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Research article

Effect of tactile stimulation on primary motor cortex excitability during action observation combined with motor imagery

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HIGHLIGHTS

- Effect of tactile input during action observation on M1 excitability was examined.
- That effect on M1 excitability was decreased in muscle worked in action observed.
- The decreased M1 excitability was reversed to facilitation by motor imagery.

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ABSTRACT

We aimed to investigate the effects of the tactile stimulation to an observer's fingertips at the moment that they saw an object being pinched by another person on the excitability of observer's primary motor cortex (M1) using transcranial magnetic stimulation (TMS). In addition, the above effects were examined during action observation combined with the motor imagery. Motor evoked potentials (MEP) were evoked from the subjects' right first dorsal interosseous (FDI) and abductor digiti minimi (ADM) muscles. Electrical stimulation (ES) inducing tactile sensation was delivered to the subjects' first and second fingertips at the moment of pinching action performed by another person. Although neither the ES nor action observation alone had significant effects on the MEP amplitude of the FDI or ADM, the FDI MEP amplitude which acts as the prime mover during pinching was reduced when ES and action observation were combined; however, no such changes were seen in the ADM. Conversely, that reduced FDI MEP amplitude was increased during the motor imagery. These results indicated that the M1 excitability during the action observation of pinching action combined with motor imagery could be enhanced by the tactile stimulation delivered to the observer's fingertips at the moment corresponding to the pinching being observed.

1. Introduction

When a person is learning a new motor skill, observing the action being performed well by another person, imitating the action, and then executing it can be a useful strategy. This approach is employed not only during motor skill learning, but also for neural rehabilitation aimed at improving the movements of stroke patients. In fact, significant improvements in stroke patients' upper arm movements have been reported after so-called action observation therapy [1]. In terms of the neurophysiological basis of this approach, the effects of action observation therapy are attributed to activation of the mirror neuron system. Mirror neurons were originally found in region F5 of the ventral premotor cortex in monkeys during action observation and imitation [2,3]. In humans, several brain cortices; i.e., the premotor ventral cortex, inferior frontal gyrus, superior temporal sulcus, and inferior parietal lobe, are considered to be involved in the mirror neuron system [4]. In addition, previous transcranial magnetic stimulation (TMS) studies have reported that the primary motor cortex (M1) is activated as part of the mirror neuron system during action observation [5,6]. Other previous studies have reported that the M1 excitability is hardly activated by the action observation only, and the motor imagery of an observed action combined with action observation was much effective to enhance the M1 excitability innervating the

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muscle activated during the performance of the observed action [7,8]. Motor imagery is a covert cognitive process controlled by a forward internal model that does not involve any actual movement, but rather involves the generation of sensory information that simulates the sensory information that would be produced if the imaged movement were actually performed [9–16]. Studies suggest that a higher brain system is involved in motor imagery and that sensory information could affect M1 excitability during action observation. In fact, it has been reported that a mirror neuron system that performs the cross-modal processing required to integrate visual and tactile information exists in the somatosensory area [17].

In the present study, we aimed to investigate the effects of tactile stimulation of a subject's fingertips at the moment that they saw another person performing a pinching motion; i.e., action observation, on the subject's M1 excitability, in order to identify the neural factors that enhance the activation of the mirror neuron system. This study might aid the development of much more effective types of action observation therapy for neural rehabilitation.

2. Materials and methods

2.1. Subjects

Eight (8 males, 22–29 years old) and 10 (7 males and 3 females, 22–9 years old) normal healthy right-handed subjects participated in experiments 1 and 2, respectively, after giving their written informed consent. The handedness of each subject was evaluated using the Edinburgh Handedness Inventory [18]. All experimental procedures were carried out in accordance with the Declaration of Helsinki and were approved by the ethics committee of Hiroshima University. The subjects sat in a reclining chair and put both hands in a pronated position on a horizontal plate attached to the chair's armrests.

