Chapter 1

Spinal Neural Function during Motor Imagery

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Abstract

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 shown that corticospinal excitability during motor imagery may result from an increase in the MEP amplitude, as measured by transcranial magnetic stimulation (TMS) (Hashimoto & Rothwell, 1999; Li, Latash, & Zatsiorsky, 2004). However, the H-reflex, T-wave, and F-wave measurements as indices of the excitability of spinal neural function
during motor imagery were not obtained in these studies (Hale et al., 2003; Jeannerod, 1995; Kasai et al., 1997; Oishi et al., 1994). 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 identify the best method to improve the excitability of spinal neural function in the clinical setting.

We would like to introduce our study on motor imagery. At first, we introduce the study entitled “Excitability of Spinal Neural Function during Several Motor Imagery Tasks involving Isometric Opponens Pollicis Activity (Suzuki et al., 2013).” Motor imagery under the “with sensor” and “without sensor” conditions at approximately 50% MVC 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 F/M amplitude ratio during motor imagery under the “with sensor” condition were higher than those during that under the “without sensor” condition, the movement preparation for a motor imagery task involving 50% MVC of the opponens pollicis is extremely important.

Next, we introduce the study entitled “Excitability of Spinal Neural Function by Motor Imagery with Isometric Opponens Pollicis Activity: Influence of Vision during Motor Imagery (Suzuki et al., 2014).” Motor imagery while maintaining 50% MVC of the opponens pollicis muscle without overt motor output with a subject’s eyes open or closed increased the excitability of spinal neural output to the subject’s thenar muscles. There was no significant difference in the excitability of spinal neural function by motor imagery under these conditions. The subjective evaluations illustrated that motor imagery with the subject’s eyes open or closed had no effect on motor imagery.

Finally, we introduce the study “Excitability of Spinal Neural Function during Motor Imagery in Parkinson’s disease (Suzuki et al., 2014).” Motor imagery under both the “with sensor” and “without sensor” conditions at approximately 50% MVC of the opponens pollicis without overt motor output increased the excitability of spinal neural output to the thenar muscles in 10 patients with Parkinson’s disease. Because persistence and the F/M amplitude ratio during motor imagery under the “with sensor” condition were significantly higher compared with those at rest, movement preparation for a motor imagery task involving 50% MVC of the opponens pollicis is extremely important.
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 from an increase in the MEP amplitude, as measured by transcranial magnetic stimulation (TMS) (Hashimoto & Rothwell, 1999; Li, Latash, & Zatsiorsky, 2004). However, the H-reflex, T-wave, and F-wave measurements as indices of the excitability of spinal neural function during motor imagery were not obtained in these studies (Hale et al., 2003; Jeannerod, 1995; Kasai et al., 1997; Oishi et al., 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 identify the best method to improve the excitability of spinal neural function in the clinical setting.

We would like to introduce our study on motor imagery. However, first, we introduce the study entitled “Excitability of Spinal Neural Function during Several Motor Imagery Tasks involving Isometric Opponens Pollicis Activity (Suzuki et al., 2013).” This research founded the best method of motor imagery in healthy persons. Next, we introduce the study entitled “Excitability of Spinal Neural Function by Motor Imagery with Isometric Opponens Pollicis Activity: Influence of Vision during Motor Imagery (Suzuki et al., 2014).” This study had evaluated the influence of vision on motor imagery in healthy subjects. Finally, we introduce the study “Excitability of Spinal Neural Function during Motor Imagery in Parkinson’s disease (Suzuki et al., 2014).”
2. Excitability of Spinal Neural Function during Several Motor Imagery Tasks Involving Isometric Opponens Pollicis Activity (Suzuki et al., 2013)

2.1. Purpose

In this study, subjects learned 50% maximal voluntary contraction (MVC) through isometric contraction of 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 sensor of pinch meter between the thumb and index finger (“with sensor”; holding condition) and not holding the sensor of pinch meter (without sensor”; resting condition). 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 α-motoneurons after antidromic invasion of the propagated impulse across the axon hillock (Kimura, 1974). Its occurrence reflects excitability changes in the spinal motoneurons, as reported in patients with spasticity (Odusote & Eisen, 1979) and in healthy subjects with isometric contraction (Suzuki, Fujiwara, & Takeda, 1993).

