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Original Article

Excitability of spinal motor neurons during motor imagery of thenar muscle activity under maximal voluntary contractions of 50% and 100%

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Abstract. [Purpose] We often perform physical therapy using motor imagery of muscle contraction to improve motor function for healthy subjects and central nerve disorders. This study aimed to determine the differences in the excitability of spinal motor neurons during motor imagery of a muscle contraction at different contraction strengths. [Subjects] We recorded the F-wave in 15 healthy subjects. [Methods] In resting trial, the muscle was relaxed during F-wave recording. For motor imagery trial, subjects were instructed to imagine maximal voluntary contractions of 50% and 100% while holding the sensor of a pinch meter, and F-waves were recorded for each contraction. The F-wave was recorded immediately after motor imagery. [Results] Persistence and F/M amplitude ratio during motor imagery under maximal voluntary contractions of 50% and 100% were significantly higher than that at rest. In addition, the relative values of persistence, F/M amplitude ratio, and latency were similar during motor imagery under the two muscle contraction strengths. [Conclusion] Motor imagery under maximal voluntary contractions of 50% and 100% can increase the excitability of spinal motor neurons. Differences in the imagined muscle contraction strengths are not involved in changes in the excitability of spinal motor neurons.

Key words: Motor imagery, F-wave, Muscle contraction strength

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INTRODUCTION

Motor imagery (MI) is considered as an active process during which the representation of specific action is internally reproduced within working memory without any overt movement and muscle contraction[1)]. Physical therapy using MI can improve motor function for healthy subjects and central nerve disorders[2)]. Many neurophysiological studies demonstrated the brain activity during MI; the primary motor area (M1), supplementary motor area (SMA), premotor area (PM), primary somatosensory area (S1), cingulate area (Cg), cerebellum (Cb), and basal ganglia (BG)[3–6)]. Corticospinal excitability during MI may result from an increase in the MEP amplitude as measured by transcranial magnetic stimulation (TMS)[7)].

However, these studies could not determine the H-reflex and F-wave measurements as indices of the excitability of spinal motor neurons during MI[7–11)]. In our previous study, the excitability of spinal motor neurons during MI under maximal voluntary contraction of 50% (50% MVC) was similar compared with that under 10% and 30% MVC[12)]. Also, a few reports have examined changes in the excitability of spinal motor neurons during MI of muscle contraction using different contraction strengths. In present study, we investigated the effect of MI of muscle contraction under 50% and 100% MVC on spinal motor neurons excitability by analyzing F-wave.

SUBJECTS AND METHODS

Subjects

In present study, we included 15 healthy subjects (males, 13; females, 2; mean age, 25.3±5.04 years). All subjects provided informed consent prior to the study's commencement. This study was approved by the Research Ethics Committee at Graduate School of Kansai University of Health Sciences (14-18). The experiments were conducted in accordance with the Declaration of Helsinki.

Methods

Subjects were instructed to fix one eye on the pinch meter display (Unipulse, Digital indicator F304A) throughout the test while in the supine position. To maintain the skin impedance below 5kΩ, an abrasive gel was applied. The room temperature was maintained at 25 °C. F-waves were recorded by electromyography [VIASYS; Viking Quest electromyog-

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raphy machine (Natus Medical Inc.)]. After stimulating the left median nerve at the wrist, we recorded the F-wave of the left thenar muscle with a pair of round disks attached to the skin with a collodion. The disks were placed over the muscle belly and on the thumb metacarpophalangeal joint. The electrodes comprised of a cathode placed over the left median nerve 3 cm proximal to the palmar crease 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 20% higher than the maximum stimulus) were delivered at 0.5 Hz for acquisition of F-waves. The bandwidth filter ranged from 2 Hz to 3kHz.

In the resting trial (rest), the F-wave was recorded while the muscle was relaxed. Next, we measured 100% MVC; that is, the subjects held the sensor of the pinch meter while exerting their maximum effort for 10s. Subsequently, the subjects learned the isometric thenar muscle activity under 100% MVC for 1 min as a motor task. They performed the activity using visual feedback while watching the digital display of the pinch meter. They were then instructed to imagine the activity under 100% MVC by holding the sensor between the thumb and index finger. F-waves were recorded during the MI (100%MI). The F-wave was recorded immediately after 100%MI trial (post). We defined the above process as the MI using 100% MVC condition (100%MI condition). With regard to the MI using 50% MVC condition (50%MI condition), F-waves were recorded using the same process. These conditions were randomly performed on different days.

