Investigation on the Cutaneous/Proprioceptive Contribution to the Force Sensation Induced by Electrical Stimulation Above Tendon

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ABSTRACT

A method to present force sensation based on electrical stimulation to the tendon has been suggested, and the occurrence of the sensation was considered due to the contribution of proprioceptors such as Golgi tendon organs. However, there was no clear evidence about the contributing receptors and because the method uses percutaneous electrical stimulation, there are other candidates, the cutaneous receptors. In this paper, we conducted experiments to determine whether the force sensation generated by this method is due to cutaneous sensation or proprioception, by changing the effective depth of electrical stimulation with electrodes spacing. As a result, it was shown that when the electrical stimulation could reach to deep tissue receptors, the force sensation was felt clearer, suggesting possible contribution of the proprioceptor.

CCS CONCEPTS

• Human-centered computing, Interaction devices, Haptic devices

KEYWORDS

Force sensation, Golgi tendon organ, Haptic Interface, Tendon electrical stimulation (TES)

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1 Introduction

As one of the major technologies of Virtual Reality (VR) and Augmented Reality (AR), there are many researches on the presentation of force sensation. The most popular method is one using a mechanical device that presents actual force by motors such as robot arms. They can present delicate and strong feeling, but they occupy large space, especially not practical for home use.

To cope with this issue, methods utilizing illusions were proposed [1, 2]. Receptors that contribute to force sensation are categorized into two: cutaneous receptors and proprioceptors. By efficiently stimulating them, it is possible to make illusion of external forces that are not actually presented.

Takahashi et al. has proposed a method based on electrical stimulation to the tendon (TES) [3]. In the tendon, there are proprioceptors called Golgi tendon organs that monitors the force of the muscles contracting, and they considered that stimulation of this could elicit the force sensation. Yem et al. also confirmed that a force sensation occurs by electrical stimulation to the tendon [4].

However, since TES is applied from the electrode placed on the skin, it cannot be confirmed that the tendon is actually stimulated, and the generated haptic sensation might be only derived from cutaneous pressure sensation. This study investigates which of the two types of sensations, cutaneous sensation or proprioception, contributes to force sensation induced by TES.

2 Experiment

In this experiment, we aimed to distinguish which receptors, cutaneous receptors or proprioceptors, largely contribute to the force sensation caused by percutaneous electrical stimulation directly above the tendon; examining how changes occurred in the magnitude of force and tactile sensation by changing the spacing between the electrodes. When the spacing is narrow (1 mm), the nerves passing through the shallow part of the skin are excited easily, while the deep nerves are hard to get excited. In contrast, when the spacing is wide (16mm), the deep part is relatively easily excited (Figure 1). Therefore, if the force sensation is strong when the spacing of the electrode is wide and

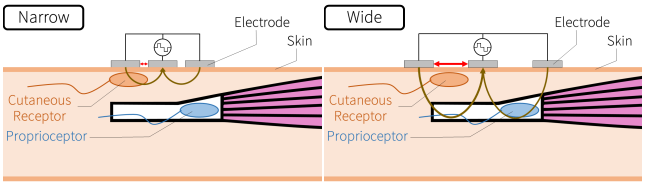

Figure 1: Conditions of the experiment in which we varied the electrode intervals to investigate the receptor that contribute to the force sensation.

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weak when it is narrow, it is thought that this haptic sensation has at least partial contribution from deep tissue receptors.

As depicted in Figure 2 (Left), participants wore a wristband on their right wrist and electrodes on their left wrist. The wristband was connected to a spring scale using wire-pulley mechanism. The electrical stimulation device used in the experiment is shown in Figure 2 (Right) [5], which is the same setup as the previous literature [3].

Percutaneous electrical stimulation was performed immediately above the tendon under the conditions defined in the previous subsection. In each trial, we first performed the Wide condition, and had the participant answer the magnitude of force sensation. The participants were asked to quantify their perceived force by pulling the spring balance. Next, the Narrow condition was performed and the force was quantified again. At this time, we also asked the strength of cutaneous sensation, relative to the previous Wide condition by setting the Wide condition as 100 (magnitude estimation method). For example, participants might answer 200 if the magnitude was about two times of the previous condition, and 50 if it was about half. Three trials were conducted for each participants. Nine people (six men, 21-32 years of age) in the laboratory were recruited for the experiment.

3 Results and Discussion

The results are shown in Figure 3. In the case of cutaneous sensation, the Wide condition was considered to be always 100.

t-test on the electrodes' interval conditions showed a significant difference in force sensation at 1% level (t = 3.308, degree of freedom (DoF): 26, $p = 2.75 \times 10^{-3}$). There was not significant difference in cutaneous magnitude, but was a trend where the magnitude slightly declines under narrower condition (t = 1.960, DoF: 26, $p = 6.08 \times 10^{-2}$). For force sensation, the mean of magnitude under the Narrow condition is 34.5% lower than that under the wide condition; while for cutaneous sensation, the mean under the Narrow condition is 6.1% lower than that under the Wide condition.

This result suggests that the wider electrodes spacing can generate clearer force sensation than narrower electrodes spacing, while there was little difference in the amount of cutaneous sensation. Note that the variation of cutaneous sensation was quite small, implying that the non-significance is not due to large variation among trials/participants. As the wider electrodes spacing should stimulate deeper region, this suggests that the force sensation generate by the TES is at least partly due to the receptors in deeper region. Since the anatomical findings on the stimulation points (wrist) and the sensation that occurred being force sensation, the possibility that the sensation was derived from the Golgi tendon organ is considered high.

4 Conclusion

In this paper, we discussed whether the occurrence of force sensation by percutaneous electrical stimulation directly above the tendon is due to cutaneous or proprioceptive receptors. The

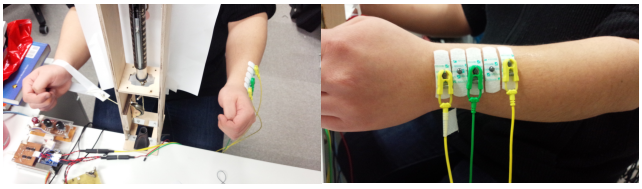

Figure 2: (Left): Actual condition of the experiment. (Right): Stimulation site (on the Wide condition). On the Narrow condition, the cables were reconnect to inner three.

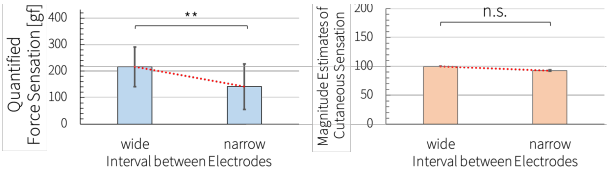

Figure 3: (Left) Comparison of magnitude of force sensation (bar graph: mean, error bar: standard deviation (S.D.)). (Right) Comparison of magnitude of tactile sensation (geo-mean and geo-S.D.). **: p< .01, n.s.: no significance but trend.

experiment was conducted using the fact that the proprioceptors are located deeper than the cutaneous receptors, and the characteristics of the electrical stimulation that wider spaced electrodes can stimulate deeper region. As a result, relationship between the electrode interval and the force sensation was found, whereas there was little difference with respect to the magnitude of the tactile sensation. More detailed investigation with larger sample size is necessary, but the present results suggested that the electrical stimulation on tendon part causes force sensation by stimulating deep region.

This result contains many assumptions, and there is still room for discussion. In order to discuss on the objective data, observation of Ib reflex might be necessary, which is considered as a standard and direct evidence of involvement of Golgi tendon organ [6].

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