2.2. TMS application and MEP recording

A magnetic stimulator (Model 200, Magstim, Whitland, UK) and a figure-of-eight coil were used to deliver the electromagnetic stimuli. The coil was placed tangential to the scalp with its handle pointing backward and was rotated approximately 45° away from the mid-sagittal line. In experiment 1, the optimal coil position for evoking motor evoked potentials (MEPs) in both the first dorsal interosseous (FDI) and abductor digiti minimi (ADM) of the right hand was found on the left side of the scalp above the M1 and marked on a swimming cap worn by the subjects with a soft-tip pen to ensure reliable coil placement between the trials. In experiment 2, MEP was only recorded from the FDI, based on the results of experiment 1. The resting motor threshold of the FDI was determined and defined as the minimum TMS intensity required to produce an MEP of at least 50 μV in the resting FDI muscle in five of ten trials. The TMS intensity was set at 120–130% of the resting motor threshold. As a result, the mean amplitude of the control MEP induced in the FDI was approximately 1 mV. All electromyographic (EMG) signals were recorded using paired Ag/AgCl surface electrodes (diameter: 9 mm) and amplified and filtered at bandwidths of 5–3 kHz (7S12, NEC San-ei Co., Ltd., Japan). Analog EMG signals were digitized at a sampling rate of 10 kHz and saved on a computer for off-line analysis (PowerLab system, AD Instruments Pty., Ltd., Australia). Throughout the experiments, the subjects were instructed to avoid producing background EMG. The MEP recordings that exhibited the background EMG (less than 1% of all MEP recordings) were excluded from the data analysis. 10–15 MEP were recorded in each of the conditions described below.

2.3. Electrical stimulation (ES) to induce tactile sensations in the fingertips

Bar type stimulus electrodes (length: 55 mm, width: 15 mm, diameter of each electrode: 6 mm) were attached to the first and second fingers (one on each finger). For both fingers, the cathode was attached to the fingertip, and the anode was attached to the second joint of the finger. A burst-type electrical stimulus (ES), composed of five 1 ms square pulses at 200 Hz, was simultaneously administered to the first and second fingertips to induce a tactile sensation using a constant current isolator (SS-102J, Nihon Koden Co., Ltd., Japan) coupled with an electrical stimulator (SEN7203, Nihon Koden Co., Ltd., Japan). The ES was delivered at the moment that another person pinched a horizontal U-shaped metal plate. The intensity of the ES was set at 130% of the tactile sensation threshold of each fingertip. In a preliminary experiment, we confirmed that the ES induced a similar tactile sensation to that experienced when the subject pinched the horizontal U-shaped metal plate themselves.

2.4. Action observation and the ES trigger

The subjects were instructed to watch a 26 in. computer display placed on a desk approximately 1 m in front of them. They repeatedly watched a short live movie clip (approximately 1.5 s) on the display, which showed the horizontal U-shaped metal plate (the gap between the 2 plates was 30 mm) being pinched by another person, who used the first and second fingers of their right hand to perform the action (OBS). The pinching action was performed from the right to left direction on a display. A strain gauge attached to the U-shaped metal plate detected the deflecting force produced as it was pinched, which was used to trigger the ES. Thus, the subjects felt the ES-evoked tactile sensation at the same time as they observed the pinching action on the short live movie. The TMS was triggered 25 ms after the onset of the ES, based on the interval between the ES and the associated signals reaching the M1. Fig. 1 shows the 3 phases of the observed pinching action, and a schema of the MEP recording and the ES protocol.

2.5. Experimental conditions

In experiment 1, we examined the effects of "ES", "OBS", and "OBS + ES" on the MEP amplitude of the FDI, which acts as the prime mover during pinching, and the ADM, which is relaxed during pinching. In experiment 2, to examine the effects of motor imagery on the FDI MEP amplitude in the "OBS + ES" conditions, the subjects were instructed to imagine themselves performing the motor action being observed.

2.6. Evaluation of motor imagery

Just after each motor imagery trial, the subjects were asked to evaluate the quality of their motor imagery using a six-point-grade visual-analog scale (VAS) sheet. The subjects marked a number on the VAS sheet, which was labeled from 0 (the motor imagery was a failure) to 5 (the motor imagery was a success), according to their view of the quality of the motor imagery.

2.7. Statistical analysis

Two-way repeated measures ANOVA was carried out to analyze the effects of "condition × muscle" (Fig. 2) and "condition × imagery" (Fig. 3) on the MEP amplitude evoked in the target muscles. As a post-hoc test, a paired t-test was performed to find the significant difference between two MEP amplitudes in each condition, respectively.