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Research article

Modulation of corticospinal excitability during positive and negative motor imageries

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ABSTRACT

We investigated corticospinal excitability during positive (execution) and negative (suppression) imageries for the right and left upper and lower limbs. In the Positive Imagery tasks, sixteen subjects were instructed to repeatedly imagine rotation of the index finger of the right or left hand, or the ankle of the right or left foot. In the Negative Imagery tasks, they were asked to imagine the suppression of movements for the index finger of the right or left hand, or the ankle of the right or left foot. A single-pulse transcranial magnetic stimulation was delivered over the left hand primary motor cortex, and motor evoked potentials (MEPs) were recorded from the right first dorsal interosseous (FDI) muscle under all conditions. The MEP amplitudes of the FDI were significantly larger in the Positive and Negative Imagery tasks than in the resting control task during motor imagery of the right hand, left hand, and left foot, but not during that of right foot. Our results indicate that imageries of suppressing hand and foot movements enhanced corticospinal excitability.

1. Introduction

Motor imagery is defined as the mental execution of a movement without any overt movement or muscle activation. The general concept of motor imagery has been specified utilizing a wide range of terms including mental imagery, movement imagery, mental practice, imagery rehearsal, visualization, kinesthetic imagery, visuomotor behavioral rehearsal, and internal imagery [14]. Previous studies focused on the characteristics of corticospinal excitability during motor imagery [4,7,20], which was estimated from the amplitude of motor evoked potentials (MEPs) in response to a transcranial magnetic stimulation (TMS) delivered over the primary motor cortex (M1). During motor imagery, corticospinal excitability is increased above the resting excitability level [7]. For example, MEP amplitudes during the imagery of squeezing a ball are enhanced with the real touch of the ball [13], and the enhancement of MEP amplitudes during motor imagery is associated with an increase in the imagined force level [15].

In contrast to the imagination of motor execution (i.e. positive motor imagery), a previous study reported corticospinal excitability during the imagination of suppressing movement (i.e. negative motor imagery) [21]. Sohn and colleagues [21] used auditory Go/No-go paradigms, and subjects were asked to imagine squeezing hands after a Go stimulus, and attempt the suppression of TMS-induced twitching movement by increasing the amount of relaxation after a No-go stimulus. In general, during Go/No-go paradigms, subjects were asked to respond to one cue (the Go stimulus) and not respond to another cue (the No-go stimulus). In TMS studies involving a No-go trial, the suppression of MEP amplitudes with respect to a resting control was observed after a No-go signal [18,25,26]. MEP amplitudes in the first dorsal interosseus (FDI) were significantly suppressed during negative motor imagery, but remained unchanged during positive motor imagery [21]. These findings suggest that the excitatory corticospinal drive is inhibited during imagery of suppressing movements. To the best of our knowledge, no further studies have investigated the characteristics of corticospinal excitability during negative motor imagery; however, most of the studies on motor imagery have focused on positive motor imagery. In some sports such as figure skating, dance, and gymnastics, posing skills and lithe movement stopping plays an important role in their performance. Thus, negative motor imagery, similar to positive motor imagery, is expected to aid in the acquisition of the fine motor control of body parts. Furthermore, some neuroimaging studies utilizing functional magnetic resonance imaging (fMRI) examined neural substrates for positive motor imagery, and showed that brain areas activated during motor imagery involved the supplemental motor area

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(SMA), premotor cortex (PM), primary sensorimotor area (SM1), dorsolateral prefrontal cortex (DLPFC), inferior parietal lobule (IPL), basal ganglia, and cerebellum [16,17]. These brain regions were also similar to those activated during motor execution [2,5,6]. However, neural substrates for negative motor imagery have not been examined in detail. The present study focused on the 'remote effect' of negative motor imagery, which was related to a phenomenon in which movement in one limb affected movements in other limbs [24], to clarify one of the characteristics of negative motor imagery. This effect was confirmed during muscle contraction, muscle relaxation, and movement preparation [8,9]. For example, Komeilipoor and colleagues [9] reported higher corticospinal excitability in the FDI during the preparation and execution of teeth clenching and ipsilateral foot dorsiflexion than during the observation of a fixation cross. Their findings suggest neural interactions underlying muscle contraction in different body parts. We hypothesized that the remote effect in corticospinal excitability is present in positive and negative motor imageries if neural substrates are similar between motor execution and motor imagery. Thus, we evaluated the modulation of MEP amplitudes elicited by TMS applied to the hand area of M1 during positive and negative motor imageries under four conditions (i.e. right hand, left hand, right foot, and left foot).

2. Methods

Sixteen normal female subjects (mean age 20.6 years, range 20–22 years) participated in this study. Subjects did not have a history of any neurological or psychiatric disorders. Informed consent was obtained from all participants. The study was approved by the Ethics Committee of Nara Women's University, Nara, Japan. Experiments were conducted in accordance with the Declaration of Helsinki.

