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Effective Motor Imagery Application: Examining Spinal Cord Excitability from the F-Wave and Autonomic Nervous Activity from LF/HF

Yuki Fukumoto

Abstract

Motor imagery can be helpful for the therapeutic approach for the patients who have difficulty in the actual motion. This chapter explains the following important six points for getting high-effective motor imagery based on the neuroscience. First, excitability of spinal motor neuron was increased by motor imagery. However, adding effect on breathing state, both expiration and inspiration phase on the relax respiration, does not influence the excitability of spinal motor neuron. Also, motor imagery increased the excitability of spinal motor neuron and cardiac sympathetic nerve activity. However, vividness of motor imagery was to converge a degree. Motor practice before motor imagery was important. Motor practice was appropriate for 30 s using intermittent visual feedback, and for doing motor imagery, time enough was 1 min. Adding motor imagery method was a recommended composite for kinesthetic and visual motor imagery. Unfortunately, motor imagery has few effects for the other hand. Therefore, motor imagery should be done on the ipsilateral side from the previous motor practice.

Keywords: motor imagery, motor practice, F-wave, LF/HF, breathing state, motor accuracy, pinch task

1. Introduction

The aim of rehabilitation is to improve motor function. Physical therapists distinguish physical limitations and do therapy for patients. The other effective method was doing self-training for the patient oneself [1]. However, self-training may be carefulness or contraindication when it merges heart trouble and respiratory illness. Therefore, we think necessarily self-training without actual motion, and we suggest motor imagery on self-training. Motor imagery especially involves the activation of cognitive processes from working memory [2]. Motor imagery is not limitation time, place, and using special equipment. Combination therapy for actual motion and motor imagery was improvement of upper limb function than only actual motion in post-stroke hemiparesis patients [3]. The only motor imagery case [4] is the comparison of muscular strengths after motor imagery of the little finger maximum voluntary contraction (MVC) abduction movement for 4 weeks

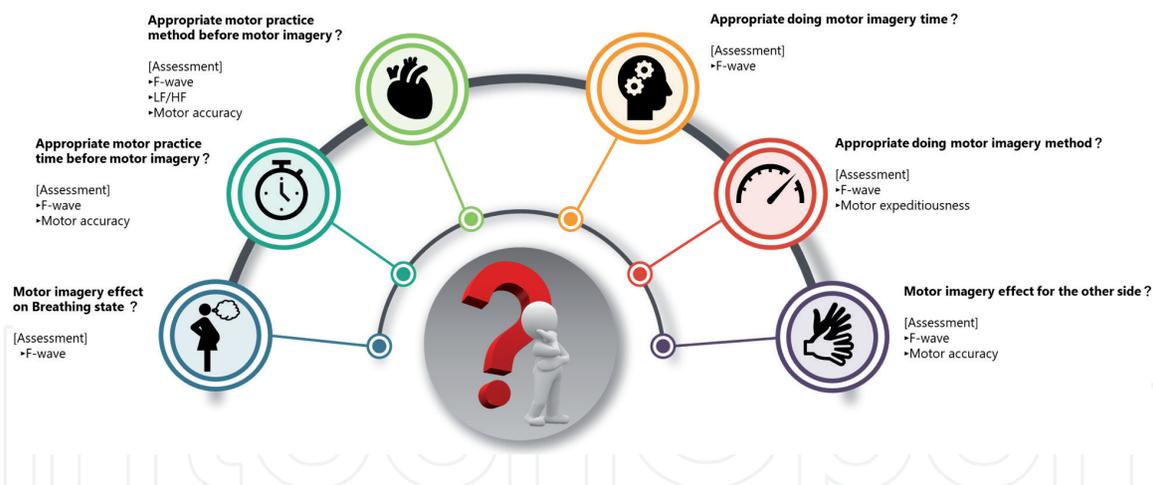


Figure 1.
Important six points for getting high-effective motor imagery.

among motor imagery, physical training, and control groups. They found that muscular strength was reinforced at 30% in the physical strength training group and at 22% in the motor imagery group. The reason of increasing muscular strength was to expand the little finger scope at primary motor area. We thought that motor imagery was an effective treatment means. This chapter explains the following important six points for getting high-effective motor imagery (**Figure 1**).

