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Excitability of spinal neural function during several motor imagery tasks involving isometric opponens pollicis activity

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Abstract.
BACKGROUND: It is unclear whether mental simulation without actual muscle contraction associated with actual motion can increase the excitability of the spinal neural function.
OBJECTIVE: To determine the best method for mental simulation without actual muscle contraction, we analyzed the F-wave of thenar muscles after stimulating the median nerve by motor imagery whilst holding the sensor of a pinch meter between the thumb and index finger and without holding the sensor.
METHODS: Healthy volunteers ($n = 11$; mean age, 34 years) participated in this study after providing informed consent. We examined the F-wave of the left thenar muscles after stimulating the left median nerve at the wrist at rest and under holding and motor imagery conditions. For the motor imagery condition, the subjects were asked to establish 50% maximal voluntary contraction (MVC) of isometric contraction while holding the sensor between the thumb and index finger (motor imagery with the sensor condition) and without holding the sensor on another day (motor imagery without the sensor condition).
RESULTS: The persistence and amplitude ratio of F/M during motor imagery with or without the sensor was better than that during relaxation. In particular, this ratio was significantly higher under the with sensor condition than under the without sensor condition.
CONCLUSION: Movement preparation for a motor imagery task involving 50% MVC isometric contraction of the opponens pollicis is important.

Keywords: Motor imagery, F-wave, movement preparation

1. Introduction

Motor imagery, the mental rehearsal of a motor act without overt movement, has been shown to improve motor performance in healthy subjects (Pascual-Leone et al., 1995). It also aids in the recovery of motor function following stroke (Ryding, Decety, Sjoholm, Stenberg, & Ingvar, 1993; Stevens & Stoykov, 2003). The effects of motor imagery have been discussed in many neurophysiological studies using motor-evoked potentials (MEPs), the Hoffman reflex (H-reflex), the T-wave, and the F-wave. Results have shown that corticospinal excitability during motor imagery may result because of an increase in MEP amplitude as measured by transcranial magnetic stimulation (TMS) (Hashimoto & Rothwell, 1999; Li, Latash, & Zatsiorsky, 2004).

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However, H-reflex, T-wave, and F-wave measurement as indices of excitability of spinal neural function during motor imagery were not obtained in these studies (Hale, Raglin, & Koceja 2003; Jeannerod, 1995; Kasai et al., 1997; Oishi, Kimura, Yasukawa, Yoneda, & Maeshima, 1994). Motor imagery may be more precisely defined as imagery that produces spatial and temporal modulation of motor cortical function that mirrors the modulation observed during the actual performance of a task, without activation of spinal neural function.

If motor imagery is used as part of a patient's rehabilitation, it has the potential to increase both motor cortical function and spinal neural function. In turn, improved spinal neural function can result in improved muscle function. Our final goal of motor imagery research is to find the best way to improve the excitability of spinal neural function in the clinical setting. One of the best ways to do this in the clinical setting is to use motor imagery similar to actual motion. In this research, subjects learnt 50% maximal voluntary contraction (MVC) by isometrically contracting the opponens pollicis muscle by holding a pinch meter with a sensor between the thumb and index finger. Next, the subjects were asked to imagine the same contraction under two conditions: holding the pinch meter and sensor between the thumb and index finger ("with sensor") and not holding the pinch meter and sensor ("without sensor"). We aimed to determine whether mental simulation without the actual muscle contraction associated with the actual motion of holding the pinch meter and sensor, can increase the excitability of spinal neural function. During these motor imagery conditions, we tested the F-wave of the left thenar muscles after stimulating the left median nerve at the wrist. The F-wave resulted from the backfiring of the $\tilde{\alpha}$motoneurons after antidromic invasion of the propagated impulse across the axon hillock (Kimura, 1974). Its occurrence reflects excitability changes in the spinal motor neurons as reported in patients with spasticity (Odusote & Eisen, 1979) and in healthy subjects with isometric contraction (Suzuki, Fujiwara, & Takeda, 1993).

2. Materials and methods

2.1. Subjects

A total of 11 healthy volunteers (8 males and 3 females; mean age, 34 years) participated in the study. Written informed consent was obtained from all subjects. This study was approved by the Research Ethics Committee at Kansai University of Health Sciences. The experiments were conducted in accordance with the Declaration of Helsinki. This study was not concerned in Conflict of Interests.

