Presentation of a hard surface via a soft moving ball

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***Abstract*— When two fingers face and contact one another repeatedly at the same speed, they can evoke the perception of an imaginary flat surface. This illusion is thought to be caused by "mirrored" skin deformation of the two fingers, such that the surface of the boundary between the fingers is flat. This phenomenon could be utilized to develop an encounter-type haptic display in which the sensation of a hard surface is presented by a soft moving ball. In this paper, we verified this phenomenon using a finger model that contacted the user's finger at exactly the same speed from the opposite direction of movement. Compared with a stationary finger model, the moving finger model produced the sensation of a harder surface.**

I. Introduction

When the finger-pads of two opposing fingers are pressed together, and the pressing force is repeatedly increased or decreased, it is sometimes possible to perceive an illusory thin and hard plate between the fingers. This type of illusion is thought to be based on the following physical phenomena.

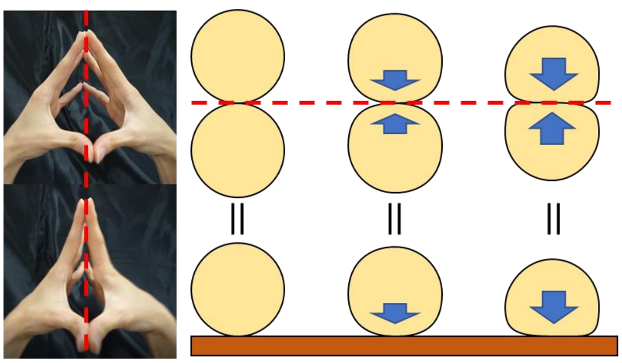

Figure 1. The illusion of a hard plate due to opposing finger contact (left), corresponding physical phenomena (right)

As shown in Fig. 1, contact between two spherical elastic bodies with the same shape and the same elastic modulus causes symmetrical deformation. The sensation can be treated as equivalent to contact with a rigid plane without friction because the boundary surface becomes a plane [1]. In a previously described situation, contact between the finger-pads can also be regarded as contact between two balls of the same elastic body. Thus, the deformation of the boundary surface is expected to be flat. In addition, if both of the finger-pads are facing each other and moving at the same speed, the absolute position of the contact plane is considered to remain constant.

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Given the above consideration, it is supposed that the opposing contact between the finger-pads causes the same degree of skin deformation and proprioception as when the finger-pads are pressed against a rigid flat plate fixed in space. Many physical quantities, such as the spring constant, elastic modulus [2], and viscosity [3], are known to affect hardness perception. We considered these to be integrated into skin deformation and proprioception [4] in the described illusion.

The purpose of this study was to confirm the presence of the phenomenon in which a flexible sphere is perceived to be harder when it is moving opposite the direction of movement of a finger, with the goal of utilizing this phenomenon for the development of a safe encounter-type haptic display that can present the sensation of a surface and does not require the direction control via a soft moving ball. In this paper, as an initial step, we measured the subjective change in hardness-softness that occurred when a finger contacted a dummy finger that was either static or moving.

II. Materials and Methods

We prepared eight samples of elastic rubber (Human Skin, EXSEAL). We made comparison stimuli with different hardnesses by changing the ratio of hardener. The samples were 3 cm thick, and the hardness values (Type E2 Asker hardness) were 3.0, 11.2, 19.2, 29.5, 38.9, 45.8, 54.0, and 62.2, wherein the softest one had the softness of a baby's skin and the hardest one had the softness of a rubber tire.

We used the elastic rubber with an Asker hardness of 29.5 to manufacture a dummy finger. We made a mold of an index finger of a mannequin that was close to the average finger size of a Japanese adult [5]. Finger bones and nails were reproduced using a wood stick (disposable chopsticks) and plastic plates, to approximate an actual finger (Fig. 3 (left)). The hardness of the dummy finger was not measured because the surface area required for measurement was insufficient.

The experimental setup is shown in Fig. 2. A DC motor (Maxon, RE 25, 10 W, 135079) rotated pulleys such that two fingers were positioned facing each other and driven with the same speed. Position control was carried out via a PD control using a microcontroller (Espressif, ESP 32 DevkitC).