2. Motor imagery effect on breathing state?

2.1 The difference between expiration and inspiration on spinal cord excitability

Motor imagery and actual motion have a community of neural system. So, the respiration rates and the heart rate increase during motor imagery [5–7]. A previous study reported that the F-wave was influenced by difference of respiration phase [8, 9]. We want to be cleared up with the mechanism for the excitability of spinal motor neuron. We thought that the excitability of spinal motor neuron should be caused not secondary to respiration by primarily to the motor imagery.

The average respiration rates are 12–18 every minute on healthy subject. Generally, the ratio of expiration and inspiration is 1.5:1. Therefore, expiration is a little long than inspiration. We were defined to prohibit doing breath holding for making an adjustment to time ratio of expiration and inspiration. But, this role has no problems, because Iwamoto et al. [10] reported that the ratio of expiration and inspiration at 1:1 condition can do respiration on the relax and not voluntarily. In this study, expiration and inspiration every 2 s are natural. First, F-waves were recorded under these subjects to relax. Next, these subjects were asked to practice pinch force generation at an adjustment of 50% MVC using visual feedback for 30 s. Finally, F-waves were recorded again under these subjects doing motor imagery.

A Viking Quest electromyography machine [Natus Medical Inc.] was used to record F-waves. We recorded the F-waves by stimulating the left median nerve at the wrist. Supramaximal shocks (adjusted up to the value 20% higher than the maximal stimulus) were delivered at 0.5 Hz and 0.2 ms for F-wave acquisition. We recorded F-waves of the left thenar muscles using a pair of disks attached with collodion to the skin over the eminence of the thumb and the bones of the metacarpophalangeal joint of the thumb. The stimulating electrodes were comprised of 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 (**Figure 2**).

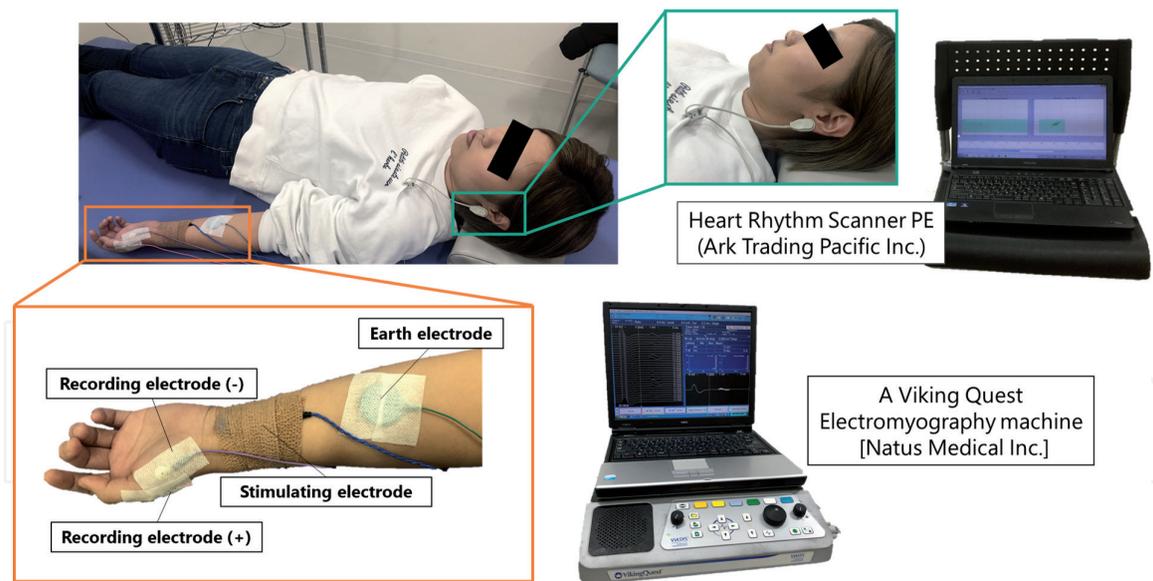


Figure 2.
 Recording method for the F-wave.