2.2. F-wave during motor imagery

Subjects were maintained comfortably in a supine position with external rotation of both shoulder joints. The skin was prepared with abrasive gel to maintain the impedance below 5 KΩ. A VIASYS Viking Quest electromyography machine (Nicolet) was used to record the F-waves. We tested the F-wave of the left thenar muscles with a pair of round disks attached to the skin with collodion over the belly and the bone of the metacarpal–phalangeal joint of the thumb after stimulating the left median nerve at the wrist at rest and under touch and motor imagery conditions. The stimulating electrodes comprised a cathode placed over the left median nerve at 3 cm proximal to the palmar crease of the wrist joint and an anode placed 2 cm further proximally. The maximal stimulus was determined by delivering 0.2-ms square-wave pulses of increasing intensity to elicit the largest compound muscle action potentials. Supramaximal shocks (adjusted up to the value of 20% higher than the maximal stimulus) were delivered at 0.5 Hz for acquisition of F-waves. The bandwidth filter ranged from 2 Hz to 3 kHz.

In the resting condition, we tested the F-wave during relaxation. In the holding condition, the subject held the pinch meter and sensor between the thumb and index finger. For the motor imagery condition, subjects first learnt 50% MVC by isometrically contracting the opponens pollicis muscle by holding the pinch meter and sensor between the thumb and index finger. Next, the subjects were asked to imagine the contraction while holding the pinch meter (motor imagery under the "with sensor" condition) on one day and while not holding the sensor on another day (motor imagery under the "without sensor" condition).

2.3. Data analysis

The F-waves from 30 trials were analyzed with respect to persistence, amplitude ratio of F/M, and latency. Persistence was defined by the number of measurable F-wave responses divided by 30 trials of supramaximal stimulation. The amplitude ratio of F/M was defined as the mean amplitude of all responses divided by the amplitude of the M-wave. Latency was

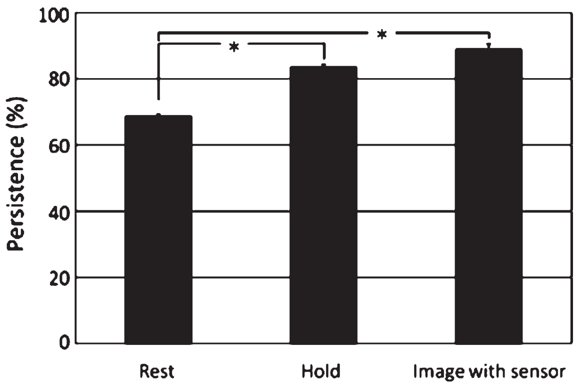

Fig. 1. Persistence during resting, holding, and motor imagery under "with sensor" conditions.
Persistence during the holding condition and during motor imagery under the "with sensor" condition is significantly higher than that during the resting condition (Dunnett's test: $^{*}p < 0.01$).

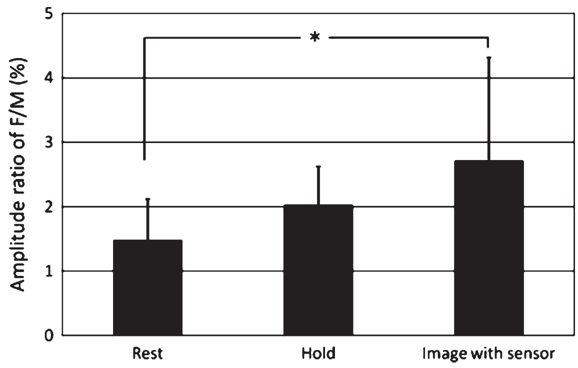

Fig. 2. Amplitude ratio of F/M during resting, holding, and motor imagery under "with sensor" conditions.
Amplitude ratio of F/M during motor imagery under the "with sensor" condition was significantly higher than that during the resting condition (Dunnett's test: $^{*}p < 0.01$).

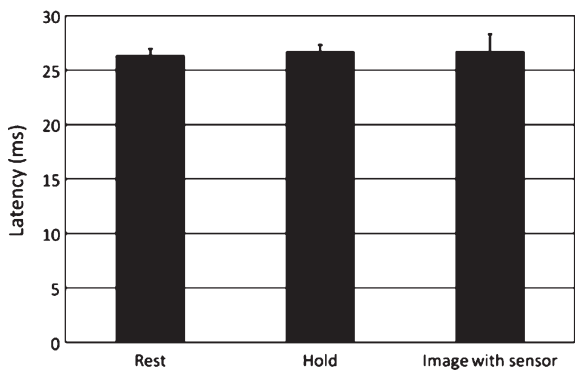

Fig. 3. Latency during resting, holding, and motor imagery under "with sensor" conditions.
There were no significant differences in latency between the three conditions.

defined as the mean latency from the time of stimulation to the onset of a measurable F-wave.

Dunnett's test was used to compare results between the rest condition and the other two conditions. A paired *t*-test was used to compare F-wave results during motor imagery under the "with sensor" and "without sensor" conditions.

