Effect of motor imagery on excitability of spinal neural function and its impact on the accuracy of movement-considering the point at which subjects subjectively determine the 50%MVC point

Yuki Fukumoto, PT1)*, Yoshibumi Bunno, PT, PhD1), Toshiaki Suzuki, PT, DMSc1)

1) Kansai University of Health Sciences: 2-11-1 Wakaba, Sennangun Kumatori, Osaka 590-0433, Japan

Abstract. [Purpose] This study aimed to examine the effect of motor imagery on the accuracy of motion and the excitability of spinal neural function. [Subjects and Methods] Thirty healthy volunteers (males, 15; females, 15; mean age, 20.3 ± 1.0 years) were recruited. F-waves was recorded at rest, while holding a sensor, and while using motor imagery. Next, subjects learned 50% maximum voluntary contraction. The pinch force was measured without visual feedback before and after motor imagery. F-waves were analyzed with respect to persistence and the F/M amplitude ratio. Correction time and coefficient of variation were calculated from the pinch force. [Results] Persistence and F/M amplitude ratio were significantly higher in the holding sensor and motor imagery conditions than in the resting condition. In addition, persistence under motor imagery was significantly higher than that in the holding sensor condition. No significant differences were observed in relative values of correction time and coefficient of variation between the two pinch action conditions. The pinch force in task 2 approximated a more authentic 50%MVC than that in task 1. [Conclusion] Motor imagery increases the excitability of spinal neural function, suggesting that it also affects accurate control of muscle force.

Key words: F-waves, Motor imagery, Accurate control of muscle force

(This article was submitted Jun. 24, 2016, and was accepted Aug. 23, 2016)

INTRODUCTION

Motor imagery (MI) is a process by which working memory is produced without actual motion. The activation of the primary sensory motor cortex, supplementary motor area, and premotor area during MI have been demonstrated1, 2). In our previous study, the excitability of spinal neural function during MI at 50% maximum voluntary contractions (MVC) was significantly higher than that during rest3). MI may increase the excitability of the cerebral cortex and spinal neural function. Regarding effect of MI on movement, Page et al.4) reported that upper-limb function was improved using a combination of physical therapy and MI. In addition, Dickstein et al.5) reported that gait was improved using MI in post-stroke hemiparesis. This suggests that the accuracy of actual movement is influenced by MI. However, it is unclear whether MI affects the accurate control of muscle force. In our previous study, the excitability of spinal neural function using F-waves during MI and the effect of MI on the accuracy of the movement was examined. An F-wave is a compound action potential obtained as a result of re-excitation of an antidromic impulse following distal electrical stimulation of motor nerve fibers of the spinal anterior horn cells. The correction time, (total time of 50%MVC ± 5%) was defined as the index of accurate control of muscle force. We studied the accurate control of muscle force by including the pinch force rising phase in the pinch force graph. In our previous study, persistence during MI was significantly greater than that at rest. The correction time is not shown...
to be significantly different before and after MI\textsuperscript{6}. Accordingly, MI increased the excitability of the spinal neural function; however, it did not affect the accurate control of muscle force. With regard to the cause, the first hypothesis that we did not fully understand at which point a subject would subjectively determine they had reached 50%MVC. Therefore, we studied accurate control of muscle force, including the pinch force rising phase. We examined including aim at 50%MVC and out of aim at 50%MVC by subjects. The subject of difficult to imagine the 50%MVC, those subjects decrease the correction time. Otherwise, the correction time is decreased by taking additional time for 50%MVC, but the subject is aim at 50%MVC by MI. Accordingly, it was the limit for awareness of improving the ability of actual motion in case of including the phase pinch force rising in the pinch force graph. The second hypothesis, the subjects did not learn 50%MVC for 10s, the MI under 50%MVC of the subjects was different from that under an authentic 50%MVC. We should have examined within the subject aimed at 50%MVC. In this study, after the point at which subjects subjectively determined they had reached 50%MVC, we studied the excitability of spinal neural function using F-waves recorded during MI as well as the effect of MI on the accuracy of the movement by new subjects.

SUBJECTS AND METHODS

Thirty healthy subjects (males, 15; females, 15; mean age, 20.3 ± 1.0 years) participated in this study after providing informed consent. This study was approved by the Research Ethics Committee at Kansai University of Health Sciences (Approval number: 15-04). Experiments were performed in accordance with the Declaration of Helsinki.

