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Enhancement of Perceptual Force by Presenting Vibration to the Strained Skin of the Finger

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Abstract— **To achieve compact and simple haptic devices, many studies have used skin deformation to generate a perceptual force. However, the amount of skin deformation is limited, and more efficient generation of the illusion is required. We discovered a phenomenon in which perceptual force caused by skin strain on the index finger in the flexion or extension direction is enhanced when vibration is presented to the strained skin. The results of the experiment suggested that when skin strain is generated in the flexion direction, clear enhancement of force in the direction of flexion was observed following the vibration. On the contrary, in extension direction, the result was not clear, but several participants reported that they perceived a force and that it was enhanced by the vibration stimulation.**

I. Introduction

Haptic feedback to the finger is important for hands-on tasks in virtual reality (VR) and remote operation. In particular, recent advances in high-performance and low-cost head-mounted displays (HMD) have highlighted the importance of haptics for VR.

While there are several commercially available haptic devices, the actuators for these devices need to be large and heavy to present sufficient force, which prevents their general use. To solve this issue, several methods that use perceptual illusions have been proposed. Among the several types of haptic illusions induced by visual, auditory, and tactile stimuli, methods using skin deformation have the advantage of presenting to multiple body parts simultaneously (i.e., a visual haptic illusion is elicited only when the user sees the relevant body parts, whereas a skin induced haptic illusion can be elicited at multiple body parts). However, there are limitations to the strength of the illusion using skin deformation alone.

To solve this issue, we propose a method to enhance the presented perceptual force by adding vibration to strained skin. In this paper, we report the details of this phenomenon and evaluate a system we developed that generates this phenomenon at the finger.

II. Related Work

Conventional haptic devices reproduce a physical force to present a force sensation to the fingers [1][2][3][4]. This technique can produce a high-quality experience, because the users perceive the same amount of force on the fingers as in the real world. However, these devices require large and expensive actuators.

To cope with this issue, various techniques using perceptual illusions of force have been studied. In particular, numerous studies have proposed the use of skin deformation [5][6][7]. Such devices tend to be compact, because they require only a mechanism for deforming the skin. For the fingers, many studies have proposed the presentation of haptic sensation by deforming the finger tips and presenting pressure, which is perceived as an external force [8][9].

Our approach is an alternative to the previous work, and operates by presenting a vibration to the strained skin of the finger. Contrary to the fingertip type skin deformation devices mentioned above, the fingertip is free and the users of the device can handle real-world objects.

It has previously been reported that lateral skin stretch [10] and presenting a vibration to the tendon [11] induce a posture illusion at the finger, and our approach might have a strong relationship with these illusions. Our contribution is that to use the illusion as a haptic display, we confirmed that by presenting a vibration to the strained skin, the user feels a force, not a posture displacement. We also discovered that the direction of the force switches when the direction of the skin strain changes.

III. Experiment

We conducted an experiment to confirm whether this phenomenon occurs in naïve participants. For this experiment, we developed a device to produce a skin strain and a vibration on the index finger. Participants were asked to answer two questions about the perceptual force induced by the device.

A. Participants

We recruited 14 laboratory members, 13 males, aged between 21 and 30. All participants were naïve to this phenomenon and did not know the purpose of the experiment.

B. Setup

The device consisted of a contacting part, an elastic band, disposable gel electrodes, a vibrator, a microcontroller, and an audio amplifier. The contacting part consisted of two parts, which were connected together by an elastic band. The contacting part was made of ABS plastic printed by a 3D printer, and multiple-sized contacting parts were prepared so as to fit to all participants. Two disposable gel electrodes (F-150s, NIHON KOHDEN Inc.) were attached on the dorsal and volar parts of the index finger, and the contacting parts were attached to the electrodes (the electrodes worked as a base) (Figure 1.). Skin strain was generated by tension of the elastic band. By changing the position of the gel electrodes, the direction of the skin strain could be switched (Figure 2.

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(Top)). A vibrator (HaptuatorMark2, Tactile Labs Inc.) was placed on top of the contacting part on the dorsal side, and was vibrated by a signal generated by the microcontroller (mbed LPC1768, NXP Inc.) and amplified by an audio amplifier (RSDA202, RASTEME SYSTEMS Inc.). We used a 100Hz sine wave with fixed amplitude (1G=9.8m/s^2) (Figure 2. (Bottom)).

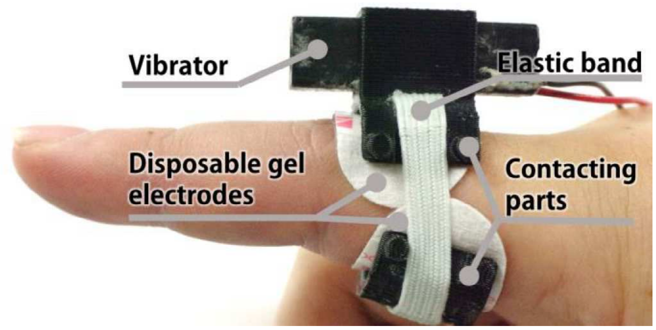

Figure 1. Configuration of the developed device

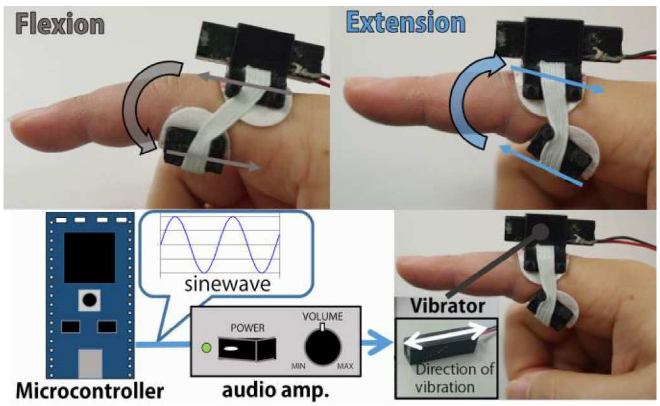

Figure 2. (Top)Two directions of skin strain caused by the device, (Bottom) System for presenting vibration to the device

C. Procedures and conditions

We asked participants to answer two questions. The first question was answered after equipping the device, and the second question was answered after presenting a vibration.