3. Results

3.1. F-wave results during motor imagery under the "with sensor" condition

Persistence during the holding condition and during motor imagery under the "with sensor" condition was significantly better than that observed at rest (Dunnett's test: $^{*}p < 0.01$) (Fig. 1). In addition, the amplitude ratio of F/M during motor imagery under the "with sensor" condition was significantly greater than that observed at rest (Dunnett's test: $^{*}p < 0.01$) (Fig. 2). There were no significant differences in latency among all three conditions (Fig. 3).

3.2. F-wave results during motor imagery under the "without sensor" condition

Persistence during the holding condition and during motor imagery under the "without sensor" condition was significantly better than that observed at rest (Dunnett's test: $^{*}p < 0.01$) (Fig. 4), and the amplitude ratio of F/M during the holding condition and during motor imagery under the same condition was slightly greater than that observed at rest (Fig. 5). There were no significant differences in latency among all three conditions (Fig. 6).

3.3. Comparison of F-wave results between motor imagery under the "with sensor" condition and that under the "without sensor" condition

Relative data for persistence and amplitude ratio of F/M during motor imagery under the "with sensor" condition were higher than those during motor imagery under the "without sensor" condition (Figs. 7, 8). In particular, relative data for amplitude ratio of F/M during motor imagery under the "with sensor" condition were significantly higher than those during motor imagery under the "without sensor" condition (paired *t*-test: $p < 0.05$).

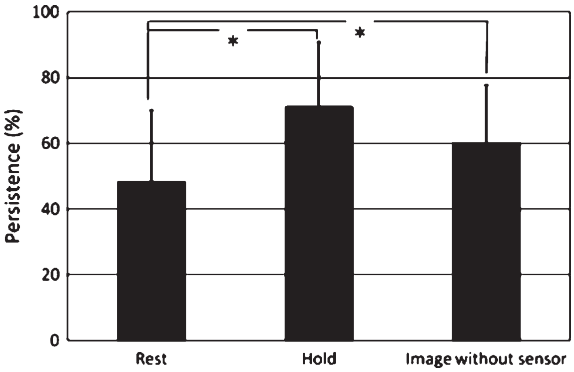

Fig. 4. Persistence during the resting, holding, and motor imagery under "without sensor" conditions.
Persistence during the holding condition and during motor imagery under the "without sensor" condition was significantly higher than that during the resting condition (Dunnett's test: $^{*}p < 0.01$).

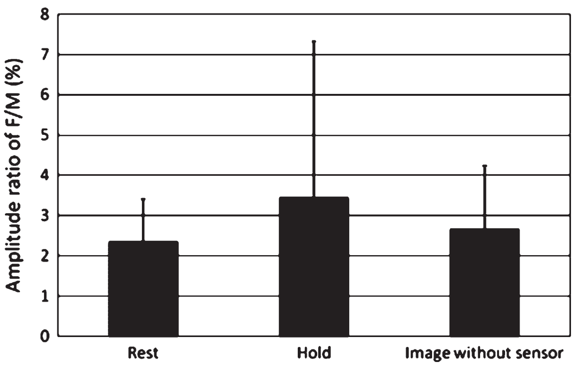

Fig. 5. Amplitude ratio of F/M during resting, holding, and motor imagery under "without sensor" conditions.
Amplitude ratio of F/M during the holding condition and during motor imagery under the "without sensor" condition was likely to increase compared with that during the resting condition.

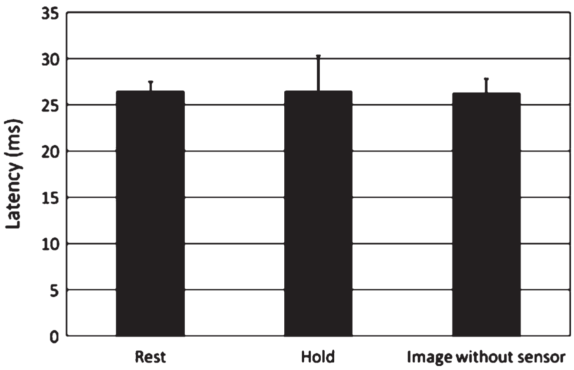

Fig. 6. Latency during resting, holding, and motor imagery under "without sensor" conditions.
There were no significant differences in latency between the three conditions.

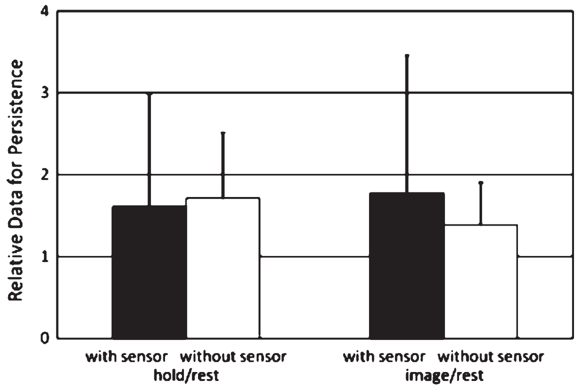

Fig. 7. Relative data for persistence during the holding condition and during motor imagery under "with sensor" and "without sensor" conditions.

