were performed for the AO condition and the AO + MI condition in a random order (i.e., 1. control of AO; 2. AO; 3. control of AO + MI; 4. AO + MI; or 1. control of AO + MI; 2. AO + MI; 3. control of AO; 4. AO). Thirty-six trials were performed for each condition (control of AO, control of AO + MI, AO, and AO + MI) for each participant. In each trial, one response of the H-reflex was recorded in the soleus (SOL) muscle.

2.3. Electromyographic (EMG) recording

The EMG recordings were made from bipolar Ag/AgCl surface electrodes (Vitrode F-150S, Nihon Kohden, Tokyo, Japan) on the SOL, medial gastrocnemius (MG), and tibialis anterior (TA) muscles of the right leg. After cleaning the skin with alcohol, the electrodes were placed over the muscle belly with an interelectrode distance of 20 mm. The EMG signals were amplified (×1000) and filtered with a band-pass filter between 15 Hz and 3 kHz using a bio-amplifier system (MEG-6108, Nihon Kohden, Tokyo, Japan). The signals from 100 ms before stimulus to 200 ms after stimulus were sampled at 10 kHz using a 16-bit A/D converter (NI USB-6259 BNC, National Instruments Inc., Austin, TX, USA).

2.4. H-reflex

The SOL H-reflex was evoked by stimulating the right tibial nerve (rectangular pulse, 1 ms duration) with an electrical stimulator (DS7A, Digitimer Ltd., Welwyn Garden City, Hertfordshire, UK). A cathode (18 × 36 mm) was placed on the popliteal fossa and an anode (50 × 50 mm) was placed over the patella (Fig. 1b). These electrodes were secured with adhesive tape. To prevent movement of the leg being

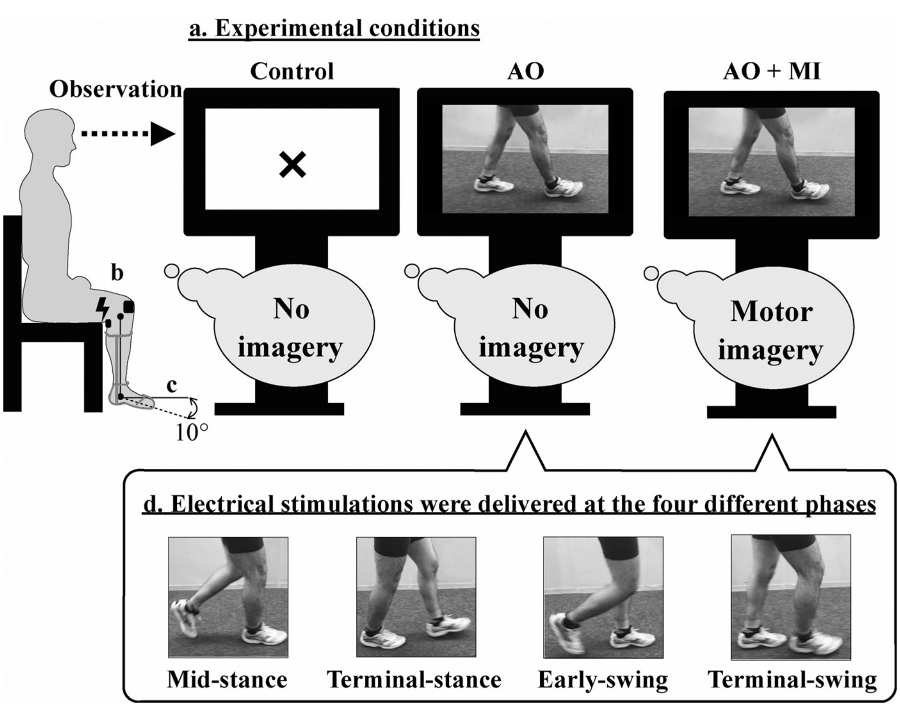

Fig. 1. Experimental setup. Participants were seated on a comfortable chair and asked to observe the monitor. The Hoffmann reflex (H-reflex) was obtained for the following three conditions: (1) control; (2) AO; and (3) AO + MI (a). To stimulate the posterior tibial nerve, a cathode was placed on the popliteal fossa and an anode was placed over the patella (b). To prevent movement of the tested leg during the experiment, the right ankle joint was fixed at 10 degrees plantar-flexion using an ankle foot orthosis (c). In the AO and AO + MI conditions, electrical stimulations were randomly delivered during the following four phases: 1) mid-stance; 2) terminal-stance; 3) early-swing; and 4) terminal-swing (d).