	Expiration	Inspiration
Increase rate for F/M amplitude ratio (%)	1.0±1.7	0.7±1.2
Increase rate for Persistence (%)	12.7±21.9	8.7±17.8

average ± standard deviation

Table 1.
 The result of motor imagery effect on breathing state.

In the result, no significant differences were observed in the increase rate for persistence and F/M amplitude ratio between motor imagery with expiration and inspiration. Respiration have two patterns for the relax or voluntarily. Relax respiration is controlled by brain stem [11]. And, voluntarily respiration is controlled by cerebral cortex. Previous study reported that MEP from hand finger was increased by voluntarily respiration [12]. Hand finger was not related to respiration, but activation of trunk area was influenced for the proximate hand finger area on primary motor area [8]. From the above, the increasing spinal motor neuron might be recognizing only voluntarily respiration. But, this study was only allowed to relax respiration. In conclusion, both expiration and inspiration phase on the relax respiration was not influenced by activation of cerebral cortex (Table 1).

3. Appropriate motor practice time before motor imagery

3.1 Motor imagery effect from motor practice time on the accuracy and spinal cord excitability

Our previous study [13] investigated motor imagery effect for the motor accuracy on the hand finger. As a result, 30 s or 1 min motor practice was good to get the high motor imagery effect. But, 10 s or 2 min motor practice was bad to get the high motor imagery effect. Then, we perceived that the excitability of spinal motor neuron was dependent on motor imagery implementation status.

A total of 44 healthy subjects were randomly and evenly allocated into four groups based on the allowed motor practice time: either 10, 30, 60, or 120 s.

F-waves were recorded at rest. Next, subjects were asked to practice pinch force generation at 50% MVC, using visual feedback for guidance. The subjects were then asked to generate pinch force at 50% MVC without visual feedback. The index of accuracy was recorded. Next, these subjects were asked to perform motor imagery, and F-waves were recorded. Finally, these subjects repeated the non-guided pinch task again.

An index reflecting the motor accuracy was applied as follows. Since the index representing the motor accuracy was not defined in the past literature, the index used herein was absolute error at 50% MVC (kgf), obtained by subtraction of the measurement pinch force value (=subject believes 50% MVC) from target pinch force value (=prescribed 50% MVC). In addition, this index was converted to an absolute value. We measured the pinch force value using electromyogram recording software VitalRecorder2 (KISSEI COMTEC). We calculated two indexes reflecting the motor accuracy using a versatile biological analysis system, the BIMUTAS-Video (KISSEI COMTEC) (**Figure 3**).

The absolute error at 50% MVC, persistence, and F/M amplitude ratio were significantly increased in the 10 s and 2 min group than 30 s and 1 min group. Add, the case of decreasing the absolute error at 50% MVC in after than before motor imagery converged within 0.5–1.1% on F/M amplitude ratio and 1.0–1.2% on persistence. The motor imagery effect was changed by individual motor imagery ability [14]. The important point to bring out the motor imagery effect was the quality of being distinct of motor imagery on every single person. Therefore, the motor imagery effect was dependent on the influence of previous motor practice. In this study, motor practice of 30 s or 1 min might be acquired accurate motor memory, and these subjects were doing quality of being distinct of motor imagery using accurate motor memory. Oishi et al. [15] reported that no significant differences were observed in the H-reflex amplitude between rest and during motor imagery, only the subjects of doing quality of being distinct of motor imagery on speed skate player. Nomura et al. [16] reported that no significant differences were observed in the F/M amplitude ratio between rest and during motor imagery, only the subjects of doing quality of being distinct of motor imagery. But, F/M amplitude ratio was significantly increased in during motor imagery than rest on the subjects of quality of being indistinct. In conclusion, these subjects of the decreasing absolute error