2.2. Materials and Methods

2.2.1. Subjects

In total, 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 of Kansai University of Health Sciences. The experiments were conducted in accordance with the Declaration of Helsinki. There are no conflicts of interest associated with this study.
2.2.2. F-wave during Motor Imagery (Figure 1)

Subjects were positioned 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 Viking Quest electromyography machine (Natus Medical Inc., CA, USA) was used to record the F-waves. We tested the F-waves of the left thenar muscles with a pair of round disks attached (with collodion) to the skin over the belly and the bone of the metacarpophalangeal 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 a value of 20% higher than the maximal stimulus) were delivered at 0.5 Hz for the acquisition of F-waves. The bandwidth filter ranged from 2 Hz to 3 kHz.

![Figure 1. Test conditions.](image)

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 learned 50% MVC through isometric contraction of the opponens pollicis muscle by holding the pinch meter. Next, the subjects were asked to imagine the contraction while holding the pinch meter and sensor between the thumb and index finger (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).
2.2.3. Data Analysis

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

2.3. Results

2.3.1. 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) (Figure 2).

![Figure 2. Persistence during resting, holding, and 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 during the resting condition (Dunnett’s test: *p < 0.01).](image)
Figure 3. The F/M amplitude ratio during resting, holding, and motor imagery under the “with sensor” condition. The F/M amplitude ratio during motor imagery under the “with sensor” condition was significantly greater than that during the resting condition (Dunnett’s test: \(*p < 0.01\)).

Figure 4. Latency during resting, holding, and motor imagery under the “with sensor” condition. There were no significant differences in latency among the three conditions.
In addition, the F/M amplitude ratio during motor imagery under the “with sensor” condition was significantly greater than that observed at rest (Dunnett’s test: *p < 0.01) (Figure 3). There were no significant differences in latency among the three conditions (Figure 4).

2.3.2. 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) (Figure 5), and the F/M amplitude ratio during the holding condition and during motor imagery under the same condition was slightly greater than that observed at rest (Figure 6). There were no significant differences in latency among the three conditions (Figure 7).

The F-wave results between motor imagery under the “with sensor” condition and those under the “without sensor” condition were compared. The relative persistence and F/M amplitude ratio during motor imagery under the “with sensor” condition were higher than those during motor imagery under the “without sensor” condition (Figures 8 and 9). In particular, the relative data for the F/M amplitude ratio during motor imagery under the “with sensor”
condition was significantly higher than that during motor imagery under the “without sensor” condition (paired t-test: *p < 0.05) (Figure 9).

Figure 6. The F/M amplitude ratio during resting, holding, and motor imagery under the “without sensor” condition. The F/M amplitude ratio during the holding condition and during motor imagery under the “without sensor” condition was likely to increase compared with that during the resting condition.

Figure 7. Latency during resting, holding, and motor imagery under the “without sensor” condition. There were no significant differences in latency among the three conditions.
Figure 8. The relative persistence during the holding condition and during motor imagery under the “with sensor” and “without sensor” conditions.

Figure 9. The relative F/M amplitude ratio during the holding condition and during motor imagery under “with sensor” and “without sensor” conditions.
2.4. 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, supplementary motor area, prefrontal cortex, and the cingulate gyrus. However, various studies 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 was 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 greater 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, the excitability of spinal neural function by motor imagery was affected by the excitability of α-motoneurons. 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 the present 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 F/M amplitude ratio during motor imagery with or without the sensor were higher 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. Because the persistence and F/M amplitude ratio are indices of excitability of spinal neural function, motor imagery with or without the sensor facilitated spinal neural function.

The relative persistence and amplitude ratio 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 the responsiveness of 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 it. 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.


3.1. Purpose

In the present study, subjects were instructed to achieve 50% MVC by isometrically contracting the opponens pollicis muscle using a pinch meter to accurately track the number of movements on a monitor. The subjects were then asked to maintain the number of contractions on the display of the pinch meter by mental imaging. The patients were instructed to hold the sensor between their thumbs and index fingers and mimic the number of contractions displayed on the pinch meter while watching (eyes open) or not watching it (eyes closed). During these motor imagery conditions, we monitored the F-waves of the left thenar muscles after stimulating the left median nerve at the wrist. The F-wave data were obtained from the backfiring of the α-motoneurons after antidromic invasion of the propagated impulses across the axon hillock (Kimura, 1974). Its occurrence reflects excitability changes of the spinal motoneurons, as reported in patients with spasticity (Odusote & Eisen,
1979) and healthy subjects by isometric contraction (Suzuki, Fujiwara, & Takeda, 2013).