The study process was as follows. In a resting condition, a holding sensor condition, and a MI condition F-waves were recorded during isometric contraction of the opponens pollicis muscle were recorded. The pinch force without visual feedback before and after MI was measured. In the resting condition, F-waves from the left thenar muscles during relaxation were recorded. In the holding sensor condition, the F-wave was recorded while the subject held the pinch pressure sensor [Digital indicator F340A (Unipulse Medical Inc.)] between the thumb and index finger. In the MI conditions, subjects were first required to learn 50%MVC during isometric contraction of the opponens pollicis muscle while holding pinch pressure sensor. The magnitude of MVC was numerically recorded on the pinch pressure sensor display after reaching 50%MVC, and subjects were instructed to keep the 50%MVC value on the pinch pressure sensor display for 10 s. Subsequently, we measured the pinch force without using visual feedback for 10 s with the subjects subjectively determining when they had reached 50%MVC (task 1). Subjects were then asked to imagine the contraction while holding the pinch pressure sensor between their thumb and index finger (MI while holding sensor). Additionally, F-waves were recorded during MI. Ultimately, we measured the pinch force without using visual feedback for 10 s with the subject subjectively determining when they had reached 50%MVC (task 2). On a different day, while not using MI (without-MI condition under the holding sensor) in similar process, F-waves were recorded (Fig. 1).

Testing conditions for F-waves measurement were as follows. The subjects were comfortably placed in the supine position with both shoulder joints externally rotated and both forearms in an extension version. A Viking Quest Electromyography machine (Natus Medical Inc.) was used to record F-waves. The skin was prepared with abrasive gel to keep the impedance below 5 KΩ. F-waves of the left thenar muscles were recorded using a pair of disks attached with collodion to the skin over the belly of the thumb, and the bones of the metacarpophalangeal joint of the thumb. 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 more 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 to 3 kHz. By stimulating the left median nerve at the wrist, F-waves were recorded. F-waves were analyzed with respect to persistence, the F/M amplitude ratio, and latency using 30 stimuli (Fig. 2). Persistence was defined as the number of measurable F-wave responses divided by 30 supramaximal stimuli. 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.

Tasks 1 and 2 were as follows. Subjects touched the copper board with their right index finger when 50%MVC was reached. The point where subjects subjectively determined where they had reached 50%MVC by a spike on the screen was determined by authors. An error range of plus or minus 5% for the pinch force was adopted. The correction time (total time of 50%MVC ± 5%), was defined as the index of accurate control of muscle force. Additionally, the coefficient of variation, which was extent of pinch force transition, was defined as the index of accurate control of muscle force. Therefore, exerted apposite and sustained force of pinch action by the correction time (the total time of 50%MVC ± 5%), and coefficient of variation within after the point at which subjects subjectively determined they had reached 50%MVC, was examined. The correction time and coefficient of variation from task 1 and 2 was calculated. The pinch force using electromyogram recording software VitalRecorder2 (KISSEI COMTEC) was calculated in addition to the correction time using a versatile biological analysis system BIMUTAS-Video (KISSEI COMTEC) (Fig. 3).

SPSS ver. 19 was used for statistical analysis. Statistical analysis for normal distribution was performed using Kolmogorov–Smirnov and Shapiro–Wilk tests. The data were not recognized as showing normal distribution thus the Friedmann test was used to compare results between resting and other conditions. Thereafter, the Scheffe test was used to compare the
RESULTS

With regard to changes in the F-wave, persistence significantly increased in the holding sensor and MI conditions compared to the resting condition, and persistence was significantly higher in the MI condition than in the holding sensor condition (*p<0.05, **p<0.01, respectively; Table 1). The F/M amplitude ratio was significantly higher in the holding sensor and MI conditions than in the resting condition. No significant differences were found in the F/M amplitude ratio, and between the holding sensor and MI conditions (*p<0.05, **p<0.01, respectively; Table 1). There were no significant differences in latency among all three conditions (Table 1). Results for the control group without MI were as follows. Persistence was significantly

Table 1. Changes in the F-wave during MVC50% (MI group)

|                  | Rest          | Holding sensor | MI          |
|------------------|---------------|----------------|-------------|
| Persistence (%)  | 63.4±22.7     | 78.1±17.2      | 90.5±9.6**  |
| F/M amplitude ratio (%) | 1.2±0.6     | 1.8±0.8*      | 2.2±1.5**   |
| Latency (ms)    | 23.5±1.7      | 23.4±1.7      | 23.2±2.0    |

Mean ± SD. *significant (p<0.05), **significant (p<0.01) vs. at rest. *significant (p<0.05) vs. with sensor.
MI: motor imagery

results across all three conditions. Wilcoxon signed-rank test was used to compare correction time and coefficient of variation between tasks 1 and 2. Significance level was set at p<0.05.
Table 2. Changes in the F-wave during MVC50% (without MI group)

|                  | Rest              | Holding sensor | Without MI |
|------------------|-------------------|----------------|------------|
| Persistence (%)  | 47.4 ± 19.1       | 72.1 ± 16.5**  | 67.5 ± 17.6* |
| F/M amplitude ratio (%) | 1.2 ± 0.5       | 1.9 ± 1.1*     | 1.8 ± 1.1**  |
| Latency (ms)     | 23.9 ± 1.7        | 23.5 ± 1.7     | 23.5 ± 1.8  |

Mean ± SD. *significant (p<0.05), ** significant(p<0.01) vs. at rest.