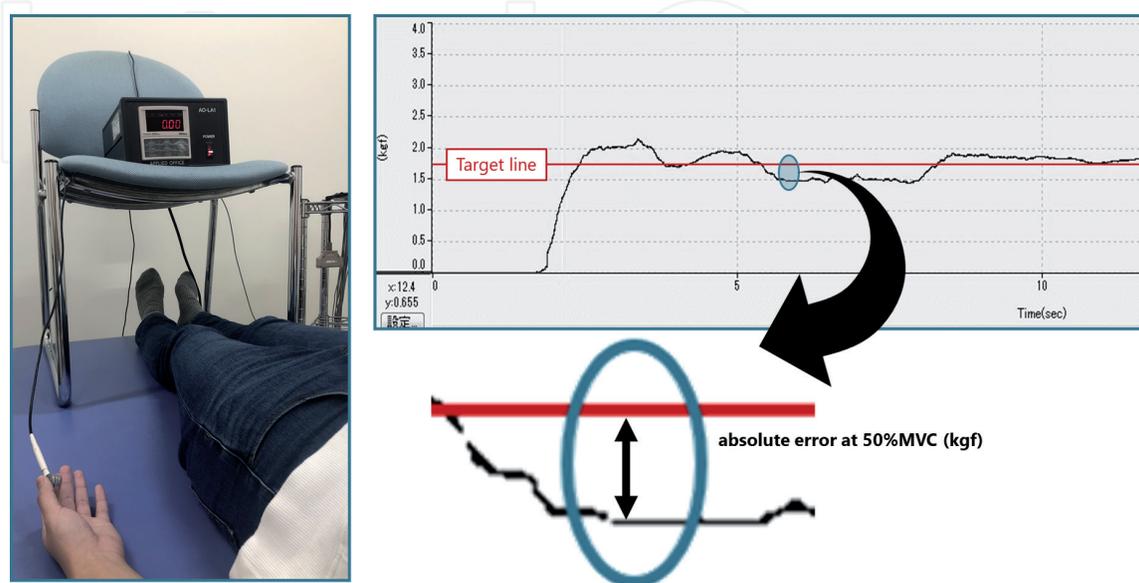


Figure 3.
Assessment method for motor accuracy.

	10sec group	30sec group	1min group	2min group
Increase rate for F/M amplitude ratio (%)	1.6±2.4***	0.4±0.8	0.4±0.4	1.2±0.8***
Increase rate for Persistence (%)	23±14***	8.7±8.4	10±11	20±13***
Increase rate for Absolute error at 50%MVC (kgf)	0.4±0.5***	0.0±0.2	-0.1±0.2	0.3±0.3**

average ± standard deviation. *p<0.05(vs 30sec), **p<0.05(vs 1min), *: p=0.07(vs 30sec)

Table 2.
 The result of differ motor practice time.

at 50% MVC (=improvement motor accuracy) were doing the quality of being distinct of motor imagery based on the 30 s or 1 min motor practice. Above subjects were not necessarily overmuch increasing excitability of spinal motor neuron (Table 2).

4. Appropriate motor practice method before motor imagery?

4.1 Motor imagery effect from motor practice method on the accuracy, spinal cord excitability, and autonomic nervous activity

Our previous study [13] reported that the motor imagery after motor learning with consecutive using visual feedback was to maintain the motor accuracy. And, Heuer and Hegele [17] reported that the motor learning with intermittent using visual feedback was effective than consecutive. This section was investigated for the motor imagery effect after intermittent motor learning on motor accuracy, spinal motor neuron, and low frequency/high frequency ratio (LF/HF).

