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Excitability Changes in the Human Primary Motor Cortex During Observation with Motor Imagery of Chopstick Use

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Abstract. [Purpose] The aim of this study was to investigate whether the performance of a combination of observation and motor imagery of chopstick use (complex task) increased corticospinal excitability more than the performance of observation alone. [Subjects and Methods] We recruited 10 healthy subjects with no history of neurological diseases. Corticospinal excitability was assessed with the participants seated in front of a computer screen performing three tasks: (1) control, the subjects were instructed to relax; (2) OBS, the subjects were told to observe an action depicted in the video, and (3) OBS + IMG, the subjects were told to imagine performing an action depicted in a video. During tasks (2) and (3), a video was displayed on the computer screen showing the hand of a male subject using chopsticks to move small items of food from one dish to another (first person perspective). Imagery was performed kinesthetically. [Results] The MEP amplitude in the first dorsal interosseous was significantly increased during OBS+IMG relative to that in the control condition, but not that in the OBS condition. The MEP amplitude in the thenar muscles was significantly different between OBS and OBS+IMG. [Conclusion] These results suggest that the combination of observation and motor imagery of a complex task may be more effective than observation alone for motor rehabilitation purposes.
Key words: Action observation, Motor imagery, Motor evoked potential, Complex task

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INTRODUCTION

In recent years, along with advances in brain imaging technology, attention has been directed toward neurorehabilitation on the basis of findings about brain mechanisms. In particular, the positive effect of mental practice, which is designed to improve performance and involves repeated mental imaging of a certain movement, has been identified by many previous studies[1–7)]. Mental practice is performed without actually moving, so it is suitable for patients in the acute period of stroke when the ability to perform voluntary movements has not yet sufficiently recovered; in addition, it involves little risk. Many neuroimaging studies have confirmed that brain activation in motor-related areas occurs when subjects imagine the performance of a movement in exactly the same manner as if they had actually performed the action, and have suggested that the primary motor cortex plays a role during such motor imagery[8)]. Further more, involvement of the corticospinal pathway has been reported in several transcranial magnetic stimulation (TMS) studies which showed the motor-evoked potential (MEP) was significantly higher during motor imagery than in the control condition[9–11)].

As in motor imagery, certain areas of the human brain related to motor execution are activated during observation of the actions performed by others. This activation of motor areas during action observation is attributed to the mirror neuron system, which is believed to play an important role in motor learning. The discovery of the mirror neuron system was made by Rizzolatti et al.[12)] in a monkey study of the ventral premotor cortex (area F5), and the existence of a similar system in humans has since been demonstrated[13,14)]. Those studies revealed that the motor system in the brain is activated when individuals observe the actions of others, and therefore, observation of actions as well as motor imagery is expected to be applicable to rehabilitation[15)].

Almost all previous studies have examined the effect of either action observation or motor imagery alone on brain activity, and only a few studies have investigated cortical activation during action observation and motor imagery in a single study. Leonard and Tremblay[16] investigated, using TMS, whether normal aging would affect the ability of elderly people to engage the motor system when observing or imagining motor action. On the basis of their result, they suggested that the capacity of healthy elderly people to produce such corticomotor facilitation in the hand muscles was largely preserved, although with a loss of selectivity with regard to the muscle involved in the task compared with young people. Furthermore, their colleagues extended these observations to a group of elderly patients diagnosed with Parkinson's disease and concluded that, even when properly medicated, elderly people with Parkinson's disease may experience major difficulties in engaging the motor system for covert action, particularly when asked to observe another person's action[17]. For the lower extremities, Liepert and Neveling[18] have demonstrated that observation or motor imagery of foot dorsiflexion increased motor excitability in the tibial anterior muscle.

Recently, Sakamoto et al.[19] demonstrated that the combination of observation and motor imagery of an action enhanced corticospinal excitability compared with the excitability that occurred during observation or motor imagery alone. This finding is very interesting for situations where observation and motor imagery of an action are used for rehabilitation. However, their research used a relatively simple task (repeated flexion and extension of the elbow). Several studies have reported that motor representation during observation and imagery of simple versus complex tasks results in different activations. Accordingly, it is necessary to investigate the effects complex tasks that require skill of movement for motor rehabilitation.

The aim of the present study was to investigate whether the performance of the combination of observation and motor imagery of a complex task increased corticospinal excitability more than the performance of observation alone. In the present study, chopstick use was adopted as the complex task, as it is commonly used in rehabilitation.

SUBJECTS AND METHODS

The study subjects were 10 healthy individuals who ranged in age from 18 to 22 years (mean: 20.4 ± 1.3 years). All subjects were right-handed and had no history of neurological diseases. The study was approved by the local committee for ethical standards in accordance with the Declaration of Helsinki (1964). Subjects gave written informed consent prior to their participation.

