Combining observation and imagery of an action enhances human corticospinal excitability

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ABSTRACT

The present study investigated whether combining observation and imagery of an action increased corticospinal excitability over the effects of either manipulation performed alone. Corticospinal excitability was assessed by motor-evoked potentials in the biceps brachii muscle following transcranial magnetic stimulation over the motor cortex during observation, imagery or both. The action utilized was repetitive elbow flexion/extension. Simultaneous observation and imagery of the elbow action facilitated corticospinal excitability as compared to that recorded during observation or imagery alone. However, facilitation due to the combination of observation and imagery was not obtained when the participants imagined the action pattern while they observed the same action presented out of phase. These findings suggest that a combination of observation and imagery can enhance corticospinal excitability. This enhancement depends on phase consistency between the observed and imagined actions.

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1. Introduction

Simulation of an action represents a crucial element for numerous motor abilities, such as learning of complex motor skills, improvement of sports performance, or mental rehearsal of movements. Such mental simulation of an action is generally called motor imagery. Motor imagery can be defined as the covert movement of body parts without an actual movement (Jeannerod, 2001). In our everyday life, there are situations where imagery of an action is accompanied by an observation of the same action. For example, when humans learn a particular body action, they first observe that action performed by others, and then they internally and unconsciously imagine the observed actions. This suggests an interaction between the imagery and observation of an action.

Recent studies have revealed an overlap between the neural mechanisms involved in observation, imagery, and actual execution of an action. Brain imaging techniques have demonstrated that the cortical areas involved in action execution, such as the supplementary motor area, premotor cortex, superior parietal lobe, cingulate gyrus and cerebellum, are activated when actions are “observed” or “imaged” (Decety and Grèzes, 1999; Grèzes and Decety, 2001). In addition, the electroencephalographic patterns during execution of an action are similar to those during observation (Babiloni et al., 2002; Cochin et al., 1999; Muthukumaraswamy and Johanson, 2004) or imagery (Carrillo-de-la-Peña et al., 2006; McFarland et al., 2000; Pfurtscheller et al., 2006) of that action.

Observation or imagery of an action also modulates the excitability of the descending motor pathways relevant to that action. When humans observed the grasping motion of a hand, the size of the motor-evoked potential (MEP) in the hand muscles after transcranial magnetic stimulation (TMS) over the primary motor cortex, which reflects corticospinal excitability (Rothwell, 1997; Petersen et al., 2003), increased (Fadiga et al., 1995). Similarly, corticospinal excitability in the wrist flexor was larger during the imagery of wrist flexion, while that in the wrist extensor muscle was larger during imagery of wrist extension (Hashimoto and Rothwell, 1999). These modulations of corticospinal excitability were specific to the muscles involved in the observed (Maeda et al., 2002; Urgesi et al., 2006) or imagined (Fadiga et al., 1999; Rossini et al., 1999) actions.

Previous work has examined the effect of either observation or motor imagery alone on brain activity. If observation and imagery of an action are performed simultaneously, will the effect be further enhanced? In the present study, we investigated this question by assessing the size of the MEP when participants performed (1) observation, (2) imagery, or (3) both.
2. Materials and methods

2.1. Participants

Eight right-handed volunteers aged 22–34 years, naive to the purpose of the experiments, participated in the study. All participants were within the normal range on physical and neurological examinations and gave written informed consent. This study was approved by the Human Research Ethics Committee of the Faculty of Sport Sciences, Waseda University. The experiments were conducted in accordance with the Declaration of Helsinki.

2.2. TMS and MEP recording procedures

Electromyographic responses (EMG) were recorded from the right biceps brachii (BB) muscle with disposable Ag–AgCl electrodes placed over the belly of the muscles. The EMG signal was amplified (MEB-2216, Nihonkoden, Japan) and bandpass filtered between 5 and 1500 Hz. All signals were converted into digital data for later analysis via an A/D converter system at a sampling rate of 3000 Hz.

TMS was performed with a 140 mm round coil and a transcranial magnetic stimulator (SMN-1200, Nihon Koden, Japan). Single-pulse TMS was delivered to the scalp position of the left hemisphere where the maximum MEP sizes were produced in BB. Stimulus intensity was set at 120% of the resting motor threshold (RMT), defined as the minimum stimulus intensity that produced EMG responses greater than 50 μV in BB muscle in at least five out of ten trials. The EMG signal was recorded from 100 ms before to 100 ms after the TMS pulse. Participants wore a tightly fitting swimming cap on which the scalp positions for stimulation were marked. The coil was held by hand, and its position, which respect to the marks, was checked continuously.