3.2. Material and Methods

3.2.1. Subjects

In total, 16 healthy volunteers (12 males and 4 females; mean age, 35.1 years) participated in this study. Written informed consent was obtained from all subjects. This study was approved by the Research Ethics Committee of Kansai University of Health Sciences (Osaka, Japan), and all experiments were conducted in accordance with the Declaration of Helsinki.

3.2.2. Methods

Subjects were comfortably positioned in a supine position while rotating both shoulders. The skin of the patients was prepared with an abrasive gel to maintain the impedance below 5 kΩ. A Viking Quest electromyography machine (Natus Medical Inc., CA, USA) was used to record the F-waves of the left thenar muscles with a pair of round disks attached (with collodion) to the skin over the abdomen of the thenar muscle and the metacarpophalangeal 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 3 cm proximal to the palmar crease of the wrist and an anode placed 2 cm further proximally. The maximum 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 to a value of 20% higher than the maximal stimulus, were delivered at 0.5 Hz for F-wave acquisition. The bandwidth filter ranged from 2 Hz to 3 kHz.

In the resting condition, we tested the F-wave during relaxation and using motor imagery. First, we gauged MVC using a pinch meter by instructing the patients to isometrically contract their opponens pollicis muscles. The magnitude of MVC was numerically recorded on the display of the pinch meter. Next, the subjects were instructed to obtain 50% MVC by isometrically contracting their opponens pollicis muscles while maintaining the recorded value displayed on the pinch meter. Under motor imagery conditions, the subjects were asked to imagine maintaining the numerical value displayed on the pinch meter by holding the sensor between the thumb and index finger.
while either watching the display of the pinch meter (eyes open) or not watching it (eyes closed) (Figure 1).

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

The Kruskal–Wallis, Mann–Whitney, and Bonferroni tests were used to compare results among the resting and motor imagery conditions under the conditions of eyes open or closed. A p-value of <0.05 was considered statistically significant.

For subjective comparisons after the test, we asked the patients whether imaging was easier with eyes open or closed. We compared the effects on the F-waves during motor imagery and by subjective evaluation.

3.3. Results

Persistence during motor imagery conditions with the eyes open and eyes closed parameters tended to increase compared with that observed at rest (Figure 10). Persistence remained unchanged under both conditions (Figure 10). The F/M amplitude ratio during motor imagery with the eyes open and eyes closed parameters was significantly greater than that observed at rest (Kruskal–Wallis test, Mann–Whitney test, and Bonferroni test; *p < 0.05) (Figure 11). There was no difference in the F/M amplitude ratio with the eyes open and eyes closed parameters (Figure 11). There was no significant difference in latency among the three conditions (Figure 12).

Almost all subjects (14/16) were adept at imaging using the eyes-open condition compared with the eyes-closed condition in subjective evaluations. However, there was no relationship between the F-wave data and subjective evaluations. In five of the 14 subjects, no changes were found in the F-waves using either the eyes-open or eyes-closed condition (Figure 13). A higher F-wave value was detected under the eyes-open condition in four subjects (Figure 14), and a higher F-wave value was detected in five subjects under the eyes-closed condition (Figure 15).

The remaining two subjects found it easier to foster an image without vision than with vision via subjective impression. However, the F/M amplitude
ratio during imaging without vision was lower than that during imaging with vision.

Figure 10. Persistence during resting and during imaging with and without vision.

Figure 11. The F/M amplitude ratio during resting and during imaging with and without vision.
Figure 12. Latency of F-waves during resting and during imaging with and without vision.

![Figure 12](image)

Figure 13. Typical F-waves during resting and during imaging with and without vision in 16 subjects (Cases with unchanged F-waves).

![Figure 13](image)
3.4. Discussion

In the present study, the subjects were asked whether imaging was easier with eyes open or closed. We hypothesized that imagery to maintain the
number of concentrations recorded by the pinch meter with eyes open is more effective for the excitability of spinal neural function and that imagery used to maintain the number displayed on the pinch meter was easier for patients under the eyes-closed condition. The excitability of spinal neural function under both motor imagery conditions was increased compared with that in the resting condition, but there was no difference in the magnitudes of the excitability of spinal neural function under either condition.

