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Effect of kinesthetic illusion induced by visual stimulation on muscular output function after short-term immobilization

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ABSTRACT

Kinesthetic illusions by visual stimulation (KiNVIS) enhances corticomotor excitability and activates motor association areas. The purpose of this study was to investigate the effect of KiNVIS induction on muscular output function after short-term immobilization. Thirty subjects were assigned to 3 groups: an immobilization group, with the left hand immobilized for 12 h (immobilization period); an illusion group, with the left hand immobilized and additionally subjected to KiNVIS of the immobilized part during the immobilization period; and a control group with no manipulation. The maximum voluntary contraction (MVC), fluctuation of force (force fluctuation) during a force modulation task, and twitch force were measured both before (pre-test) and after (post-test) the immobilization period. Data were analyzed by performing two-way (TIME × GROUP) repeated measures ANOVA. The MVC decreased in the immobilization group only (pre-test; 37.8 ± 6.1 N, post-test; 32.8 ± 6.9 N, $p < 0.0005$) after the immobilization period. The force fluctuation increased only in the immobilization group (pre-test; 2.19 ± 0.54%, post-test; 2.78 ± 0.87%, $p = 0.007$) after the immobilization period. These results demonstrate that induction of KiNVIS prevents negative effect on MVC and force fluctuation after 12 h of immobilization.

1. Introduction

Long-term immobilization of skeletal muscle decreases muscle output function (Seki et al., 2001a,b). Preventing the acute negative effect on muscular output function may be important to prevent the long-term effects of immobilization. Thus, systematic approaches for treating patients with immobilized extremities are important. Previous reports have indicated that decreased motor cortex excitability is associated with decreased muscle output function after immobilization (Kaneko et al., 2003). Corticomotor excitability is reduced by even short-term immobilization, in the range of days or hours (Facchini et al., 2002; Huber et al., 2006; Avanzino et al., 2011; Bassolino et al., 2014) and affects motor behavior (Moisello et al., 2008; Bassolino et al., 2012). Therefore, muscle output function may decrease in parallel with reduction in corticomotor excitability. Therefore, we hypothesized that muscle output decline after several hours of immobilization, even by means of a cast, can be prevented by motor cortex activation.

We have reported that kinesthetic illusions induction by visual stimulation (KiNVIS) significantly increases motor cortex excitability (Kaneko et al., 2007; Aoyama et al., 2012). We used a visual stimulus method involving a monitor showing a movie, on the subject's distal forearm, of another individual's index finger moving (Kaneko et al., 2007). This method may prevent muscular output function decline after cast immobilization, during which patients must remain at rest without engaging in muscle contraction. KiNVIS induction appears similar to the action-observation technique (Fadiga et al., 1995); however, Kaneko et al. (2015) indicated that the motor-related areas of the fronto-parietal cortex, insula, and striatum are more strongly activated during KiNVIS than during simple action observation. Furthermore, subjects reported feeling as if they were moving their own hand while watching a movie that induced KiNVIS. Hence, we hypothesized that cerebral network activation during KiNVIS induction prevents motor output function impairment during immobilization. However, the exact

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nature of the effects of KiNVIS induction on muscular output function decline after immobilization remains unclear.

Thus, we investigated the effect of KiNVIS induction on muscular output function after 12 h of upper limb immobilization. Major movements performed in the course of daily life involve both maximum and adjustment contractions, which were examined by maximum voluntary contraction (MVC) as well as force fluctuation during submaximal force modulation.

2. Methods

2.1. Subjects

Informed consent was obtained from all subjects, and all experimental procedures were conducted in accordance with both the recommendations of the Declaration of Helsinki for Human Experimentation and the guidelines of the local ethics committee. Experiments were performed on the left hand of 30 healthy men (age: 29.5 ± 4.2 years, height: 171.1 ± 4.4 cm, and weight: 66.5 ± 6.8 kg), all of whom were right-handed. None of the subjects had neural disorders, were taking any medication, or were engaged in high-dexterity finger function activities, such as playing musical instruments. Thirty subjects were randomly assigned to the following three groups: immobilization, illusion, and control (n = 10 in each group). Force and myoelectric data were collected from the first dorsal interosseous (FDI) muscle of the non-dominant (left) hand.

2.2. Pre-experiment

A pre-experiment and primary experiment were performed. The pre-experiment investigated whether induction of KiNVIS affects corticospinal tract excitability; subjects in the illusion group were evaluated with regard to increased motor-evoked potential (MEP) amplitude during KiNVIS, as we hypothesized that the KiNVIS effect on excitability changes in the FDI muscle in the corticospinal tract may affect muscular output function. The myoelectric activity of the immobilized FDI in the illusion group was not monitored during KiNVIS induction in the primary experiment. Therefore, to prevent contraction of the FDI during KiNVIS, the subjects underwent KiNVIS induction in the pre-experiment.