2.3. Procedures and stimuli

Participants sat comfortably in an armchair with the right arm immobilized in a supinated position. The participants’ right elbow angle was maintained in a flexed position (around 90°). A video screen was placed 80 cm from the participant. A video-clip showed the right arm of a person lifting up and putting down an 8 kg dumbbell at 0.34 Hz (Fig. 1). The video-clip lasted for 30 s. At this time, the elbow movement was presented 10 times. This video sequence of the action was repeated with a 5 s interval.

Participants performed four conditions in experiment 1. For the observation condition (OBS), the participants were asked to observe a simple and repeated flexion and extension of the right elbow action and “not to imagine” the elbow movement. TMS was applied randomly at some point between the 5th and 8th elbow movements in each video-clip. TMS was triggered while the elbow angle in the video was flexed at 90°. For the imagery condition (IMAG), the participants were first asked to view the same video of the elbow action as presented in OBS for 4 or 5 cycles of elbow movements, then to close their eyes and to imagine flexing and extending of their right elbow at the same rate as in the video. TMS was delivered while a participant’s right elbow was flexed at around 90° in their mental image. For the observation and imagery condition (OBS + IMAG), the participants observed the same video while they imagined a flexion-extension movement of their right elbow. In this condition, the participants were asked to adjust the pace of their imaged elbow movement to the movement presented on the screen. TMS was delivered when the elbow angle presented on the screen was flexed (around 90°). In the IMAG and OBS + IMAG conditions we asked the participants, immediately after the stimulation, to indicate the elbow angle at which TMS had been applied with their left elbow. But, we also asked the participants not to imagine the left elbow movement. When the elbow angle was outside the range of 90 ± 10°, the trial was discarded from the analysis. For the control condition, MEPs were recorded when the participants viewed the fixed point presented on the screen center with no muscle activity. Sixteen trials of each condition, for a total of 64 trials, were conducted. The order of the trials was randomized. For the recording session, we grouped the different task conditions in separate blocks. Each block consisted of eight stimuli.

To determine whether the facilitation of MEP size during OBS + IMAG depended on the phase relationship between the observation and imagery, experiment 2 was performed utilizing the same subjects. MEPs were elicited from BB when the participants performed the four different tasks. First, the participants closed their eyes and imagined the elbow action (IMAG). Second, the participants imagined the elbow flexion-extension movement while they observed the same action presented 180° out of phase (OBS + IMAG reverse). For example, when the participants observed elbow flexion, they actually imagined elbow extension, and vice versa. Third, the participants imagined the same action while they observed a static picture on the screen showing a dumbbell being held with the elbow angle at 90° (OBS + IMAG static). The static picture was presented at an effortful phase of elbow flexion as shown in the right panel of Fig. 1. Finally, they observed a fixed point presented on the screen with no muscle activity (control). The order of the trials was randomized. For the recording session, we grouped the different task conditions in separate blocks. Each block consisted of eight stimuli.

2.4. Data analysis

The average prestimulus EMG activity was obtained by calculating the root mean square for the 100 ms before the TMS in each trial. The MEP size was measured as a peak-to-peak amplitude and was normalized with respect to that obtained in the control condition. For modulation of the MEP and prestimulus EMG across the different conditions, a one-way repeated measures analysis of variance (ANOVA) was performed. For post hoc comparisons, multiple pair-wise tests with Bonferroni’s correction were performed. To investigate whether the MEP sizes were significantly facilitated relative to the control conditions, multiple comparisons were conducted using Dunnett’s test. Data were expressed as the mean ± one standard deviation (SD). Significance was set at p < 0.05 for all analyses.
3. Results

Fig. 2A shows typical recordings of the MEP obtained from a single subject in experiment 1. Onset latencies (subjects’ mean ± SD) of MEPS were 11.4 ± 0.9 ms (control), 11.3 ± 0.6 ms (OBS), 11.3 ± 0.6 ms (IMAG) and 11.1 ± 0.7 ms (OBS + IMAG). When the participants performed observation and imagery (OBS + IMAG) of the elbow action (repeated flexion and extension) simultaneously, extra facilitation of the MEP amplitude was observed. The stimulus artifact of MEP in IMAG condition in Fig. 2A was smaller than in the other conditions. This was not always the case for the other participants. Fig. 2B shows the MEP group means for BB during OBS, IMAG and OBS + IMAG. One-way repeated measures ANOVA demonstrated a significant main effect for the task (F(2, 14) = 15.17, p < 0.001). Amplitude of the MEP during IMAG and OBS + IMAG significantly increased as compared to that observed during the control condition (IMAG: p < 0.05; OBS + IMAG: p < 0.001). In addition, the degree of facilitation of MEP during OBS + IMAG was significantly greater than that during OBS (p < 0.001) and IMAG (p < 0.05). Furthermore, the degree of increase in MEP size during OBS + IMAG was significantly larger than the sum of the effect caused by OBS and IMAG (dashed line in OBS + IMAG panel, p < 0.05). The modulation of MEP amplitudes in BB was not changed across all tasks (all p > 0.05). Therefore, alteration of the MEP amplitude during any of the tasks could not have resulted from a change in muscle activity.

