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Enhancement process of Kinesthetic Illusion caused by stimuli of vibrations and movies

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ABSTRACT

The kinesthetic illusion (KI) is an illusion that when a suitable vibration stimulus is applied to tendons or muscles. In KI, the participants feel as if their stimulated tendons or muscles were stretched and their related limbs moves in the exteded direction. In the previous study, we investigated the effect of strengthening the moving image in the process of repeating experiments performed by naïve persons who have not experienced the KI so far. An experiment in which a vibration stimulus was applied to the Flexor Carpal Radius (FCR) muscle tendon of the right hand was repeated 5 times to confirm the training effect on KI, which was evaluated by the magnitude estimation method. In this study, we investigated the effect of the rubber hand illusion (RHI) on the KI with displaying a movie of the wrist extension movement on a display placed in front of the arm.

1 INTRODUCTION

With the development of brain science, it has become clear that the brain has plasticity. Based on the neurorehabilitation using the brain's plasticity, it has been confirmed that recovery of a motor function can be expected even in patients who have been in a maintenance phase. Based on this fact, a rehabilitation system utilizing robotics has been developed. However, many rehabilitation systems are usually large and complicated. Furthermore they are not suitable for patients to perform rehabilitation alone at home. For this reason, our laboratory pays attention to the utilization of the kinesthetic illusion (KI) phenomenon with the aim of developing a simple, compact, and inexpensive rehabilitation system[1]~[3].

The kinesthetic illusion (KI) is a phenomenon that when a specific stimulus is applied to the muscle tendons of the limbs, the person perceives the proprioception without an actual motion[5]. The process of KI occurrence consists of 4 steps: (1) Apply vibration stimulation to muscle tendons of body parts. (2) Sensory receptors inside muscle get excited. (3) The signal that "stimulated muscles are stretched" is transmitted into the brain through the afferent nerve fiber. (4) Person feel the illusion that "joint movement occurs in the body part near the stimulated muscle tendon" without an actual joint motion.

In the previous studies on KI[1]-[2], the experiment was carried out on the premise that KI naturally occur in all subjects. However, in fact, it is known that whether or not occur KI depends on each subject. There are some subjects who hardly perceive KI. This difference of KI intensity between subjects may be caused by the accustom effect of KI. If it is true, we have to consider how much KI subjects has experienced in the past when we perform the KI experiment.

Therefore, in this study, we investigate the effect of the repeated experience on the KI intensity using our experimental device (Fig. 1, left).

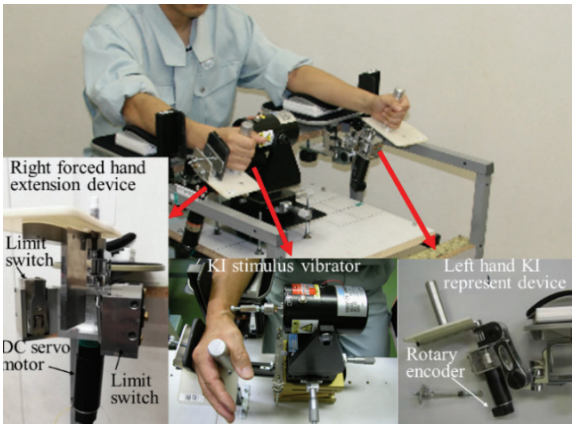

Fig. 1 Experimental apparatus for generating and evaluating KI

2 Illusion phenomena

2.1 Kinesthetic illusion

The kinesthetic illusion is an illusion of proprioception when muscles and tendons are vibrated by the external stimulus and the muscle spindle is excited, which was first reported by Goodwin et al. in 1972[4]-[5]. This

phenomenon occurs when the primary nerve ending (Group Ia) is ignited by giving a vibration stimulus to the muscle spindle, and the brain receives this signal. At this time, the participants feel their muscle stretched. Many researches have been reported regarding the method of inducing KI and the neural basis of KI [6].