MI: motor imagery

Table 3. Changes in the accurate control of muscle force (MI group)

|                  | Task 1 | Task 2 |
|------------------|--------|--------|
| Correction time (s) | 1.2 ± 1.5 | 0.7 ± 1.6 |
| Coefficient of variation | 0.1 ± 0.1 | 0.1 ± 0.1 |

Table 4. Changes in the accurate control of muscle force (without MI group)

|                  | Task 1 | Task 2 |
|------------------|--------|--------|
| Correction time (s) | 1.2 ± 1.7 | 0.7 ± 1.2 |
| Coefficient of variation | 0.1 ± 0.1 | 0.1 ± 0.1 |

DISCUSSION

An F-wave is a compound action potential obtained as a result of re-excitation (i.e., “backfiring”) of an antidromic impulse following distal electrical stimulation of motor nerve fibers at the anterior horn. Persistence reflects the number of backfiring anterior horn cells. The F/M amplitude ratio reflects the number of backfiring anterior horn cells and the excitability of individual anterior horn cells. Therefore, persistence and the F/M amplitude ratio are considered as indices of the excitability of spinal neural function. The persistence under the MI condition was higher than in the resting and holding sensor conditions. We attributed this to the influence of the descending pathways that supply the thenar muscle. In detail, excitatory inputs travels to anterior horn cells through the corticospinal pathway and reticulospinal tract from the upper motor neurons. Suzuki et al.3) reported that the excitability of spinal neural function in the MI condition was influenced by the descending pathways from the cerebral cortex. Stephan, Luft, and Lotze1,2,7) demonstrated the activation of the cerebral cortex, the primary motor area, the primary somatosensory area, the supplementary motor area, premotor area, cerebellum, and basal ganglia during MI. The supplementary motor area, premotor area, cerebellum, and basal ganglia all have roles in planning and preparing movement and have connections with the primary motor area. The bulbar reticular formation, red nucleus, cerebellum, and caudate nucleus have connections to anterior horn cells. The bulbar reticular formation has connections with the primary motor area, the supplementary motor area, premotor area, cerebellum and the red nucleus has connections to the cerebellum. Therefore, activation of the cerebral cortex during MI condition presumably increased the excitability of spinal neural function via the corticospinal pathway and extrapyramidal tract.

In addition, subjects performed MI while holding the pinch pressure sensor. Therefore, the influence of tactile and proprioceptive inputs should be considered. Mizuguchi et al.8,9) reported that the responsiveness of afferent pathways to the primary somatosensory area during MI, while utilizing an object, was modulated by a combination of tactile and proprioceptive inputs while touching the object. Somatosensory inputs from the periphery are projected to the primary somatosensory area. Tactile and proprioceptive inputs from the periphery are integrated after they are hierarchically processed and then projected to the primary motor area. Proprioceptive inputs project to the cerebellar nucleus via the spino-cerebellar pathway and to the primary motor area via the red nucleus and thalamic nucleus. Besides, Suzuki et al.3) reported that the excitability of spinal neural function at MI under the “with sensor” condition was higher than that of the spinal neural function at MI under the “without sensor” condition. It is considered that tactile and proprioceptive inputs, while holding the pinch pressure sensor, may increase the excitability of spinal neural function as part of the synergistic effect.