The subjects were seated on a chair with a 24-inch PC monitor positioned at a distance of one meter from their face at eye level and were required to place their forearm in a pronated position on the desk in front of them. During the test session, the subjects were instructed to relax and reduce the tension in their upper extremities.

In this study, the subjects performed under the following three tasks: (1)relaxing without imaging with the eyes directed towards the blacked out computer screen (hereinafter referred to as "control"), (2) observing an action depicted on a video (hereinafter referred to as "OBS"), and (3) kinesthetically imagining (as if performing the action themselves) the performance of the depicted action on the video (hereinafter referred to as "OBS+IMG"). Previous reports have indicated that the effects of motor imagery and action observation depend on whether the subjects have had experience of the experimental task/action and whether they know their role in advance[20,21]. Therefore, we decided to select chopstick use as an experimental stimulus, since it is a task that is commonly used in clinical rehabilitation, that is very familiar to the subjects, and that is relatively complex. A video displayed on the computer screen showed the hand of a male subject using chopsticks to move small items of food from one dish to another (the right plate contained 5 pieces of fried chicken, and the left plate contained no food). Each piece of food was moved from one plate to the other with a pair of chopsticks, one by one, within 20 seconds.

Before the experiment, the subjects were trained in this procedure until they felt sufficiently familiar with the motor imaging process. In the experiment, we monitored the presence or absence of muscle contraction using electromyography, and we excluded samples in which discharges generated as a result of background muscle activation were observed. In addition, in order to rate the vividness of subjects' motor imagery, the subjects were asked to complete a self-evaluation using a visual analogue scale (VAS)[22,23] in the OBS+IMG condition. That is, after completing the OBS+IMG task, the subjects marked a location on a 100 mm horizontal line, the two ends of which were labeled '0=None at all' and '100=Very vivid image', according to the vividness of the imagery they experienced.

MEP was measured from the first dorsal interosseous (FDI) and the thenar (TH) muscles in the right hand, with paired surface Ag/AgCl cup electrodes on a belly-tendon montage. The surface EMG signals, amplified (MEB-2200, Nihon Kouden, Japan) at a bandwidth of 5 Hz to 3 kHz, were sampled at 2 Hz, and input to a computer for off-line analysis (MacLab system, AD Instruments Pty. Ltd.). TMS was delivered to the motor hotspot, which was marked with a pen on a swimming cap covering the scalps of the subjects, using a figure-of-8-shaped coil (Magstim200, Magstim Company, UK). The stimulation intensity was set at a light supra-threshold level of MEP to evoke MEPs in both muscles consistently. The coil was placed tangentially to the scalp with the handle pointing backward and rotated approximately 45° away from the mid-sagittal line. The coil was held by hand, and its position, with respect to the marks, was checked continuously. The resting motor threshold (rMT) was defined as the lowest stimulus intensity evoking MEP in both muscles with amplitudes of at least 50μV in at least five out of ten trials. The test stimulus intensity was adjusted to evoke control response with a peak-to-peak MEP amplitude of approximately 0.5–1 mV in both muscles (1.1–1.3 times rMT).

TMS were applied when the model in the video sequence picked up the third piece of food with chopsticks. The MEP amplitudes were calculated from 12 trials with intervals of 5 seconds in the control condition, from 12 trials in the

OBS condition, and from 12 trials in the OBS+IMG condition, giving a total of 36 trials in all. The test order between "OBS" and "OBS+IMG" was determined at random. MEP data were obtained by calculating the peak-to-peak values after testing and were compared with the data were obtained in the different tasks.

All statistical analyses were performed with SPSS ver.15.0J for Windows, using one-way analysis of variance and a repeated-measures test, and Bonferroni's method to adjust for multiple comparisons. The level of statistical significance was chosen as $p<0.05$.

RESULTS

Typical MEP waveforms of the TH and FDI muscles produced in the three tasks are shown in Fig. 1. There was a tendency for the MEP amplitudes in the FDI muscles in OBS and OBS+IMG conditions to be higher than those in the control condition, whereas in the case of the TH muscles, there were no clear modulations.

Table 1 shows the mean values of all subjects in both conditions (N=10) in all the tasks. In the FDI muscles, one-way repeated-measure ANOVA demonstrated a significant main effect among tasks ($F=8.205$, $p<0.05$). Additionally, when the multiple comparison procedure was used, significant differences were found between the control and OBS+IMG tasks, and between the OBS and OBS+IMG tasks ($p<0.05$). In the TH muscles, one-way repeated-measure ANOVA demonstrated a significant main effect among tasks ($F=3.805$, $p<0.05$), and when the multiple comparison procedure was used, significant difference was found between the OBS and OBS+IMG tasks ($p<0.05$).

