Reinforcement of Kinesthetic Illusion by Simultaneous Multi-Point Vibratory Stimulation

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Figure 1: Left: positions of vibrators and trackers. Right: an image of the induced kinesthetic illusion.

ABSTRACT

The kinesthetic sensation is important in terms of creating presence in virtual reality applications. One possible way of presenting the kinesthetic sensation with compact equipment is to use the kinesthetic illusion, which is an illusion of position and movement of the one's own body, generated by vibration. However, the kinesthetic illusion observed currently is an illusion of neither large nor rapid movement. To resolve this issue, we propose simultaneous stimulation of numerous tendons and muscles related to arm movement. Our investigation of the chest, lower arm, and upper arm finds an intensity change of the illusion when multiple points are stimulated.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; *Haptic devices.*

KEYWORDS

tendon vibration, kinesthetic illusion, haptic interface

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1 INTRODUCTION

The kinesthetic sensation is indispensable to improving a presence in virtual reality applications. The system to present kinesthetic sensation usually requires a large space for user's actual motion. It could be made more compact by using kinesthetic illusion, which is an illusion of the position and movement of the one's own body without physical motion. A kinesthetic illusion is known to be evoked by applying about 100 Hz mechanical vibration to tendons [Goodwin et al. 1972]. However, for practical use in virtual reality, the illusion is generally quite subtle.

Several methods have been proposed for enhancing the illusion, including the optimization of the vibration frequency [Roll and Vedel 1982], simultaneous stimulation of tendons at both ends, and stimulation of tendons of synergist muscles [Yaguchi et al. 2010]. However, the intensity of the illusion in preceding studies is still not enough, possibly because the studies stimulated tendons at a limited number of points. In this paper, we investigate how the illusion changes when tendons of more than two synergist muscles are stimulated at multiple points to further enhance the illusion.

2 METHODS

2.1 Setup

Seven vibrators (Acouve Lab Vp 210) were attached to the arm and chest of each participant by supporters (Figure 1, left). These vibrators presented a 70Hz sinusoidal vibration, which is the frequency inducing an illusion of relatively rapid movement [Roll and Vedel 1982]. The amplitude was preliminarily adjusted in the range from 80 to 100 m/s^2 when the vibrators were attached to the experimenter's body. The input signal was generated by audio processing software (Cycling '74 Max7) and amplified by audio amplifiers (FX-AUDIO-FX-202 A/FX-36 A PRO). Trackers (HTC Vive Tracker) were attached to the contralateral (other) shoulder and wrist (Figure 1, left) of each participant to measure the movement.

2.2 Procedure

Seven participants (21 to 25 years of age, all right-handed), including two authors, were recruited. The participants were instructed to adopt the posture and wear the equipment shown in Figure 1. Vibrators were set on the tendons of arm flexors, such as the clavicular part of the pectoralis major (vibrator #1 in Figure 1, left), coracobrachialis (#2, #4), biceps brachii (#3, #5), brachioradialis (#6), and wrist flexors (#7). Three vibration conditions were randomly presented three times for each participant as follows.

- Condition 1: One vibrator (#5 only).
- Condition 2: Two vibrators (#5, #6) as in [Yaguchi et al. 2010]
- Condition 3: All seven vibrators (#1 to #7).

Prior to data collection for each participant, it was confirmed whether the participants could perceive the illusion in a practice stage. Participants were asked to close their eyes . The sound cue was masked by white noise from headphones.

Vibration was presented for 10 seconds for each condition with a rest interval of about 1 minute. During stimulation, participants were asked to express the perceived movement of the stimulated arm with their contralateral arm. After the stimulation, the participants were asked to report the directional clarity and magnitude of the illusion on five level Likert scales.

3 RESULTS

There was a fault during the experiment for one participant and thus the results are presented only for six participants.

Figure 2 shows the evaluation of directional clarity and magnitude of the illusion. A Friedman test reveals 5% significant differences between Conditions 2 and 3 (p=.018) in directional clarity, and between Conditions 1 and 3 (p=.004) in magnitude.

Figure 3 shows the movement expressed by the contralateral arm under Conditions 2 and 3. Positive values indicate extension while negative values indicate flexion. The mean angular velocity, obtained by averaging angular velocities calculated using linear regression with the least-squares method for each participant, is shown on the same graph (red line). Under Condition 1, three participants expressed flexion movement, although we expected extension movement. Under Condition 2, two participants expressed flexion. Under Condition 3, no participant expressed flexion.

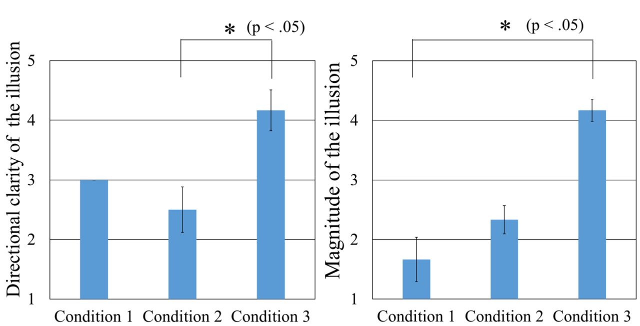

Figure 2: Resuls of the evaluation on five level Likert scales (the average and standard deviation). (a) Directional clarity, (b) magnitude of the illusion.

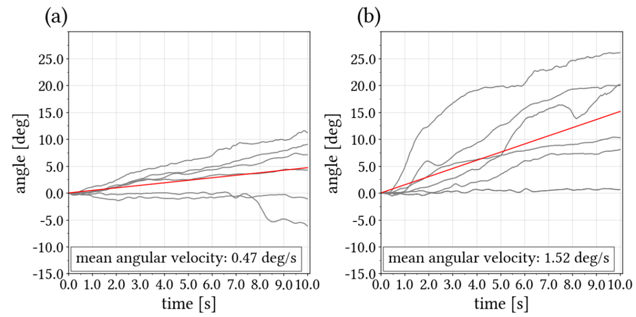

Figure 3: Rotational movement of each participant under Conditions 2 (a) and 3 (b), and the mean angular velocity.

4 DISCUSSION

The reason why some participants expressed flexion movement under Conditions 1 and 2 might be that a tonic vibration reflex occurred, or that the vibrators were potentially set at wrong positions. By increasing the number of stimulated tendons and muscles, the illusion seems to become robust and more comprehensible. Thus, no participants expressed flexion under Condition 3.

In addition, Condition 3 had the highest values of both the mean angular velocity and the magnitude of the illusion (Figure 2 (b)). Therefore, there is a possibility that stimulating more than two synergist muscles is effective in strengthening the kinesthetic illusion.

The angular velocity of the movement under Condition 3 (Figure 3 (b)) was about 2.5 deg/s at most, which was not greatly different from reported in a previous study [Yaguchi et al. 2010], in which the tendons of the biceps brachii and brachioradialis were stimulated. It is therefore necessary to consider further optimization, such as efficiently finding "sweet spot" for the illusion, since we sometimes observe during experiment that slight change of stimulating position drastically change the magnitude of the illusion.

5 CONCLUSION AND FUTURE WORK

We attempted to enhance the kinesthetic illusion of arm extension by increasing the number of stimulated synergist muscles. The effectiveness of increasing the number of stimulation points in terms of strengthening the kinesthetic illusion was confirmed. However, the illusion was still too slow for practical use and further investigation on the optimization of the illusion is needed.

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