We applied stimuli with a 7-cm figure-of-eight coil connected to a Magstim Super Rapid (The Magstim Company, Dyfed, UK) with a biphasic current system. TMS was delivered over the hand motor cortex of the left hemisphere, and we identified the optimal position and direction of the coil for which the largest MEP was obtained from the right FDI muscle. The stimulating coil was orientated to generate induced current in a posterior to anterior current direction. Subjects wore a swimming cap, and the optimal position for eliciting MEPs in the contralateral FDI, which was marked directly on the cap, was established. Resting motor threshold was defined as the minimum intensity evoking MEPs of more than 50 μV in at least five out of 10 trials in FDI [19]. The intensity of TMS throughout the experiment was set at 110% of the resting motor threshold. The electromyography (EMG) of FDI was recorded with a bandpass of 5–1500 Hz using Ag/AgCl disk electrodes, and the sampling rate was 5000 Hz. The recording time was 100 ms, including a prestimulus baseline period of 10 ms. EMG signals were collected on a signal processor (Neuropack MEB-2200 System; Nihon-Kohden, Tokyo, Japan). We followed the same TMS and recording systems described in a previous study [18].

The experiment was performed in a quiet room maintained at 24° C, and subjects sat comfortably in a chair. Recordings were conducted under four conditions, (1) Right Hand (RH), (2) Left Hand (LH), (3) Right Foot (RF), and (4) Left Foot (LF) conditions. Each condition included three tasks: Control, Positive Imagery, and Negative Imagery. In the Control tasks under all conditions, subjects were asked to relax and rest quietly with no specific task. In the Positive Imagery tasks for the RH and LH conditions, subjects were instructed to repeatedly imagine the rotation of the index finger of the right or left hand. In the Negative Imagery tasks for the RH and LH conditions, subjects were instructed to imagine suppressing the movement of the index finger of the right or left hand. In the Positive Imagery tasks for the RF and LF conditions, subjects were instructed to repeatedly imagine the rotation of the ankle of the right or left foot. In the Negative Imagery tasks for the RF and LF conditions, subjects were instructed to imagine suppressing the movement of the ankle of the right or left foot. Subjects were instructed to perform the imaging of movements with a comfortable and self-paced rhythm, and to keep the same rhythm among the four conditions. Before the practice session, the difference between the first-person perspective (kinematic imagery) and third-person perspective (visual imagery) [22] was explained to subjects. During imagery, subjects were instructed to "imagine with a first-person perspective", and concentrate on performing the required task. A practice session with ten trials of positive and negative motor imageries including rotation and suppression under each condition was performed before the recording in order to enable the subjects to become familiar with the situation. Before starting one condition (ex. the RH condition), subjects were informed about the condition to perform, and were then also informed about the type of task (Control, Positive, and Negative). The start cue of imagery was presented by an experimenter verbally, and subjects were instructed to continue the same imagery until the verbal end cue was presented when finishing 20 stimuli in a task. In addition, before starting the experiment, we strongly requested that subjects were not to move their hand and were to relax and rest during the experiment. After each task, subjects were asked to estimate the quality of their imagery using a seven-point Likert Scale: 1 = very hard to feel; 7 = very easy to feel [10]. A 5-min break was set to avoid the effects of fatigue after each condition. The order of the four conditions was randomized for each subject and counterbalanced across all subjects. TMS stimuli were delivered randomly between 4 and 6 s apart, and 20 stimuli were applied in each task (i.e. a total of 60 stimuli in one condition).

Scores of imagery quality for the four conditions and three tasks (Control, Positive, and Negative) were evaluated with the Friedman test. In order to evaluate corticospinal excitability, peak-to-peak MEP amplitudes were measured. The averaged values of MEP amplitudes in each task of the four conditions were then calculated. MEP amplitudes were submitted to three-way repeated measures ANOVAs using Limb, Laterality, and Task (Control, Positive, and Negative) as within-subject factors. Bonferroni post hoc multiple comparison tests were conducted to evaluate differences among Tasks. We also analyzed the bivariate correlative relationship between imagery quality scores and MEP amplitudes under each condition, after confirming data with a normal distribution by the Kolmogorov-Smirnov test. In addition, in order to confirm differences in MEP amplitudes among Control tasks, two-way repeated measures ANOVAs using Limb and Laterality were performed. We also analyzed background EMG activity in the FDI muscle 10 ms before TMS onset in order to confirm whether the target muscle was relaxed during data collection. Background EMG data were subjected to three-way repeated measures ANOVAs using Limb, Laterality, and Task as within-subject factors. Regarding all repeated measures factors with more than two levels, we tested whether Mauchly's sphericity assumption was violated. If the result of Mauchly's test was significant and the assumption of sphericity was violated, the Greenhouse-Geisser adjustment was used to correct sphericity by altering the degrees of freedom using a correction coefficient epsilon. In all cases, sphericity was maintained. Thus, the Greenhouse-Geisser correction was not used. Statistical tests were performed using computer software (SPSS for windows ver. 22.0, IBM). Significance was set at $p < 0.05$.

3. Results

Table 1 shows the mean scores of imagery quality under four conditions tested with standard errors (SE). The Friedman test for imagery quality showed no significant differences among conditions and tasks.

Table 1
Imagery quality scores under four conditions tested.

	RH	LH	RF	LF
Positive Imagery	4.5 (0.3)	4.5 (0.3)	4.7 (0.3)	4.4 (0.3)
Negative Imagery	4.3 (0.4)	4.4 (0.4)	4.3 (0.3)	4.2 (0.3)

Data were expressed as the mean (SE).