Expression of 2DOF Fingertip Traction with 1DOF Lateral Skin Stretch

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Abstract. To reproduce the sensation of rubbing on a surface, we need to laterally stretch the skin of the fingertip with two degrees of freedom (2DOF). Unfortunately, it is difficult to develop a compact 2DOF device for the fingertip because at least two actuators are required. However, if we can perceive the rubbing sensation regardless of the skin stretching direction, a device with 1DOF is sufficient. This study used a lateral skin deforming device with 1DOF, and evaluated the realism of the sensation. We found that even when the direction of skin stretch was opposite or perpendicular to the finger movement, users still perceived it as natural.

Keywords: fingertip, lateral skin stretch, 1DOF device, direction

1 Introduction

When we rub the surface of an object with a finger, the frictional force and the associated lateral skin stretch occur on our fingertip skin in the opposite direction of the movement. If we move the finger leftward or forward, our fingertip skin is stretched rightward or backward. Therefore, our skin stretches with two degrees of freedom (2DOF). Several skin stretch devices have been developed to reproduce this sensation [1][2][3][4]. However, these devices require at least two actuators to stretch the skin with 2DOF [5], and thus they tend to be large and heavy.

In our previous study, we developed a device named FinGAR, which can deform fingertip skin leftward or rightward for presenting various tactile sensations [6]. To make the device compact, we used only one actuator (i.e., 1DOF). During our test, we observed that, even though we can detect the direction of skin deformation when the fingers do not move, we do not notice the direction when we move our fingers.

From the above background, we came up with the hypothesis that, if the direction of lateral skin stretch does not contribute to the realism of the rubbing sensation, we do not need to use several actuators to accurately reproduce skin deformation direction. In this paper, we test this idea with a psychological experiment using part of FinGAR device. The fingertips of the index fingers are deformed to the left or right as users are

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asked to move their fingers to the left, right, backward or forward, randomly, and score the realism of the sensation.

2 Experiment

2.1 Device

Fig. 1 shows the overview of the experimental apparatus, which was originally developed to present both mechanical and electrical stimulation [6]; in this experiment, we removed the electrical stimulation component. An arm that contacts the finger-pad is driven by a DC motor (Maxon 118386) with a 16:1 gear head ratio to deform the skin.

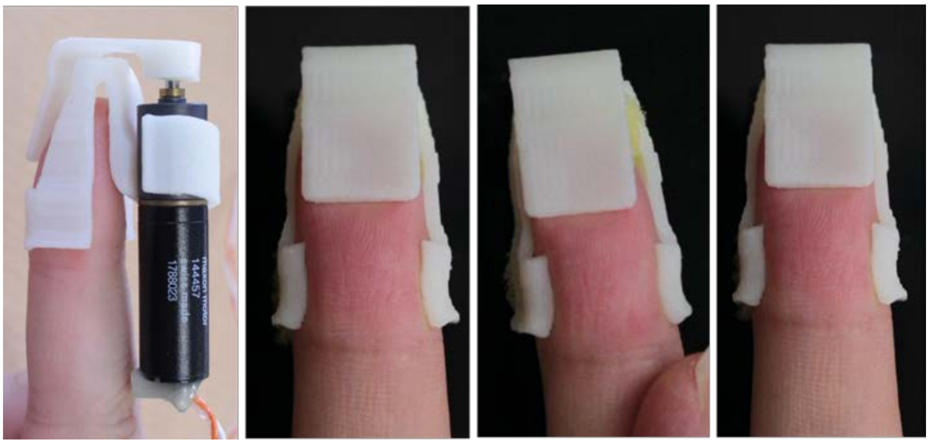

Fig. 1. Overview of wearing the device and skin deformation conditions (from left to right: no stimulus, and skin deforming to the right and left).

2.2 Design

During the experiment, we asked participants to move their fingers in accordance with a visual marker on a screen. Skin stretch was presented in accordance with the motion of the marker. The stimulus strength of skin deformation s, finger position x and velocity v are expressed by the equations below:

$$s = \frac{s_{th}}{2} \times \left(1 - Cos(2\pi ft)\right), \quad (1)$$

$$x = \frac{p}{2} \times \left(1 - Cos(2\pi ft)\right), \quad (2)$$

$$v = \dot{x} = \pi fp \times Sin(2\pi ft), \quad (3)$$

where s_{th} is the value at which each participant could clearly detect the direction of skin deformation even when they were moving their finger. p is the tracing distance of the marker (in pixels) and f is the frequency, which represents the speed of the marker. We presented one tracing loop ($0 \leq t \leq 1/f$) for each experimental.

To change the tracing velocity, the *frequency* f was set to three conditions: $f_1 =$ 1 Hz (slow), $f_2 = 2$ Hz (medium), and $f_3 = 3$ Hz (fast). There were four conditions for *tracing direction* (*left*, *right*, *forward*, *backward*) and three conditions for *stimulus* (s_{left}, s_{right}, s_{non} (no stimulus for skin deformation)). Each condition was conducted three times, so there were 108 trials (3 *frequency* × 4 *tracing direction* × 3 *stimulus* × 3 repeats of each condition) for each participant.