The participants were 13 healthy subjects. First, the F-wave and LF/HF were recorded at rest. Second, these subjects practiced for adjustment pinch force at 50% MVC for 30 s with intermittent visual feedback. Third, these subjects challenged adjustment pinch force at 50% MVC without visual feedback, and the absolute error at 50% MVC was assessment in this timing. Fourth, the F-wave and LF/HF were recorded during motor imagery. Finally, these subjects did pinch task again.

ANS activity was recorded using a heart rhythm scanner [Biocom Technologies; Heart Rhythm Scanner PE (Ark Trading Pacific Inc.)] (Figure 2). The pulse wave from the photoplethysmography sensor attached to the earlobe was recorded. The low frequency was reflected in sympathetic and parasympathetic nerves. The low frequency at band of 0.05–0.15 Hz was used. High frequency reflected only parasympathetic nerves and used band of 0.15–0.50 Hz. Therefore, the low frequency/high frequency (LF/HF) ratio reflected the cardiac sympathetic nerve activity [18]. This index was obtained by analyzing the pulse wave recorded by the Heart Rhythm Scanner PE. It is considered to be an index of the sympathetic nerve activity. The European Society of Cardiology and the North American Society of Pacing and Electrophysiology recommend 5 min recordings for heart rate variability analysis. Also, we were careful about the hours and subject condition, because the LF/HF ratio exponentially increased immediately by rising in the morning and after smoking, eating, and vigorous exercise [19].

The absolute error at 50% MVC does not differ before and after motor imagery. However, nine subjects were decreasing for the absolute error at 50% MVC after motor imagery. The persistence, F/M amplitude ratio, and LF/HF significantly increased during motor imagery than those at rest. This study's motor task was adjustment force in isometric contraction. But, this ability was difficult to maintain [20]. Therefore, motor accuracy decreased for the time course. But,

in this study's result, motor accuracy was not decreasing. Due to this reason, we thought that motor imagery was maintaining motor accuracy. The differences point on this study and our previous study [13] was majority subject improvement motor accuracy. It is considered that intermittent motor learning was to increase the motor imagery effect than consecutive. Next, we thought that the F-wave's result referred to appropriate motor imagery time. The dorsolateral prefrontal cortex (DLPFC) has a role in motor cognition and has connections with the supplementary motor area and insula cortex. The anterior cingulate and insula cortices have roles in cardiovascular regulation. Transcranial magnetic stimulation (TMS) to the primary motor cortex increases skin sympathetic nerve activity [21], and transcranial direct stimulation (tDCS) to the primary motor cortex increases the LF/HF ratio [22]. tDCS is a noninvasive neuromodulatory technique that has been used to influence corticospinal excitability. The activation of the SMA, pM, DLPFC, and insular cortex during motor imagery might influence primary motor cortex activity, and it is thought that the primary motor cortex activity during motor imagery stimulates the cardiac sympathetic nerve fibers via the corticospinal tract. In addition, Bunno et al. [23] reported that motor imagery was to increase the persistence, F/M amplitude ratio, and LF/HF ratio. This report was corresponding to the present data. And, the rostral ventromedial medulla is part of the reticulospinal tract [24] and is involved in regulation of sympathetic nerve activity and motor execution [25]. It is considered that activation of the

	rest	motor imagery
F/M amplitude ratio (%)	1.4±0.7	1.9±1.0*
Persistence (%)	62.2±11.7	77.4±19.0*
LF/HF (%)	1.5±0.4	2.9±1.5*
	Before motor imagery	After motor imagery
Absolute error at 50%MVC (kgf)	0.3±0.2	0.2±0.1

average ± standard deviation. *:p<0.05(vs 30sec)

Table 3.
The result of motor practice effect on the method.

