Immobile Haptic Interface Using Tendon Electrical Stimulation

Hiroyuki Kajimoto

The University of Electro-Communications / Japan Science and Technology Agency
kajimoto@kaji-lab.jp

Abstract. For whole-body interaction for computer entertainment, I propose applying electrical stimulations to tendons to create an illusory motion of the limbs so that real motion becomes unnecessary. Strong vibrations to joints induce the well-known kinesthetic illusion, but electrically inducing this illusion has been rarely explored. An experiment is described showing that this illusion can be generated by electrical stimulation of the tendon, and suggesting a role of the Golgi tendon organ in the illusion.

Keywords: Golgi Tendon Organ, Haptic Display, Kinesthetic Illusion, Muscle Spindle, Tendon Electrical Stimulation, Virtual Reality

1 Introduction

Whole-body interaction is an intuitive and promising form of computer interaction for entertainment and virtual reality systems. In particular, in the computer entertainment field, the recent successes of the Nintendo Wii and Microsoft Kinect impressed the importance of this form of interaction.

However, requiring input from movements of users is sometimes undesirable, because of limited workspace and physical capability or fatigue of the user. In such cases, the presentation of a kinesthetic sense without real motion is preferable (**Fig. 1**). Furthermore, the artificial generation of a kinesthetic sense might open the door to a new super-natural sensation, which should contribute to the field of computer entertainment.

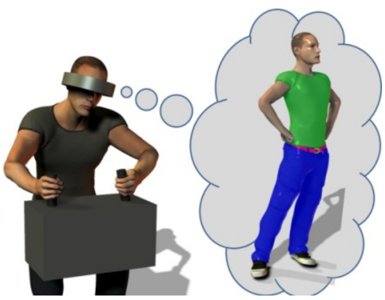

Fig. 1. Immobile haptic interface by kinesthetic illusion.

The kinesthetic illusion, a well-known phenomenon, which is created by vibratory stimulations to a tendon, and is thought to stimulate muscle spindles[1,2,3]. This phenomenon seems ideal for producing this illusory sense of motion. Roll et al. used numerous vibrators around the lower limb and induced 2D motion[4]. Collins et al. proposed combining the illusion with cutaneous sensations to enhance the illusion[5]. Yaguchi et al. proposed stimulating both ends of the muscle simultaneously so that the illusion is more distinct[6]. However, heavy actuators required to produce strong mechanical vibrations and the accompanying noise impede its practical use.

2 Tendon Electrical Stimulation

Here, I propose to use electrical stimulation to generate the illusion. If it is applicable, issues related to size and noise will be resolved. Furthermore, kinesthetic receptors could be selectively stimulated without generating unnecessary sensations.

However, electrical stimulation has rarely been used to induce the illusion, possibly because of the presumed underlying mechanism. The illusion was thought to be generated by the activity of the muscle spindles, which are indirectly stimulated by vibratory input to the tendon. If that were the case, electrical stimulation would seem difficult because it would inevitably stimulate muscle efferent nerves that cause motion. On the contrary, if the Golgi tendon organ, residing in the tendon, is at least partially responsible for the illusion, electrical stimulation of the organ without stimulating muscle becomes possible by placing electrodes on tendon. See **Fig. 2** for a schematic drawing.

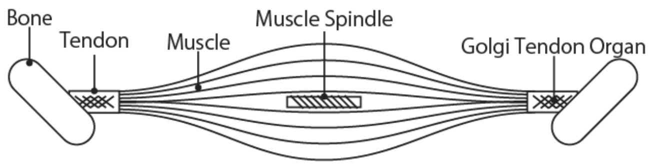

Fig. 2. Location of kinesthetic receptors.

In support of this idea, literatures exist implying the possible involvement of the Golgi tendon organ in the illusion. Macefield et al. electrically stimulated single nerve fiber of the muscle spindle, joint receptor, Golgi tendon organ, and skin mechanoreceptor[7]. They found that single nerve activation of the muscle spindle did not elicit the illusion, whereas that of the joint receptor and Golgi tendon organ did (We must note that the sample number of nerves from the Golgi tendon organ was quite limited.). Furthermore, during the 1980s and 90s, many reports stated that the muscle spindle receptors have much lower threshold than other receptors[8], but recently Fallon et al. found that the threshold among receptors is actually not so significant[9].

Given the above implications, I assert the following two hypotheses:

- H1: The Golgi tendon organ plays a partial role in the kinesthetic illusion.
- H2: Given H1, the illusory motion is possible by tendon electrical stimulation.

3 Experiment

Transcutaneous electrical stimulation of Golgi tendon organ itself has already been done to investigate the Golgi tendon reflex[10, 11]. Experiments were conducted to establish H2.

Fig. 3 shows the setup for electrical stimulation of the arm tendon. Two electrodes (Nihon-Kohden Corp., F-150S) were attached 3 cm above the elbow joint over the bicep and tricep tendons of the right arm. The electrode size was 18 mm × 36 mm; the main axis of the electrodes was set at right angles to the arm.

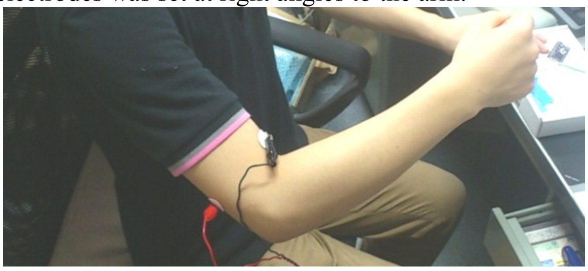

Fig. 3. Electrical stimulation to arm biceps and triceps tendons.

The electrical stimulation was a current-controlled rectangular pulse with 200 μs pulse width, up to 20 mA pulse height, and 100 Hz pulse frequency. The voltage ranged from 0 to around 150 V, depending on conditions on the skin. With the left hand, participants themselves controlled the pulse height. The pulse was monophasic, meaning that one electrode functions as an anode and the other as a cathode.

The participants were four adults, including the author, aged 22–36 years. Participants were told that the experiment was about illusory motion. With closed eyes during electrical stimulation, each was asked to provide the directional sense of motion. For each participant, test was conducted twice with the polarity of the electrodes exchanged for the second test.

4 Results and Discussions

All participants reported that when the bicep electrode was the cathode, their arms moved outward. Conversely, when the tricep side electrode was the cathode, their arms moved inward. All participants were surprised upon opening their eyes to find that their arms had not actually moved.

It is well-known that in ordinary electrical stimulations, the cathode functions as a stimulating electrode. Therefore, the results clearly showed that the illusory motion was contrary to the stimulation side. This direction agrees with the kinesthetic illusion induced by mechanical vibration of the tendon, suggesting that both are basically one and the same phenomenon.

As the electrode positions were close to the elbow joint, stimulation of the muscle spindles, as well as muscle efferent nerves, is not possible.

In summary, the experimental results established that the illusory motion by electrical stimulation of the tendon is possible (H2), and the Golgi tendon organ does play a role in kinesthetic illusion (H1).

5 Conclusion

To achieve whole-body interaction without motion, this paper proposed using electrical stimulation to tendons to generate illusory sense of motion. This kinesthetic illusion, a well-known phenomenon, is commonly created by vibratory, rather than electrical stimulation.

The experimental result showed that this illusion can be generated by electrical stimulation of the tendon. Furthermore, the direction of illusory motion is the same as for the kinesthetic illusion, suggesting that our illusion caused by electrical stimulation of the tendon is one and the same phenomenon. The possible contribution of the Golgi tendon organ to the illusion is also suggested.

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