2.2 Rubber hand illusion

The rubber hand Illusion (RHI) is a visual illusion phenomenon discovered by Botvinick in 1998[7]. Since its discovery, the several researches have been conducted from the psychological and physiological aspects of RHI[8]. To elicit this illusion, the subject's real hand is hidden out of his or her sight while the rubber hand is placed in front of him or her. When an experimenter stimulates the real hand and the rubber hand synchronously, the subject begins to experience the rubber hand as his own hand.

3 Experimental apparatus

In the previous study [1] [2], Honda et al. revealed that the clear KI is induced in the flexor carpi radialis muscle (FCR) when FCR muscle tendon is stimulated. As for the KI induction / evaluation, we used an apparatus shown in Fig. 1 which is developed in the previous research[1] [2]. For this experiment we modified it so as to provide the participants with both KI and RHI stimuli simultaneously. The KI device consists of two parts: a right-hand part and a left-hand part as shown in Fig. 1. In the right-hand part, the vibration stimulation is provided to the participant's FCR muscle tendon with the voice coil motor (EMIC Corp. 511-A) A signal is generated from the multifunction generator (NF Corp.WF1973) and this signal is boosted by the power amplifier (EMIC Corp.371-A). In the left-hand part, we measured the intensity of KI as the angle variation data by making the participants reproduce the right wrist proprioception with the left wrist. This KI measurement unit on the left hand can measure the joint angle of flexion and extension movements by attaching a rotary encoder (Maxon motor, HED-5540). The data of the rotary encoder is converted into an angle by a microcomputer and recorded in the measurement device (A & D company, WCA mini) via a D/A converter. To elicit RHI, we installed a 13.3-inch mobile LCD monitor (On-Lap1302, GeChic, Taiwan) over the participant's right hand with a 3-joint monitor arm (100-NPC004, Sanwa Direct, Japan). As a visual stimulus, a video in which the right wrist moves in the extension direction is played on the LCD. As the point of installing the LCD, the rubber hand can be seen like their own hand from the participant's view.

4 Experimental method

4.1 Subject

In this experiment, 40 male Japanese students participated in this psychophysical experiment and were paid for their participation. Since we wanted to exclude the age effect, the range of all participants are from 20 to 22. All of the tests were approved by the Ethics Committee of Nagoya University. All participants have not experienced KI and RHI since this experiment was conducted.

4.2 Experimental conditions

The 40 participants were divided into 2 groups: group A and group B. The group A was participated in the experiment 1 in which only KI was induced, and the group B was participated in the experiment 2 in which KI and RHI were induced simultaneously. For KI induction in both experiments, we prepared the sinusoidal wave vibration stimulus: the frequency was fixed at 70 Hz; the acceleration was 100 m/s^2, and the pressing force against the skin was fixed at 0.3 N. The stimulus point is 1 cm away from the base of the wrist. A vibration stimulus was presented for 30 seconds and a break of 60 seconds was provided in one trial. A total 6 trials were performed for each participant in this experiment, including the practice session. For RHI induction in experiment 2, an LCD was placed on the upper part of the right arm (Fig. 2). As a visual stimulus, a video in which the right wrist moves in the extension direction is played on the LCD. Before this RHI task was performed, the participants took a training to make the participants comprehend their body ownership with the rubber hand. In this training, their rubber hands and their real hands were stimulated with a brush synchronously until they had their body ownership to the rubber hand. In the combination of KI and RHI task, the abovementioned visual and vibrating stimuli were provided for the participants simultaneously.

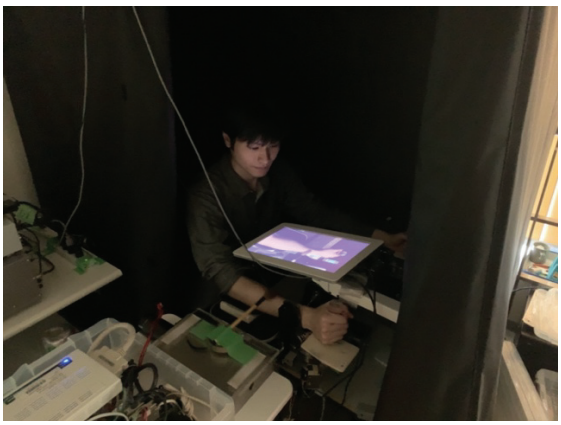

Fig. 2 Experimental apparatus for generating and evaluating KI and RHI

5 Experimental results and discussion

5.1 Maximum angle comparison

In the first analysis, the maximum angle obtained by left-hand reproduction as the intensity of illusion. In the analysis, the first measurement data of each subject was set to 1, and the second to fifth measurement values were normalized.