During the pre-experiment, MEP amplitude from the FDI was measured by transcranial magnetic stimulation (TMS). After the targeted skin region had been rubbed with alcohol and abraded with an abrasive skin-prepping gel, bipolar surface Ag–AgCl electrodes (5-mm diameter) were placed at 10-mm intervals along the FDI. MEPs were recorded using surface electrodes connected to an amplifier (Neuropack MEB-2200, Nihon Kohden Co. Ltd., Tokyo, Japan), at an appropriate gain level, and were band-pass-filtered at 5–1000 Hz. All signal values were digitized at 20 kHz using an A/D converter and were recorded on computer. TMS (Magstim 200, Magstim Co. Ltd., Whitland, UK) was delivered through a figure-eight coil to the right optimal scalp site at 3 levels of stimulus intensity: 105%, 115%, and 125% of the resting motor threshold (RMTh), with RMTh defined as the minimal intensity capable of inducing an MEP with a peak-to-peak amplitude greater than 50 μV.

2.3. Immobilization and resting condition

Ten hours of immobilization reduces corticomotor excitability (Avanzino et al., 2011; Bassolino et al., 2014), while 12 h of immobilization affects the coordination of upper-limb movements. (Huber et al., 2006; Moisello et al., 2008). We therefore chose an immobilization time of 12 h.

All of the left fingers of all of the subjects in the immobilization and illusion groups were bound in an elastic bandage for 12 h (7:30 A.M. to 7:30 P.M.; immobilization period), such that the metacarpophalangeal joint and the proximal and distal interphalangeal joints of the fingers remained extended. The thumb was adducted, remaining in contact with the radial aspect of the index finger, and all 4 fingers were adducted to remain in contact with each other. To restrict movement of the thumb and index finger, a plastic board in an elastic bandage was placed on the palm to prevent flexion (Fig. 1A), whereas isometric contraction of the FDI muscle with arm movement was minimized by applying an arm sling to the upper extremity (Fig. 1B). Similar to Seki et al. (2001a), subjects were instructed not to use the immobilized hand and arm, but were allowed to use their non-immobilized hand for daily living activities during the immobilization period. To limit the possible influences on motor cortex excitability, subjects were instructed not to sleep and not to imagine movement of their index finger, but to engage in restful activities (e.g., watching television or reading magazines) during the immobilization period. Subjects were closely observed by an experimenter who assisted subjects with daily living activities requiring two hands.

2.4. KiNVIS induction

After immobilization, the illusion group was subjected to KiNVIS by viewing a movie showing the movements of the immobilized part during the immobilization period. The subjects were instructed to watch a monitor displaying a movie, previously

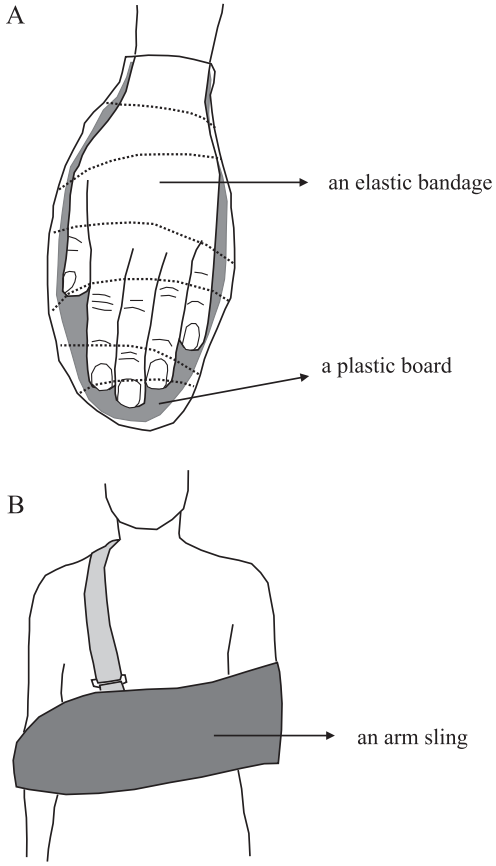

Fig. 1. Immobilization procedure. In the immobilization and illusion group, the subjects' hands were bound in an elastic bandage, with a plastic board on the palm to prevent flexion of the fingers (A). Isometric contraction in the FDI muscle that may accompany arm movement was minimized using an arm sling on the upper extremity (B).