For the motor imagery tasks in this study, the subjects were asked to imagine maintaining the number of contractions displayed on the pinch meter by holding the sensor between the thumb and index finger while watching the pinch meter display (eyes open) or not watching it (eyes closed). It is generally accepted that the observation of a movement influences the execution of that movement (Brass, Bekkering, Wohlschlager, & Prinz, 2000, Urgesi, Candidi, Fabbro, Romani, & Aglioti, 2006). When the pinch meter display was zero under the eyes-open condition, the subjects did not maintain the number displayed on the pinch meter. However, we hypothesized that during the excitability of spinal neural function by motor imagery while watching the display, the number of contractions would be higher than that observed via motor imagery without watching the display. On the basis of these results, merely watching the instrument using motor imagery was not significant.

The subjective evaluation results revealed that mental imaging with eyes open or closed had no significant influence on the excitability of spinal neural function. Therefore, motor imagery under these conditions for rehabilitation is not necessarily relevant for the excitability of spinal neural function.

### 4. Excitability of Spinal Neural Function during Motor Imagery in Parkinson’s Disease (PD) (Suzuki et al., 2014)

#### 4.1. Purpose

In this study, using the motor imagery conditions of our previous study, we tested the F-waves of the left thenar muscles after stimulating the left median nerve at the wrist in patients with PD.
4.2. Materials and Methods

4.2.1. Subjects

Ten patients with PD (2 males and 8 females; mean age, 63.9 ± 11.0 years; range, 38–81 years) participated in the study, and written informed consent was obtained from all subjects. This study was approved by the Research Ethics Committee of Kansai University of Health Sciences (Ref number 11-10). The experiments were conducted in accordance with the Declaration of Helsinki.

4.2.2. F-Waves during Motor Imagery (Figure 1)

Subjects were positioned 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 Viking Quest electromyography machine (Natus Medical Inc., CA, USA) was used to record the F-waves. We tested the F-waves of the left thenar muscles using a pair of disks attached (with collodion) to the skin over the belly and the bones of the metacarpophalangeal 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 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 the acquisition of F-waves. The bandwidth filter ranged from 2 Hz to 3 kHz.

In the resting condition, we tested the F-wave that elicited no EMG signal from the left thenar muscles during relaxation. In the holding condition, the subject held the sensor of the pinch meter between the thumb and index finger. For the motor imagery condition, subjects first learned 50% MVC by isometrically contracting the opponens pollicis muscle while holding the sensor of the pinch meter. Specifically, the magnitude of MVC was numerically recorded on the display of the pinch meter. Next, the subjects were instructed to obtain 50% MVC by isometrically contracting their opponens pollicis muscles while maintaining the display value recorded on the pinch meter for 1 min. Finally, the subjects were asked to imagine the contraction while holding the pinch meter and sensor between the thumb and index finger (motor imagery under the “with sensor” condition) and, on a
different day, while not holding the sensor (motor imagery under the “without sensor” condition).

4.2.3. Data Analysis

The F-waves from 30 trials were analyzed with respect to persistence, the F/M amplitude ratio, and latency. Persistence was defined as the number of measurable F-wave responses divided by 30 trials of supramaximal stimulation. The F/M amplitude ratio was defined as the mean amplitude of all responses divided by the amplitude of the M-wave. Latency was defined as the mean latency from the time of stimulation to the onset of a measurable F-wave. The statistical analysis for normal distribution was performed using the Komogorov–Smirnov and Shapiro–Wilk tests. From these results, because the data were not recognized as showing normal distribution, the Wilcoxon test was used to compare results between resting and the other conditions.

4.3. Results

Persistence during motor imagery under the “with sensor” condition was significantly better compared with that at rest \( (n = 10, z = 2.2509, p = 0.0244, \text{ Wilcoxon’s test, Figure 16}) \).

![Figure 16. Persistence during resting, holding, and motor imagery under the “with sensor” condition and motor imagery under the “without sensor” condition. Hold Image: motor imagery under the “with sensor” condition. Hold: motor imagery under the “without sensor” condition. Image: motor imagery under the “without sensor” condition.](image-url)
There were no significant differences in persistence among all other conditions (Figure 16). The F/M amplitude ratio during motor imagery under
the “with sensor” condition was significantly greater compared with that at rest ($n = 10$, $z = 2.1915$, $p = 0.0284$, Wilcoxon’s test, Figure 17). There were no significant differences in latency among all three conditions (Figure 18).