- Question 1: Which direction of the force do you feel? (Choice: extension, none, or flexion)
- Question 2: How does the force change during vibration? (Choice: stronger, no change, or weaker)

In these questions, the term "force" included not only the sensation where the finger was bent by others, but also the sensation of friction when the users bent their own fingers. To confirm the force, participants were allowed to bend their fingers, but slightly enough so as not to change the elastic force from the elastic band, and compare the sensation with their left index fingers that were not equipped with the device.

After the instruction, the participants wore an eye mask and waited. The experimenter attached the device between the MP and PIP joints of the index finger of their right hand, and produced skin strain. Then, the participants answered question 1. After that, vibration was presented for six seconds, and participants were asked to answer question 2. The participants could try the vibration as many times as they ask liked. The experiment was conducted for flexion and extension skin strain, and the order of the direction of skin strains was randomized among participants.

D. Results and discussion

Figure 3. shows the results of question1, and Figure 4. shows the results of question 2. In both figures, the vertical axis represents the rate of answers in each choice. In question 1, when skin strain in the flexion direction was presented, nine participants felt a force in the flexion direction and one participant felt a force in the extension direction. The results of a sign test showed that there was a significant difference between the two answers. Conversely, when skin strain in the extension direction was presented, eight participants felt a force in the extension direction and four participants felt a force in the flexion direction. The results of a sign test showed that there was no significant difference between the answers for the two directions.

In question 2, when a vibration was presented during skin strain in the flexion direction, 11 participants perceived an enhancement of the force by the vibration, and two participants perceived that the force was weakened by the vibration. The results of a sign test showed that there was a significant difference between answers of enhanced force and answers of weakened force. However, when vibration was presented during skin strain in the extension direction, nine participants perceived an enhanced force in the extension direction, and four participants perceived that the force was weakened. The results of a sign test showed that there was no significant difference between the answers for the two choices.

The results of the two questions suggest that skin strain in the flexion direction generates a force in flexion direction, and that it is enhanced by vibration. However, we could not confirm the force and its enhancement by vibration in the extension direction, possibly because of insufficient skin strain in that direction.

We also observed that when vibration was presented, some participants reported that they felt a strong force, which moved their fingers. This implies the potential of our method to be used as a haptic display, controlled by just adding vibration.

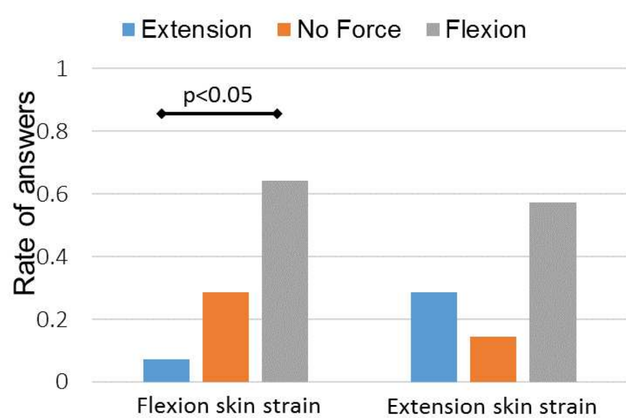

Figure 3. Results of question 1: Which direction of the force do you feel? (Choice: extension, none, or flexion)

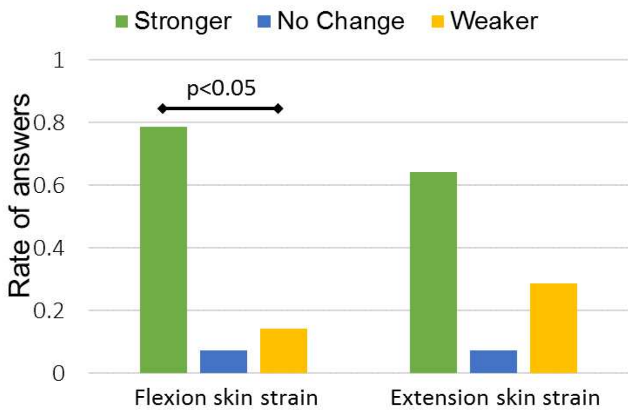

Figure 4. Results of question 2: How does the force change during vibration? (Choice: stronger, no change, or weaker)

IV. CONCLUSION

In this paper, we report the phenomenon where perceptual force, caused by skin strain on the index finger in the flexion or extension directions, is enhanced when vibration is presented to the strained skin. We developed a prototype device, and conducted an experiment to verify this phenomenon. The results of the experiment confirmed that skin strain generates a force in the flexion direction, and that this force is enhanced by the vibration stimulation, but we could not conclude this for the extension direction. We will improve the system to present more stable skin deformation in the extension direction, and confirm the robustness of the phenomenon. We will also use this device as a compact wearable finger haptic device for VR applications.

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