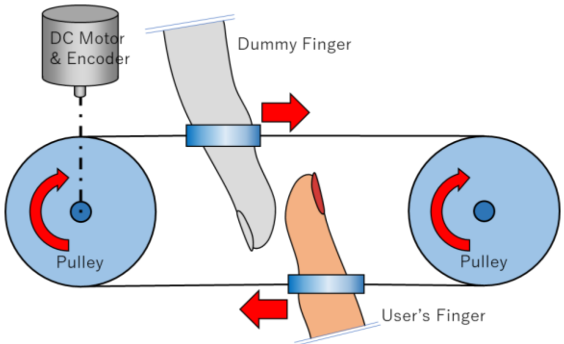

Figure 2. Overview of the device

III. EXPERIMENT

The purpose of this experiment was to confirm that the dummy finger, which had a similar shape and elasticity value as the user's finger, was perceived as being harder, compared with a case in which the dummy finger was stationary, when it moved at the same speed and opposite direction relative to the user's finger.

A. Experimental Conditions

The overview of the experiment is as shown in Fig. 3 (right). During the experiment, white noise was presented through headphones to eliminate sound cues. Participants were instructed to close their eyes and relax their fingers. Their right index finger was moved at approximately 15 mm/s, while the dummy finger was either moved at the same speed and opposite direction (condition A), or was fixed in a stationary position (condition B). After touching the dummy finger three times, the participants were instructed to remove their finger from the device and touch one of comparison stimuli. Then, they were asked if the comparison stimulus was harder or softer than the dummy finger (2AFC). The comparison stimulus was chosen using the double staircase method. An ascending and descending series were conducted until the answers were reversed three times consecutively, i.e. "soft, hard, soft".

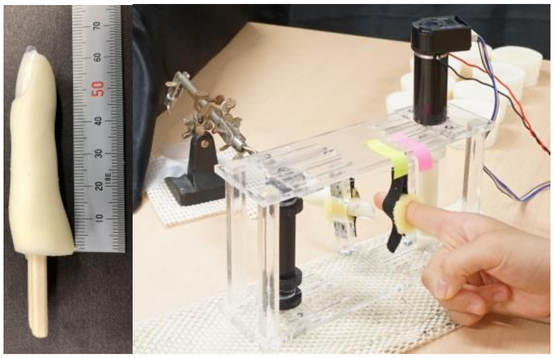
Figure 3. Dummy finger and overview of the experiment

The experiment was conducted on 16 naive participants, 12 men and four women, who were 21 to 42 years of age (average: 24.2). Fifteen participants were right-handed and one was left-handed. The dominant hand was always used. To eliminate the order effect, half of the participants started the experiment in condition A and half started in condition B.

B. Result & Discussion

Figure 4 is a box-and-whisker plot comparing the results of the two conditions.

The mean (standard deviation) value was 26.09 (12.58) when the dummy finger moved with the same speed and opposite direction relative to the user's finger (condition A), and 17.87 (10.96) when the dummy finger was stationary (condition B). A t-test with a significance level of .05 indicated a significant difference between the two conditions (p = .001). This result indicates that perception of a harder surface was possible when the dummy finger moved in the opposing direction relative to the user's finger.

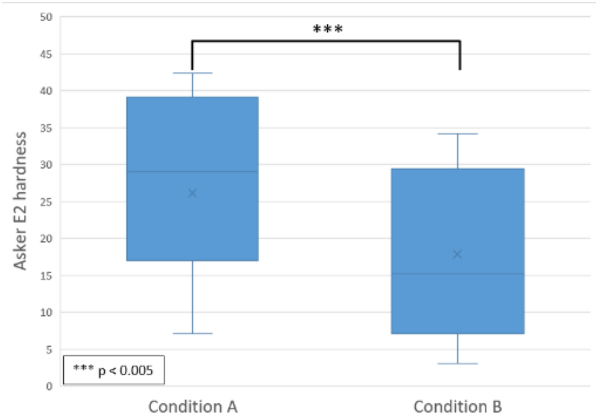

Figure 4. Result of the experiment

IV. CONCLUSION

In this paper, we conducted an experiment to confirm that an object with equivalent shape and elasticity to a finger was perceived as harder when it was moving towards the user's finger with the same speed in an opposing direction. In future work, we plan to conduct detailed verification of this phenomenon with different speed ratios between the finger and dummy finger, and to develop an encounter-type haptic display utilizing this phenomenon.

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