2.3 Procedure

Five female volunteers aged 21–24 years participated in this experiment. Four of them were right-handed, and one was left-handed.

Fig. 2 shows an overview of the experiment. The GUI on the screen is for guiding the participants during the experiment. They were asked to sit on a chair, wear the device on their index finger of their right hand, and to move a PC mouse (represented by a hand mark on the GUI) following a blue filled target circle. After each trial, they were asked to score the realism of the tracing sensation with a five-stage evaluation (zero to four). A higher score means that the sensation was more realistic.

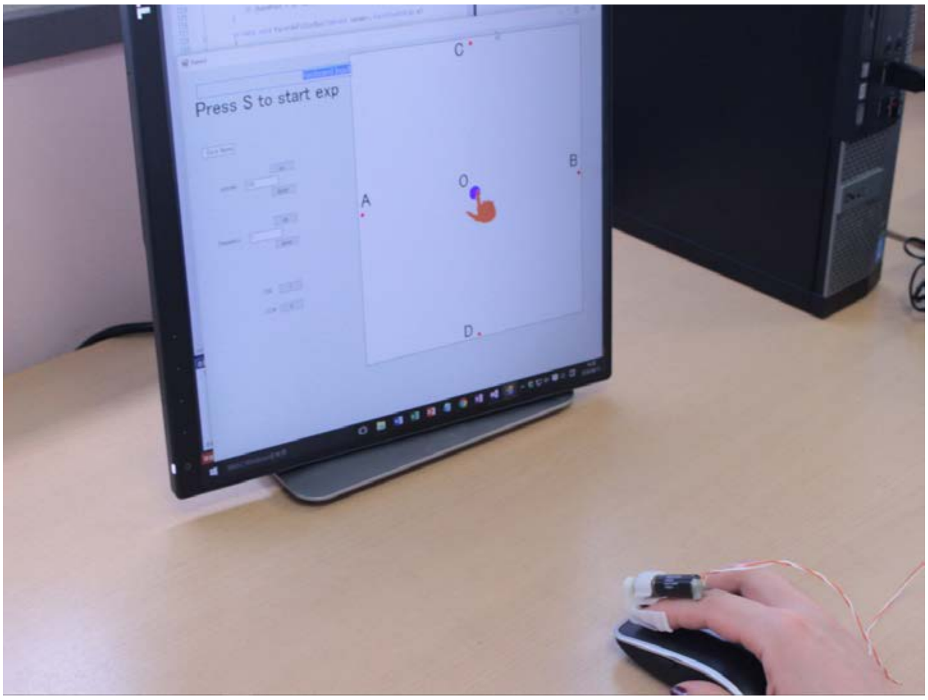

Fig. 2. Overview of the experiment.

3 Results and Discussion

Fig. 3 shows the comparison of three kinds of stimulus for each *tracing direction*. The results indicated that the average score was over 2.0 for all *frequency* and *tracing direction* conditions when the skin deformation stimulus was presented. In contrast, the score almost remained at zero when there was no stimulus.

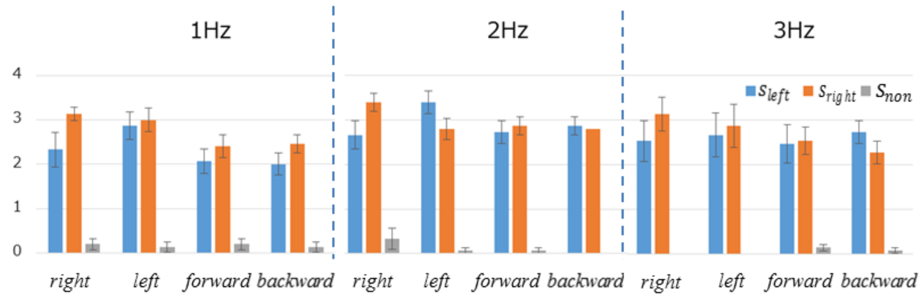

Fig. 3. Scores of realistic sensation for each tracing direction. The left, middle, and right panels show the frequency conditions of 1, 2, and 3 Hz, respectively. Error bars indicate standard deviation.

The results suggest that we can perceive the tracing sensation as realistic while skin stretch is presented regardless of the tracing direction. Therefore, a lateral skin stretch device with 1DOF, such as FinGAR and Gravity Grabber [1], might be sufficient to reproduce a tracing sensation in any movement direction. This result might be an example of the visual dominance over haptics; however, comparing the skin stretch conditions with the no skin stretch condition, the skin stretch greatly contributed to the realism of the situation.

4 Conclusion

This paper described the possibility of presenting 2DOF fingertip traction using only a 1DOF lateral skin stretch device. The experiment showed that we can perceive a realistic sensation of tracing on a surface regardless of the finger's movement direction, when users move their fingers and can see their movements. This result may be a case of visual dominance over haptics, but the skin stretch itself contributed to the realism. The result suggests that a device with 1DOF such as FinGAR or Gravity Grabber might be sufficient for presenting a tracing sensation.

We have planned two steps for future work. First, we will study the effectiveness of the stimulus waveform to make the tracing sensation more realistic. Second, we will combine FinGAR and a virtual reality system to present various kinds of tracing sensations.

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