In our previous study, we studied the effect of MI on the accuracy of the movement after learning pinch action for 10s. The correction time, which was the total time of the pinch force in suitable range, was defined as the index of accurate control of
muscle force. Regarding the effect of MI on the actual movement by pinch action, Blefari et al.\textsuperscript{10} adopted an error range of ± 5% as the index of accurate control of muscle force. The accurate control of muscle force was not defined in all previous studies. However, the current study and Blefari’s study were similar in terms of adopting pinch action. On the basis of the above, we adopted an error range of ± 5% by pinch force as the index of accurate control of muscle force. As a result, the influence of MI didn’t improve the ability of actual motion. We predicted two hypothesis. The first hypothesis, we studied the accurate control of muscle force by including the phase pinch force rising in the pinch force graph. Accordingly, we examined including aim at 50%MVC and out of aim at 50%MVC by subjects. The subject of difficult to imagine the 50%MVC, those subjects decrease the correction time. Otherwise, the correction time is decreased by taking long time for 50%MVC, but the subject is aim at 50%MVC by MI. The quickly aimed at 50%MVC was defined as the index of accurate control of muscle force. However, our purpose is to exert for the pinch force of desired value irrespective of speed. Accordingly, it was the limit for awareness of improving the ability of actual motion in case of including the phase pinch force rising in the pinch force graph. The second hypothesis, the subjects didn’t learn 50%MVC for 10s, the MI under 50%MVC of the subjects was different from an authentic 50%MVC. We reported the two abovementioned hypothesis in our previous study. In this study, we examined the accurate control of muscle force for within the subject aimed at 50%MVC. No significant differences in the correction time were observed between tasks 1 and 2 in the imagery group and the control group, respectively. This was suggested that MI didn’t improve the ability of actual motion after learning for 10s. MI did not improve the ability of actual motion in the many subjects. Mulder et al.\textsuperscript{11} reported that MI improved the ability of actual motion only in people with learning that corresponded to the MI task. Accordingly, the subjects might not learn 50%MVC for 10s, the MI under 50%MVC of the subjects collided with an authentic 50%MVC. Consequently, MI might improve the ability of actual motion on the individual differences. However, the pinch force in task 2 approximated a more authentic 50%MVC than in the nine subjects in task 1. Therefore, we considered the influence of MI improved the ability of actual motion in these subjects. No significant differences were observed in the coefficient of variation between tasks 1 and 2 in the imagery group or the control group, respectively. We posited that MI did not influence the ability to make an adjustment of pinch force before and after the MI. Therefore, we concluded that MI improved the pinch force value but not the ability to make an adjustment of pinch force. It is necessary to use MI correctly when the aim for subjects to improve their ability of actual motion. In detail, it is necessary for subjects to learn complete to the corresponding motor task. We conclude adequate learning time should be provided in future studies.

MI increases the excitability of spinal neural function suggesting it also affects the accuracy of the movement. This study may be worthy of further investigation for MI application. It is necessary to do correctly of MI when the subjects aimed at improving the ability of actual motion. In particular, it is necessary to ensure that subjects learn the corresponding motor task and adequate learning time be provided afterward.

REFERENCES

1) Luft AR, Skalej M, Stefanou A, et al.: Comparing motion- and imagery-related activation in the human cerebellum: a functional MRI study. Hum Brain Mapp, 1998, 6: 105–113. [Medline] [CrossRef]
2) Lotze M, Montoya P, Erb M, et al.: Activation of cortical and cerebellar motor areas during executed and imagined hand movements: an fMRI study. J Cogn Neurosci, 1999, 11: 491–501. [Medline] [CrossRef]
3) Suzuki T, Bunno Y, Onigata C, et al.: Excitability of spinal neural function during several motor imagery tasks involving isometric opponens pollicis activity. NeuroRehabilitation, 2013, 33: 171–176. [Medline]
4) Page SJ, Levine P, Sisto SA, et al.: Mental practice combined with physical practice for upper-limb motor deficit in subacute stroke. Phys Ther, 2001, 81: 1455–1462. [Medline]
5) Dickstein R, Dumsky A, Marcovitz E: Motor imagery for gait rehabilitation in post-stroke hemiparesis. J Phys Ther, 2004, 12: 1167–1177.
6) Fukumoto Y, Take N, Fuchimoto M, et al.: Effect of motor imagery on excitability of spinal nerve function and its impact on the accuracy of movement. J Kansai Phys Ther, 2015, 15: 79–84 (in Japanese).
7) Stephan KM, Fink GR, Passingham RE, et al.: Functional anatomy of the mental representation of upper extremity movements in healthy subjects. J Neurophysiol, 1993, 73: 373–386. [Medline]
8) Mizuguchi N, Sakamoto M, Muraoka T, et al.: Influence of touching an object on corticospinal excitability during motor imagery. Exp Brain Res, 2009, 196: 529–535. [Medline] [CrossRef]
9) Mizuguchi N, Sakamoto M, Muraoka T, et al.: The modulation of corticospinal excitability during motor imagery of actions with objects. PLoS One, 2011, 6: e26006. [Medline] [CrossRef]
10) Blefari ML, Sulzer J, Hepp-Reymond MC, et al.: Improvement in precision grip force control with self-modulation of primary motor cortex during motor imagery. Front Behav Neurosci, 2015, 9: 18. [Medline] [CrossRef]
11) Mulder T, Zijlstra S, Zijlstra W, et al.: The role of motor imagery in learning a totally novel movement. Exp Brain Res, 2004, 154: 211–217. [Medline]