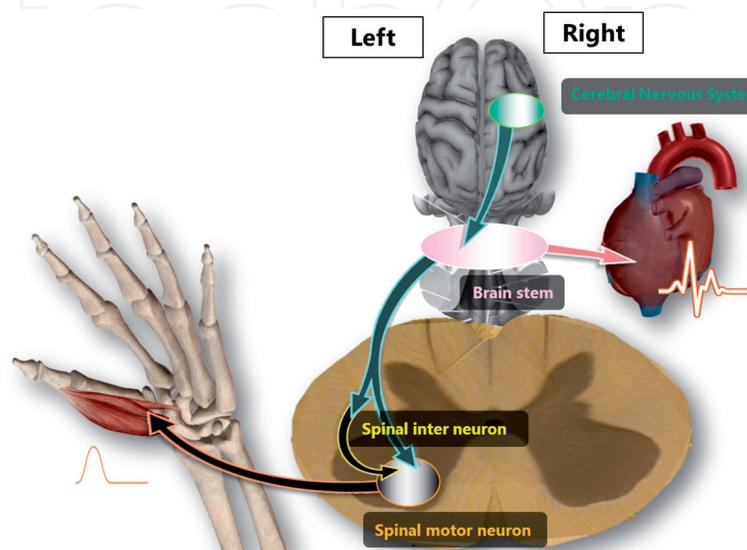


Figure 4.
Schematic model for the reason of excitability of spinal motor neuron.

cerebral cortex during motor imagery increases cardiac sympathetic nerve activity via the corticospinal and reticulospinal tracts (Table 3, Figure 4).

5. Appropriate doing motor imagery time?

5.1 Relationship between duration in the motor imagery and spinal cord excitability

Our previous study [26] investigated continuation days for motor imagery. As a result, the motor imagery improved the motor accuracy by 3 days continuation. Our previous study [26] adopted motor imagery time for 1 min. But, another report [23] adopted motor imagery time for 5 min. Effective motor imagery time around once should be clear in order to apply clinical applications. We anticipate that 5 min motor imagery was a difficult continuation in doing motor imagery. In the case of above pattern, these subjects might be divided and doing motor imagery might be repeated. About this, Umeno et al. [27] reported that the repeat doing was load or burden motor imagery effect, and performance was improvement. We thought that 5 min motor imagery was not realistic. And, we expected that the motor imagery was repeated within 5 min. Is it useful so as to be repeated? We clarified this point in this section.

The subjects were 13 healthy subjects, except those rated as lack of concentration. After doing exercise to adjust for 50% MVC of the pinch force. Next motor imagery was taken for 5 min, and F-waves were recorded at the first and last 1 min. We ordered continuation doing motor imagery whenever possible within 5 min. In the case of difficulty in this task, we additional ordered repeats doing motor imagery (Table 4).

In the result, the persistence and the amplitude F/M ratio were not different in two periods. Activation of the primary motor area, supplementary motor area, premotor area, primary somatosensory area, dorsolateral prefrontal area, cingulate cortex, and cerebellar regions occurred during motor imagery [28–30]. Furthermore, Suzuki et al. [31] reported the excitability of spinal motor neurons in the motor imagery condition to be influenced by the descending pathways from the cerebral nervous system. We attribute this to the influence of the descending pathways corresponding to the thenar muscle. By contrast, excitatory inputs travel through the corticospinal pathway and reticulospinal tract and from the corticospinal pathway and extrapyramidal tract to anterior horn cells. Also, the spinal interneuron influences the excitability of spinal motor neuron in the motor accuracy on the hand finger [32–35]. Spinal interneuron acted spinal anterior horn cell on facilitate or inhibition [36, 37]. In conclusion, the excitability of spinal motor neuron might be adjusted from descending pathways and spinal interneuron. The excitability of spinal motor neuron had the same influence on both the first and last 1 min.

	First 1min	Last 1min
<i>F/M amplitude ratio (%)</i>	1.8±0.4	1.6±0.5
<i>Persistence (%)</i>	80.9±15.8	76.5±20.6
average ± standard deviation		

Table 4.
 The result of first and last 1 min motor imagery effect.