■ Group A [Experiment 1]

The ratio of the subjects who perceived a larger amount of illusion in the latter half (third to fifth trial) than in the first half (first to second) was 70% (14 out of 20 subjects). Fig. 3 shows the results of analyzing the data of the subjects who answered that the amount of illusion in the latter half was larger. Based on this result, the illusion intensity increases as the number of trials increases. However, about a result of analysis of variance (ANOVA), there is no main effect (F (1.415, 18.396) = 0.820, p = 0.417). Since it is difficult for the subjects to accurately reproduce the state of their right hands illusion, with the left hands, it is presumed that no significant difference was observed.

■ Group B [Experiment 2]

The ratio of the subjects who perceived a larger amount of illusion in the latter half (third to fifth trial) than in the first half (first to second) was 80% (16 out of 20 subjects). Fig. 4 shows the result of analyzing the data of the subjects who answered that the amount of illusion in the latter half was larger. Based on this result, the illusion intensity increases as the number of trials increases. In addition, about a result of ANOVA, there is a main effect (F (3, 51) = 10.103, p <0.001). Furthermore, there is significant difference between the second KI intensity and fourth, fifth KI intensity, and between the third and the fifth. In other words, it was possible to show that the subject became more likely to feel the illusion as the number of trials was increased. Compared to Group A, the video of the wrist extension movement makes it easier to feel the illusion.

5.2 Magnitude estimation method

Next, the magnitude estimation data is analyzed. In the magnitude estimation method, the subject evaluated the intensity of the first KI as 1, and evaluated the KI's intensity from second to fifth based on the first evaluation.

■ Group A [Experiment 1]

The ratio of the subjects who perceived a larger amount of illusion in the latter half (third to fifth trial) than in the first half (first to second) was 80% (17 out of 20 subjects). Fig. 5 shows the results of analyzing the data of the subjects who answered that the amount of illusion in the latter half was larger. Based on this result, the illusion intensity increases as the number of trials increases. Based on the result of ANOVA, there is a main effect (F (3,48) = 5.844, p =0.002). A multiple comparison with the Bonferroni correction describes that the fourth and fifth KI intensity are significantly larger than the second.

■ Group B [Experiment 2]

The ratio of the subjects who perceived a larger amount of illusion in the latter half (third to fifth trial) than in the first half (first to second) was 80% (17 out of 20 subjects). Fig 6 shows the results of analyzing the data of the subjects who answered that the amount of illusion in the latter half was larger. Based on this result, the illusion intensity increases as the number of trials increases. There is a main effect (F (3, 51) = 14.963, p <0.001). A multiple comparison with the Bonferroni correction describes that the fourth and fifth KI intensity are significantly larger than the second, the fifth KI intensity are significantly larger than the third, and the fifth KI intensity are significantly larger than the fourth.

From this result, it was possible to show that the subject became more likely to feel the illusion of movement as the number trials was increased. That is, we confirmed the repetitive effect enhances the KI, and the combination of visual stimuli and KI can further strengthen repetitive effect.

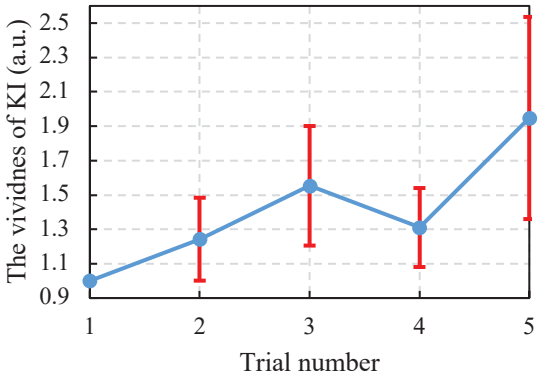

Fig. 3 Experimental result of maximum angle expressed by left hand in Experiment A (pure KI test)