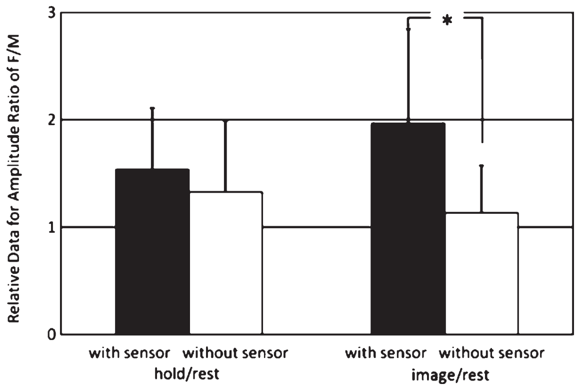

Fig. 8. Relative data for amplitude ratio of F/M during the holding condition and during motor imagery under "with sensor" and "without sensor" conditions (Paired t-test: $^{*}p < 0.05$).

4. Discussion

Research on motor imagery can be conducted using a variety of methods. With regard to MEPs obtained using TMS and single photon emission computed tomography, it is presumed that motor imagery will increase excitability at the cerebral cortex level of the motor area, supplement motor area, premotor region, and gyrus cinguli.

However, there are various studies that have reported the influence of motor imagery on the excitability of spinal neural function. Kasai et al. (1997) reported that the amplitude of the H-reflex of the radial flexor muscle during motor imagery with wrist flexion was not increased, whereas the amplitude of MEPs increased. Oishi et al. (1994) reported that the amplitude of the H-reflex during motor imagery was decreased in a speed skater. These reports support the argument that motor imagery cannot increase the excitability of spinal neural function. Jeannerod (1995) reported that the amplitudes of the H-reflex and T-wave during pedaling with motor imagery were significantly higher than those during pedaling without motor imagery. Furthermore, because the increase in the amplitude of the T-wave during motor imagery was significantly greater than that of the H-reflex, excitability of spinal neural function by motor imagery was affected by excitability of the γ-motor neuron. Hale et al. (2003) reported that the amplitude of the H-reflex of the soleus muscle during motor imagery with ankle planter flexion under 40, 60, 80, and 100% MVC gradually increased with motor imagery training. These reports further support the theory that motor imagery is effective in exciting spinal neural function.

In this study, to examine spinal neural function during motor imagery tasks, we analyzed the F-wave of the thenar muscles after stimulating the median nerve during motor imagery conditions with the sensor held between the thumb and index finger (motor imagery under the "with sensor" condition) and without the sensor held (motor imagery under the "without sensor" condition). The persistence and amplitude ratio of F/M during motor imagery with or without the sensor was better than those during relaxation. In particular, the persistence and amplitude ratio during motor imagery under the "with sensor" condition were significantly higher than those during motor imagery under the "without sensor" condition. As the persistence and amplitude ratio of F/M are indices of excitability of spinal neural function, motor imagery with or without the sensor facilitated spinal neural function.

Relative data for the persistence and amplitude ratio of F/M during motor imagery under the "with sensor" condition were higher than those during motor imagery under the "without sensor" condition. We believe that the volume of the afferent pathways from proprioception and skin mechanoreceptors to the primary somatosensory cortex tends to increase more during motor imagery under the "with sensor" condition than during motor imagery under the "without sensor" condition.

Vargas et al. (2004) reported that a proprioceptive signal enhanced corticospinal excitability during motor imagery. However, Mizuguchi, Sakamoto, Muraoka and Kanosue (2009) reported that responsiveness of the afferent mechanoreceptors to the primary somatosensory cortex did not change even during a combination of motor imagery of squeezing a ball and that of actually touching a ball. Therefore, the excitability of spinal neural function during motor imagery under the "with sensor" condition was caused by both proprioception and some modulation along the corticospinal pathway, including the primary motor cortex itself.

5. Conclusion

Motor imagery under the "with sensor" and "without sensor" conditions at approximately 50% MVC isometric contraction of the opponens pollicis without overt motor output increased the excitability of spinal neural output to the thenar muscles. Because the relative data for the persistence and amplitude ratio of F/M during motor imagery under the "with sensor" condition were higher than those during motor imagery under the "without sensor" condition, the movement preparation for a motor imagery task involving 50% MVC isometric contraction of the opponens pollicis is very important.

Declaration of interest

The authors declare that there are no conflicts of interest in this study.

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