Fig. 3 depicts modulation of MEP amplitudes when the participants imagined the elbow action while observing the static picture (OBS + IMAG static) and the same action presented 180° out of phase (OBS + IMAG reverse) in experiment 2. Onset latencies (subjects’ mean ± SD) of MEPS were 11.6 ± 0.2 ms (control), 11.6 ± 0.4 ms (IMAG), 11.6 ± 0.4 ms (OBS + IMAG static) and 11.4 ± 0.3 ms (OBS + IMAG reverse). Fig. 3A shows typical recordings of the MEP obtained from a single subject. Although increases in MEP amplitudes compared with the control condition were evident in all three conditions, extra facilitation of the MEPS by observation did not occur. Fig. 3B illustrates MEP group means for BB during IMAG, OBS + IMAG static and OBS + IMAG reverse. There was no significant difference in MEP amplitude among three conditions (F(2, 14) = 0.42, p > 0.05). The present study showed that combining observation and imagery of an action enhanced corticospinal excitability as compared with the excitability that occurred during observation or imagery alone. This enhancement of corticospinal excitability was not observed when imagery was combined with observation of incompatible actions, thus suggesting that obtaining the increased effect requires phase consistency between the observed and imagined actions.

4. Discussion

The present study showed that combining observation and imagery of an action enhanced corticospinal excitability as compared with the excitability that occurred during observation or imagery alone. This enhancement of corticospinal excitability was not observed when imagery was combined with observation of incompatible actions, thus suggesting that obtaining the increased effect requires phase consistency between the observed and imagined actions.

The modulation of MEP amplitudes following TMS reflects alteration of corticospinal excitability (Rothwell, 1997; Petersen et al., 2003). Corticospinal excitability could be altered by activity in the premotor cortex via cortico-cortical projections from the premotor cortex to the primary motor cortex (Strafella and Paus, 2000; Shimazu et al., 2004; Fadiga et al., 2005). The specialized parietal-prefrontal circuits of the “mirror neuron system” could be implicated. These circuits are involved not only with the execution of a particular action but also with observation of the same action performed by others or imagery of the same action (Iacoboni et al., 1999; Buccino et al., 2001, 2006; Rizzolatti et al., 2001). The mirror neuron system in the premotor cortex is thought to be involved with the increase in MEP amplitude during action observation (Fadiga et al., 2005; Avenanti et al., 2007).
Activity of the mirror neuron systems could contribute to the increased effect of combining observation and imagery observed in the present study. First, an fMRI study has demonstrated that the areas activated during execution, observation and imagery of movements include overlapping loci in the dorsal premotor and superior parietal cortex where the fronto-parietal mirror neuron systems are thought to exist (Filimon et al., 2007; Orr et al., 2008). If observation and imagery share common elements in the mirror neuron system, simultaneous execution of these systems should cause further facilitation of their activity, resulting in an increased enhancement of corticospinal excitability as obtained in the present study. Second, in an experiment utilizing a TMS technique similar to that of the present study, a strict phase coupling between changes in corticospinal excitability and the dynamics of the observed action were noted (Gangitano et al., 2001); during observation of a grasping action, excitability of the corticospinal system innervating finger muscles increased during the finger aperture phase and decreased during the finger closure phase. Interestingly, when the participants observed an unpredictable grasping action, corticospinal excitability did not change with the dynamics of the observed action (Gangitano et al., 2004). Recordings of mirror neurons in nonhuman primates during the observation of action indicate that the discharge of some neurons depends upon the phase of grasping or holding actions (Callao et al., 1996; Umittà et al., 2001). These reports suggest that mirror neuron systems may be able to encode some aspects of the timing of an action. In the present study, if the facilitation of MEP amplitude during OBS + IMAG had been attributable merely to motor learning or sports training. Athletes typically observe or imagine movements done by themselves as well as others. These procedures are thought to be extremely important in the acquisition of a new skill or in the improvement of an athlete's performance. Mental practice has been shown to improve the performance of athletes, although the effect of mental practice is relatively low compared to that of movement execution training (Lotze and Halsband, 2006). It is expected that combining observation and imagery of an action could increase the effects of mental practice.

In summary, we have shown that combining observation and imagery of elbow action enhanced corticospinal excitability. This enhancement did not occur when imagery was combined with observation of the same action presented out of phase, suggesting that the increased effect due to combining observation and imagery would depend on phase consistency between the observed and imagined actions. These findings provide new possibilities for enhancing the mental aspects of neurorehabilitation and physical training methods.

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