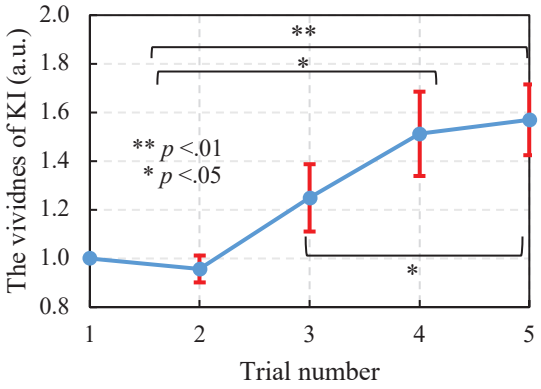

Fig. 4 Experimental result of maximum angle expressed by left hand in Experiment B (KI test powered by RHI)

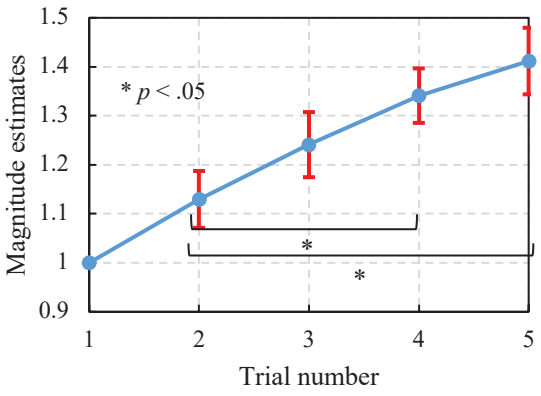

Fig. 5 Experimental result of magnitude estimates in Experiment A (pure KI test)

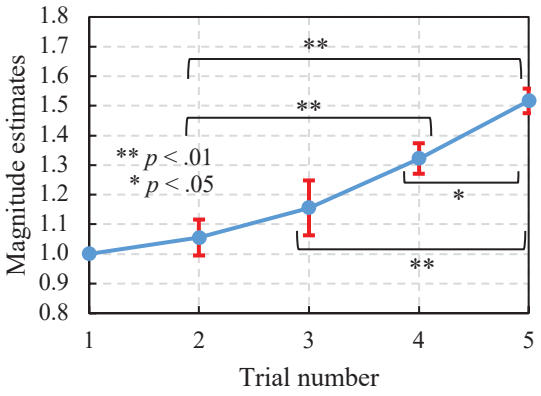

Fig. 6 Experimental result of magnitude estimates in Experiment B (KI test powered by RHI)

6 CONCLUSIONS

In this study, as one of the basic studies for utilizing the kinesthetic illusion (KI), we conducted an experiment to verify our two hypothesis that the intensity of KI increases with the number of trials and this repetitive effect is further enhanced by combination effect of KI and visual stimulus. Since it was unclear which psychophysical quantity was most suitable for the illusion evaluation, we used the two types psychophysical evaluation method for experiments; one is our original method in which participants conduced the quantitative evaluation of KI's intensity called "left-hand reproduction" and another is a magnitude estimation method. In the experiment, 40 subjects were participated in our experiment and we divided them into two groups; Group A and Group B with 20 subjects each. The Group A subjects evaluated the intensity of KI in 5 trials with above two evaluation method. The Group B subjects evaluated the intensity of RHI + KI in the same way as the Group A. We investigated that whether repetitive trials enhance the KI intensity, and whether repetitive trials further enhance the KI intensity when a visual stimulus was combined with KI. As a result, in KI condition, we only confirmed that the repetitive trials enhance KI with the magnitude estimation. On the other hand, in the combination condition of KI and RHI, this repeated effect was confirmed in both evaluation methods, and this effect seems to be higher than that of only KI condition. Therefore, we clarify that KI is enhanced as the trial number of perceiving KI increases, and this effect becomes much stronger when KI is enhanced by the visual stimulus. That is, we should make participants experience KI and RHI repeatedly before performing KI experiment in the future.

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