An F-wave is a compound action potential obtained as a result of re-excitation (“backfiring”) of an antidromic impulse following distal electrical stimulation of motor nerve fibers at the anterior horn cell[13–15]. F-waves were analyzed with respect to persistence, F/M amplitude ratio, and latency using 30 stimuli. In our study, persistence was defined as the number of measurable F-wave responses divided by 30 supramaximal stimuli. 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 onset of a measurable F-wave. 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[13, 14]. Therefore, persistence and the F/M amplitude ratio are considered indices of the excitability of spinal motor neurons.

For statistical analysis, the normality of F-wave data was confirmed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Persistence, F/M amplitude ratio, and latency among three trials (rest, MI, post) under each MVC MI conditions were compared using the Friedman test and Scheffe’s post hoc test. We also evaluated the relative values obtained under the two MI conditions by dividing the values of persistence, F/M amplitude ratio, and latency at rest with those obtained during MI at post. The relative values between the two MI conditions were compared using the Wilcoxon signed rank test. The significance level was set at $p < 0.05$. We used IBM SPSS statistics ver.19 for statistical analysis.

RESULTS

Regarding the changes in the F-wave, persistence during MI under the two MI conditions was significantly increased compared with at rest (Scheffe’s test; $^{**}p < 0.01$; Tables 1–2). Persistence immediately after MI (at post) under the two MI conditions did not show significant differences compared with at rest (Tables 1–2). No significant differences were observed between the relative values of persistence obtained under the two MI conditions (Table 3).

The F/M amplitude ratio during MI under the two MI conditions was significantly increased compared with at rest (Scheffe’s test; $^{**}p < 0.01$; Tables 1–2). The F/M amplitude ratio immediately after MI (at post) under the two MI conditions did not show the significant difference compared with at rest (Tables 1–2). No significant differences were observed between the relative values of F/M amplitude ratio obtained under the two MI conditions (Table 3).

There were no significant differences in latency among three trials (rest, MI, post) under the two conditions (Tables 1–2). No significant differences were observed between the relative values of latency obtained under the two MI conditions (Table 3).

DISCUSSION

The excitability of spinal motor neurons during MI under the two MI conditions was higher than that at rest; this was considered to be the influence of the descending pathways corresponding to the thenar muscle. Previous research has demonstrated the activation of the cerebral cortex, M1, S1, SMA, PM, Cb, and BG during MI[3–6]. The SMA, PM, Cb, and BG have roles in planning and preparing movement. Activation of the cerebral cortex during MI under two MI conditions presumably increased the excitability of spinal motor neurons.

In addition, subjects performed MI while holding the sensor of a pinch meter; therefore, the influence of tactile and proprioceptive inputs should be considered. Mizuguchi et al.[16] reported that the corticomotor excitability during MI utilizing an object was modulated by a combination of tactile and proprioceptive inputs while touching the object. Suzuki et al.[11] analyzed the changes in the excitability of spinal motor neurons during several MI tasks. The subjects were instructed to imagine isometric thenar muscle activity under 50% MVC, holding the sensor of a pinch meter between the thumb and index finger (MI under the “with sensor” condition) on one day and not holding the sensor (MI under the “without sensor” condition) on another. F-waves during MI under both with and without sensor conditions were significantly increased than those at rest. Furthermore, the F-wave during MI under the “with sensor” condition was significantly higher than that during MI under the “without sensor” condition. It is considered that tactile and proprioceptive inputs while holding the sensor of a pinch meter increase the excitability of spinal motor neurons as part of the synergistic effect.

In present study, there were no significant differences in facilitation amount of the spinal motor neurons excitability during MI between 50% and 100% MI condition. Various

Table 1. Changes in the F-wave under 50%MI condition

	rest	50%MI	post
Persistence (%)	50.8 ± 21.7	88.2 ± 13.2**	48.3 ± 19.9††
F/M amplitude ratio	1.71 ± 0.89	3.96 ± 4.56**	1.29 ± 0.56††
Latency (ms)	25.5 ± 1.40	24.9 ± 1.91	25.25 ± 1.29

Mean ± SD
$^{**}p < 0.01$; significant difference between rest and 50%MI trial.
$^{\dagger\dagger}p < 0.01$; significant difference between 50%MI and post trial.
50%MI: motor imagery of isometric opponens pollicis activity under 50%MVC

Table 2. Changes in the F-wave under 100%MI condition

	rest	100%MI	post
Persistence (%)	60.8 ± 24.9	91.9 ± 7.58**	60.7 ± 21.5††
F/M amplitude ratio	1.32 ± 1.12	3.57 ± 4.67**	1.39 ± 1.25††
Latency (ms)	25.2 ± 1.32	24.8 ± 1.31	25.2 ± 1.40