4.4. Discussion

It is unclear whether motor imagery can also be successfully applied in the rehabilitation of patients with PD. Heremans et al. (2011) evaluated 14 patients with PD (Hoehn and Yahr 1-3) and 14 healthy controls via an extensive imagery ability assessment battery consisting of two questionnaires, the Chaotic Motor Imagery Assessment battery and a test based on mental chronometry. Patients with PD performed the imagery tasks more slowly than controls, but most patients’ vividness and accuracy of motor imagery were well preserved. These results are promising with regard to the potential use of motor imagery practice in the rehabilitation of patients with PD. However, Yaguez et al. (1999) reported on 12 patients with PD who received 10 min of motor imagery training followed by a motor practice phase. In addition, a test battery for visual imagery abilities was administered to investigate the possible relationship between visual and motor imagery. The patients showed no marked improvement following motor imagery. Furthermore, the deficits observed in patients with PD may also be related to their limited attentional resources and difficulties in employing predictive motor strategies.

In the present study, to examine spinal neural function during motor imagery tasks for PD, we analyzed the F-waves of the thenar muscles after stimulating the median nerve during motor imagery conditions with a sensor held between the thumb and index finger (motor imagery under the “with sensor” condition) and without the sensor (motor imagery under the “without sensor” condition) in patients with PD. Persistence and the F/M amplitude ratio during motor imagery under the “with sensor” condition were significantly higher compared with those at rest. Because these parameters are indices of the excitability of spinal neural function, motor imagery under the “with sensor” condition facilitated this excitability.

We believe that the volume of afferent pathways from proprioception and skin mechanoreceptors to the primary somatosensory cortex tends to increase more during the touch and motor imagery conditions under the “with sensor” condition than under other conditions.

Vargas et al. (2004) reported that a proprioceptive signal enhanced corticospinal excitability during motor imagery. However, Mizuguchi, et al.
(2009) reported that the responsiveness of the afferent mechanoreceptors to the primary somatosensory cortex did not change even during the combination of the motor imagery of squeezing a ball and that of actually touching it. Because only the touch condition tended to increase spinal neural function in the above study, the excitability of spinal neural function during motor imagery under the “with sensor” condition was caused by both proprioception and a degree of modulation along the corticospinal pathway, including the primary motor cortex itself.

From this study, we believe that the motor imagery task under the “with sensor” condition involving isometric opponens pollicis activity was effective because of the excitability of spinal neural function in patients with PD, as previously observed in healthy subjects (Suzuki et al., 2013). Suzuki et al. (2013) reported that motor imagery under the “with sensor” and “without sensor” conditions at approximately 50% MVC of the opponens pollicis without overt motor output increased the excitability of spinal neural output to the thenar muscles in healthy subjects. In healthy subjects, motor imagery at approximately 50% MVC of the opponens pollicis was effective. However, both Suzuki et al. (2013) and the present study revealed that in order to use motor imagery task in the rehabilitation of patients with PD, movement preparation for a motor imagery task is extremely important.

The present study had several limitations. We used motor imagery tasks involving isometric opponens pollicis activity in patients with PD. In addition, we did not utilize other motor imagery tasks in such patients. In the future, we would like to investigate several motor imagery tasks in patients with PD.

**Conclusion**

Motor imagery under the “with sensor” and “without sensor” conditions at approximately 50% MVC 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 F/M amplitude ratio during motor imagery under the “with sensor” condition were higher than those during that under the “without sensor” condition, the movement preparation for a motor imagery task involving 50% MVC of the opponens pollicis is extremely important.

Motor imagery while maintaining 50% MVC of the opponens pollicis muscle without overt motor output with a subject’s eyes open or closed
increased the excitability of spinal neural output to the subject’s thenar muscles. There was no significant difference in the excitability of spinal neural function by motor imagery under these conditions. The subjective evaluations illustrated that motor imagery with the subject’s eyes open or closed had no effect on motor imagery.

Motor imagery under both the “with sensor” and “without sensor” conditions at approximately 50% MVC of the opponens pollicis without overt motor output increased the excitability of spinal neural output to the thenar muscles in 10 patients with PD (2 males and 8 females; mean age, 64 years). Because persistence and the F/M amplitude ratio during motor imagery under the “with sensor” condition were significantly higher compared with those at rest, movement preparation for a motor imagery task involving 50% MVC of the opponens pollicis is extremely important.

Declaration of Competing Interests: The authors declare that there are no conflicts of interest.

References