The VAS mean score of all the subjects in the OBS+IMG task was 59.9±13.9%. We judged that the vividness of the motor imagery in the present study was sufficient from this value and that the values were sufficient when the mean value of the score of VAS exceeded half the maximum, although there are no clear criteria that guarantee the vividness of the motor imagery.

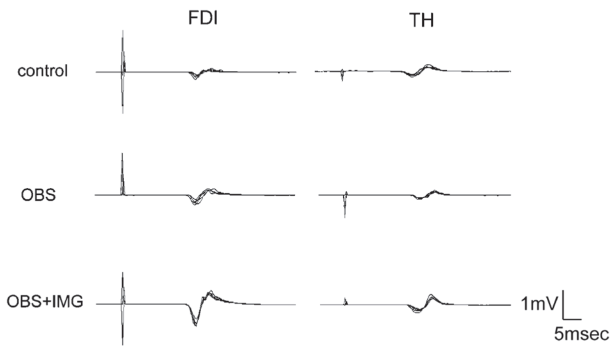

Fig. 1 Specimen records of MEP (superimposed trails) of the FDI and TH muscles obtained from a single subject.

Table 1.

	control (mV)	OBS (mV)	OBS+IMG (mV)
FDI	0.32 ± 0.12	0.40 ± 0.29	0.67 ± 0.40*†
TH	0.38 ± 0.28	0.35 ± 0.30	0.53 ± 0.36†

The means and standard deviations of MEP amplitude from all subjects tested (n=10). *$p<0.05$ VS. Control , † $p<0.05$ VS. OBS.

DISCUSSION

In the present study, we compared the effects of combining observation and motor imagery of chopstick use (complex task) and those of observation alone on corticospinal excitability, using TMS technique. The results show that combining observation and imagery of chopstick use enhanced corticospinal excitability compared with the excitability that occurred during observation alone. In addition to the present study, Sakamoto et al.[19] investigated whether combining observation and motor imagery of repetitive elbow action (a relatively simple task) increased corticospinal excitability over the effects of either manipulation performed alone. They demonstrated that combining observation and imagery of an action enhanced corticospinal excitability compared with the excitability that occurred during observation or imagery alone. In their study, they made comparisons with not only the action observation but also the motor imagery condition (the subjects were asked to close their eyes). In general, it is difficult in the closed eye condition to precisely judge the timing at which the subject's imaging progresses. Therefore, they asked the subjects, immediately after the stimulation, to indicate the elbow angle at which TMS had been applied with their left elbow in the motor imagery condition. If the elbow angle was beyond 90°, the data were discarded from the analysis. However, it was difficult in the present study using the complex task of chopstick use to discriminate imaging timing, therefore it was not executed in the motor imagery task.

Taken together, these findings indicate that the combination of observation and motor imagery of an action increases corticospinal excitability more than the effect of performing observation alone, regardless of whether a simple or a complex task is involved.

In the present study, we selected both FDI and TH as agonist muscles of chopstick use in the present study. Excitability changes explored by TMS are highly specific for the muscles involved in the observed[24,25] or imagined[10,11] actions. The MEP amplitude in the FDI muscle in the OBS+IMG task significantly increased compared with that in the control task. Although the MEP amplitude in TH showed a tendency similar to that of the MEP amplitude in FDI, the changes were not statistically significant. The reason for this could be that TH is mainly involved in the fixation of chopsticks.

Although neither the present study nor the study of Sakamoto et al. identified a significant increase in MEP amplitude during action observation compared with that elicited in the control task, several reports have shown significant enhancements of MEP amplitude during action observation[26–28]. In addition, a report by Ertelt et al. [29] described that action observation therapy, in which stroke patients observed another's movement with the intention of imitating it and later engaged in repeated practice corresponding to the actions performed on a video screen, enabled subjects to improve their upper extremity functions. The mirror neuron system, which is involved in motor learning during action observation, is now thought to be involved not only in action observation, but also in the execution of action and to be most activated when humans imitate and learn from the actions of others. Roosink and Zijdewind[30] divided their observations into two categories, passive observations performed without any prior notice and active observations performed to imitate the actions of others, and reported that the latter was more effective at indicating corticomotor excitability. Consequently, before action observation is used in rehabilitation training, more elaborate and distinctive methods need to be devised to provide patients not only with passive observation exercises but also with opportunities to observe actions with the intention of imitating them in order to help patients use their mirror neuron system more effectively.

In conclusion, our study has shown that the combination of observation and motor imagery of a complex task may be more effective than observation alone for motor rehabilitation purposes. Motor imagery and action observation have just started to be developed as rehabilitation tools. Therefore, more study is needed to clarify which method is most effective at a practical level.

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