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Full Length Article

Sensorimotor incongruence alters limb perception and movement

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ABSTRACT

Altered limb ownership or heaviness has been observed in patients with hemiplegia, chronic pain, and several other conditions. Although these sensations are thought to be caused by sensorimotor incongruence, few studies have systematically verified this relationship. In addition, it remains unclear whether these subjective sensations affect movement execution. In a psychophysical experiment, we systematically investigated the relationships between sensorimotor integration and subjective limb perception, such as sense of ownership/heaviness, and verified the relationship between subjective limb perception and movement execution. Thirty-nine healthy participants were enrolled, and a visual feedback delay system was used to systematically evoke sensorimotor incongruence. Participants periodically flexed and extended their wrist while seeing a delayed image of their hand under five delay conditions (0, 150, 250, 350, 600 ms). During wrist movement, electromyography (EMG) activity in flexor carpi radialis (FCR) was recorded. Also, to analyze the change in muscle activity and movement speed, the values of integral and peak frequency were calculated. To record changes in the subjective limb perception of the altered limb ownership and heaviness, we used a 7-point Likert scale for each participant. We found that altered ownership and heaviness increased with increasing feedback delay. Also, muscle activity and movement speed decreased with visual feedback delay. There was no significant correlation between subjective altered limb perception (i.e., altered limb ownership and heaviness) and muscle activity or movement speed. We systematically demonstrated that limb ownership, heaviness, muscle activation and movement speed were altered by sensorimotor incongruence. However, our study did not reveal the relationships between these factors. These results indicate the existence of different mechanisms governing subjective limb perception and movement execution. In the future, we should consider rehabilitation methods to improve sensorimotor incongruence.

1. Introduction

Patients suffering from limb paralysis or chronic pain commonly report several types of distorted limb perception, such as dysesthesia, distortion of limb ownership, and heaviness (Burin et al., 2015; Kuppuswamy, Clark, Rothwell, & Ward, 2016; Lewis & Schweinhardt, 2012). Most commonly, altered limb ownership and heaviness in patients' limbs are reported. The mechanisms underlying both phenomena are similar, and these limb perception distortions are reportedly caused by disturbances in sensorimotor integration (Foell, Bekrater-Bodmann, McCabe, & Flor, 2013). For example, a previous study experimentally revealed that a

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discrepancy between motor intention and sensory feedback could distort sense of ownership and exacerbate pain (Foell et al., 2013). Limb heaviness is also thought be associated with sensorimotor disturbance (Kuppuswamy, Clark, Turner, Rothwell, & Ward, 2015; Kuppuswamy et al., 2016), but not with muscle weakness (Brodie & Ross, 1984). These previous studies evaluated such altered limb ownership and heaviness using patients' subjective reports. For example, researchers recorded free answers to structured questions and measured subjective rating during exposure to sensorimotor discrepancies between motor intention and sensory feedback (Foell et al., 2013; McCabe, Haigh, Halligan, & Blake, 2005). These experimental methods are useful and meaningful ways to explore subjective limb perception distortions induced by sensorimotor incongruence. However, they can be affected by the psychological condition of participants, and include subjective bias. Therefore, the experimental methods described above involve several limitations when used to quantitatively estimate the relationship between distorted limb perception and sensorimotor incongruence. In the present study, we aimed to quantitatively reveal the relationships between the altered limb perception (i.e., ownership and heaviness) and sensorimotor incongruence using a psychophysical experiment. Meanwhile, a recent study reported that the experience of altered limb perception disrupted motor cortex excitability, suggesting a close relationship between limb perception and the motor system (Della Gatta et al., 2016; Kilteni et al., 2016; Miller & Farnè, 2016). However, few studies have examined the direct relationship between movement execution and limb perception. Therefore, we also aimed to reveal the relationships between movement execution and distorted subjective limb perception through an exploratory study using feedback delay system.

2. Method

2.1. Participants

Thirty-nine healthy right-handed students (23 male, 26 female; mean age, 20.78 years; SD, 0.42) participated in this study. The study protocol conformed to the Declaration of Helsinki. All participants were informed at the start of the study that they could discontinue participation at any time during the experiments. We explained the details of the experimental procedure, but not the purpose of the experiment, so as to avoid bias in results. Before participating, participants provided written informed consent. This study was approved by the ethics committee of Kio University Health Science Graduate School (approval number: H28-04).

2.2. Experimental setup of feedback delay system

The feedback delay method is one of the most useful experimental tools for systematically distorting sensorimotor integration (Shimada, Fukuda, & Hiraki, 2009; Shimada, Suzuki, Yoda, & Hayashi, 2014). This method can control the time between actual movement and visual feedback, so that changes in distorted limb perception and movement can be systematically estimated. Therefore, we used the feedback delay method to verify our hypothesis in the present study. In this study, the experimental setup (Fig. 1) was similar to that of the study in Shimada et al. (2009). The participant's hand was placed under a double-sided tilted mirror, and they were unable to directly view their hand. The image of the hand reflected in the double-sided mirror was filmed with a video camera (FDR-AXP35, Sony, Tokyo, Japan). The hand image was reflected from a liquid-crystal monitor (LMD-A240, Sony) onto the double-sided mirror via a video delay device (EDS-3306, FOR-A YEM ELETEX, Tokyo, Japan). The hand images from the monitor were projected onto the double-sided mirror, and the participants could observe the image of their own hand reflected in the mirror without seeing their actual hand. The angle of the mirror was finely adjusted before the experiment so that the reflected hand image was viewed from the participant's perspective as if it were placed horizontally on the table. Visual feedback delay was introduced using a hardware device (EDS3305, ELETEX, Osaka, Japan) connected between the video camera and the monitor. Five delay conditions (0, 150, 250, 350, 600 ms delay) were tested. The intrinsic delay of the visual feedback in this experimental setting was approximately 33.71 ms as measured by a time lag check device (EDD-5200, FOR-A YEM ELETEX, Tokyo, Japan). For simplicity, we refer to these delay conditions as: 0, 150, 250, 350, 600 ms.

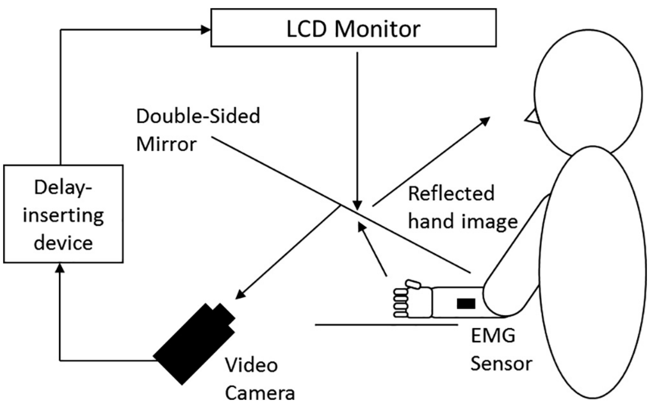

Fig. 1. Demonstration of the experimental setup. Participants watched an image of their moving hand that was delayed following their actual movement. The conditions of the visual feedback delay were 0, 150, 250, 350, and 600 ms.