6. Appropriate doing motor imagery method?

6.1 Motor imagery effect for the time of adjustment pinch force and spinal cord excitability based on the motor imagery method

We use a tool and an object, manipulated by the upper limb, for activities of daily living. For example, buttoning and unbuttoning, using chopsticks, picking up coins, and so forth, are important accuracy and expeditiousness for the motor activities. We already examined the accuracy on motor imagery effect. In this study, we examined the expeditiousness on motor imagery effect. Also, we examined the effect of motor imagery method.

The participants were 15 healthy subjects. First, F-waves were recorded at rest. Second, these subjects were practiced for adjustment pinch force at 50% MVC for 30 s. Third, these subjects were challenged for adjustment pinch force at 50% MVC with visual feedback, and the using time of adjustment pinch force at 50% MVC was assessment in this timing. Fourth, F-waves were recorded during motor imagery. These subjects were doing motor imagery at muscle imagery, vision imagery and composite imagery. Finally, these subjects did pinch task, and assessment for using time of adjustment pinch force at 50% MVC again.

The using time of adjustment pinch force at 50% MVC was significantly shortening after motor imagery than before method of composite for kinesthetic and visual. The F/M amplitude ratio did not differ between rest and during motor imagery in all motor imagery methods. The case of difficult kinesthetic motor imagery was doing vision motor imagery into unconsciousness [38]. And, kinesthetic motor imagery was having high effect on the improvement motor performance than vision image [39]. Therefore, we thought that the subject of difficult doing kinesthetic motor imagery might be doing vision motor imagery, and vision motor imagery was a severe task for improving expeditiousness. But, composite for kinesthetic and visual motor imagery was improvement expeditiousness. Itou [40] reported that the subject to make efforts for doing vision imagery like numerical value during kinesthetic motor imagery was improving motor accuracy in grip task. But, the subject doing muscle motor imagery with unrelated numerical value was not improving the motor accuracy. The quality of being distinct of motor imagery was decided not only based on constant ability but also motor imagery practice [41]. The quality of being distinct of motor imagery was to converge the excitability of spinal motor neuron and improve motor performance [13]. And, our previous study [42] reported that motor imagery might improve expeditiousness. It is considered that the composite for kinesthetic and visual motor imagery might be improving quality of being distinct of motor imagery. And, the quality of being distinct of motor imagery might be shortening time of adjustment pinch force at 50% MVC (**Table 5**).

	<i>rest</i>	<i>motor imagery</i>
<i>Evoked F/M amplitude ratio (%) [kinesthetic]</i>	0.8±0.2	0.7±0.3
<i>Evoked F/M amplitude ratio (%) [vision]</i>	0.6±0.3	0.9±0.3
<i>Evoked F/M amplitude ratio (%) [composite]</i>	0.8±0.2	1.0±0.3
	<i>Before motor imagery</i>	<i>After motor imagery</i>
<i>Using time of adjustment 50%MVC (sec) [kinesthetic]</i>	0.9±0.3	0.9±0.3
<i>Using time of adjustment 50%MVC(sec) [vision]</i>	0.9±0.4	0.9±0.2
<i>Using time of adjustment 50%MVC(sec) [composite]</i>	1.0±0.5	0.7±0.3*

average ± standard deviation. *:p<0.05(vs Before motor imagery)

Table 5.
The result of kinesthetic, vision, and compound imagery effect.

7. Motor imagery effect for the other side

7.1 Motor imagery effect for the opposite on the accuracy and spinal cord excitability

The stroke patients found it difficult exactly during motor practice on the paralysis side, because these subjects had spasticity or flaccidity. This case was difficult to motor imagery effect based on our previous study result. In this study, we examined the motor imagery effect for the other hand on motor accuracy and excitability of spinal motor neuron.

A total of 20 healthy subjects were evenly allocated into two groups, one group task was adjustment pinch force at 10% MVC; and, the other group task was 50% MVC. F-waves were recorded at rest. Next, subjects were asked to practice for the adjustment of numerical target with right hand. Next, these subjects were asked to perform motor imagery (or without motor imagery) with left hand, and F-waves were recorded. Finally, the subjects were then asked to generate pinch force at numerical target without visual feedback, and accurate index for absolute error at 50% MVC was recorded.