Mean ± SD
$^{**}p < 0.01$; significant difference between rest and 100%MI trial.
$^{\dagger\dagger}p < 0.01$; significant difference between 100%MI and post trial.
100%MI: motor imagery of isometric opponens pollicis activity under 100%MVC

Table 3. Comparison of relative values of the F-wave between 50%MI and 100%MI condition

	50%MI condition	100%MI condition
Relative values of persistence (mi/rest)	2.04 ± 1.17	2.06 ± 1.71
Relative values of persistence (post/rest)	1.12 ± 0.32	1.15 ± 0.71
Relative values of f/m amplitude ratio (mi/rest)	2.75 ± 2.04	2.53 ± 1.76
Relative values of f/m amplitude ratio (post/rest)	0.97 ± 0.56	1.12 ± 0.49
Relative values of latency (mi/rest)	0.98 ± 0.06	0.99 ± 0.03
Relative values of latency (post/rest)	0.99 ± 0.03	1.00 ± 0.03

Mean ± SD
MI: motor imagery

studies have reported about changes in the excitability of spinal motor neurons during MI of muscle contraction using different muscle contraction strengths. Hale et al.17) reported that the soleus H-reflex amplitude during plantar flexion MI under 40%, 60%, 80%, and 100% MVC gradually increased with MI trial. However, there were no differences in the changes in the H-reflex amplitude during MI among all MI conditions. Bonnet et al.18) reported that the soleus H-reflex amplitudes during plantar flexion MI under 2% and 10% MVC significantly increased compared with at rest. In addition, there was no difference in the H-reflex amplitude during MI between the two MI conditions. Aoyama and Kaneko19) reported that there was no difference in the H-reflex amplitude during plantar flexion MI between 50% and 100% MVC MI condition. The difference between present and previous study is motor task for MI; present study used thenar muscle activity as MI task, whereas previous study used plantar flexion. In present study, because we aimed to improve hand motor function by using MI, thenar muscle activity was used as MI task.

About changes in the central neural activity during MI under different muscle contraction strengths, Park and Li20) reported that the MEP amplitude during finger flexion or extension MI under 10%, 20%, 30%, 40%, 50%, and 60% MVC was significantly higher than that at rest. However, there were no differences in the changes in the MEP amplitude during MI among all MI conditions. They suggested that differences in the imagined muscle contraction strengths are not involved in changes of the corticospinal excitability. An event-related potential (ERP) study revealed that the M1 activity during MI does not correlate with the contraction strength but that the SMA and PM activity during MI do correlate with it21). In the movement-related cortical potentials (MRCPs) study, the MRCPs is thought to reflect the cortical processes involved in movement planning and preparation22), the SMA and PM were more activated for motor planning of larger force generation23). Additionally, the SMA and PM are known to have the functions of motor inhibition in the GO/NO-GO task24, 25). As MI is the mental representation of motor action without overt movement and muscle contraction, the SMA and PM might inhibit the actual muscle activity depending on muscle contraction strengths. There were not observed significant differences in facilitation amount of the corticospinal excitability including M1 during MI under different muscle contraction strengths by inhibitory mechanisms of the SMA and PM. Furthermore, the excitability of spinal motor neurons is considered to be affected by cortical and subcortical activity during MI via the extrapyramidal tract. In conclusion, the facilitation amount of spinal motor excitability during MI under different muscle contraction strengths might be modulated by facilitatory and inhibitory mechanisms of the central nervous system.

Regarding clinical use of MI for central nervous system disorders, Cicinelli et al.[26] reported that MI can facilitate corticospinal excitability in post-stroke patients. Motor cortex hyperexcitability could be necessary to efficiently generate an output to spinal motor neurons because excitatory inputs to the spinal level from MI decrease after stroke. Thus, facilitation of corticospinal excitability, including MI, is important for motor recovery after stroke. MI can increase central nervous system function and spinal motor neuron excitability, and can, we believe, effectively improve motor function after stroke.

A limitation of this study is that differences in the activation of the cerebral cortex during MI under 50% and 100% MVC were not evaluated. Further study is required to evaluate the activation of the cerebral cortex during MI under different muscle contraction strengths.

The present study revealed that MI under 50% and 100% MVC can increase the excitability of spinal motor neurons. It is suggested that differences in the imagined muscle contraction strengths are not involved in changes in the excitability of spinal motor neurons.

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