No significant differences in the absolute error at 10% or 50% MVC were observed between the pinch task after motor imagery and without motor imagery. But, the absolute error in the 50% MVC was significantly more increased than in the 10% MVC. The persistence in the motor imagery of both groups was significantly more increased than in the resting condition. Only in 10% MVC group, the F/M amplitude ratio in the motor imagery was significantly more increased than in the resting condition. Health subject's pinch force was about 6.7 kg [43]. The necessary pinch force was 3 kg on the buttoning and unbuttoning [44], and 3.8 kg on cap screw-engaged to an opening part of the PET bottle [45]. Therefore, we were in need of about 44–56% MVC pinch force for smoothly doing ADL. In this study, we thought that 50% MVC pinch force was more frequently used, but 10% MVC pinch force was not used. Jenkins [46] reported that we decided standard central point at 50–60% MVC in task of adjustment force. We thought that 50% MVC pinch force was misrecognition to easy. But, these subjects were potentially difficult control for this pinch force. Our previous study [47] reported that motor imagery based on the false motor memory was decreasing motor performance. These subjects might be doing motor imagery based on the false motor memory in 50% MVC task. Therefore, motor accuracy was more deteriorated in 50% MVC than in the 10% MVC task. Also, persistence was increased during motor imagery. But, the F/M amplitude ratio was only increased during kinesthetic muscle motor imagery in 10% MVC group [48]. Kinesthetic motor imagery was having high effect on the improvement of motor performance than vision image [39]. It is considered that motor imagery effect for the other hand might be not obtained in adjustment pinch force task. Also, contraction strength might be influenced for the motor imagery effect from the motor imagery method (Table 6).

	10%MVC group		50%MVC group		Comparison between groups	
	rest	motor imagery	rest	motor imagery	10%MVC	50%MVC
F/M amplitude ratio (%)	0.8±0.4	1.2±0.7*	1.5±1.1	1.1±0.5		
Persistence (%)	73.5±11.4	88.1±10.5*	57.6±18.3	70.8±12.5*		
Absolute error at 50%MVC (kg)	10%MVC group		50%MVC group		Comparison between groups	
	motor imagery	without motor imagery	motor imagery	without motor imagery	10%MVC	50%MVC
	0.0±0.1	0.0±0.0	0.5±0.1	0.4±0.3	0.0±0.1	0.1±0.2**

average ± standard deviation. *p<0.05(vs rest), **p<0.05(vs 10%MVC)

Table 6.
 The result of motor imagery effect for the other side.

8. Conclusion

Self-training may be carefulness or contraindication when it merges heart trouble and respiratory illness. Therefore, we think necessarily self-training without actual motion. Motor imagery is not limitation time, place, and using special equipment. Excitability of spinal motor neuron was increased by motor imagery. Adding effect on the breathing state, both expiration and inspiration phase on the relax respiration, was not influenced for excitability of spinal motor neuron and cardiac sympathetic nerve activity. Also, motor imagery increased excitability of spinal motor neuron. However, vividness of motor imagery was to converge a degree. Motor practice before motor imagery was important. Motor practice was appropriate for 30 s using intermittent visual feedback. And, for doing motor imagery, time enough was 1 min. The motor imagery method was a recommended composite for kinesthetic and visual motor imagery. Unfortunately, motor imagery was few effects for the other hand. Therefore, motor imagery should be done on the ipsilateral side from the previous motor practice.

Combination of rehabilitation and self-training was having high effect on the improvement of a patient's performance. The self-training may be carefulness or contraindication when it merges heart trouble and respiratory illness. For their patient, motor imagery was effective, because motor imagery is not limitation time, place, and using special equipment.

Conflict of interest

Nothing.

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