Tactile Enhancement Structure Mimicking Hair Follicle Receptors

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Abstract

We propose a tactile enhancement structure inspired by hair follicle receptors. Unlike other receptors, part of the hair follicle receptor is exposed to the outside. Recent research has shown that skin hair contributes to perception of minute forces that cannot be perceived with glabrous skin. We considered how the skin perceives these minute forces. Our tactile enhancement device mimics the structure of hair follicle receptors. A matrix structure simulating artificial body hair is driven by minute forces external to the skin surface. This structure can be used on any surface of the human body because it is fully composed of passive elements.

Keywords: Tactile, enhancement, hair follicle receptor

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interface-Haptic I/O; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems, Artificial, augmented, and virtual realities.

1 Introduction

Human tactile sensitivity is largely dependent on highly sensitive tactile receptors and mechanical structures surrounding tactile receptors. For example, papillary ridges contribute to the sensitivity of the Meissner corpuscle [1]. Maeno et al. analyzed the structure of finger skin using finite element analysis and found that both the geometry of the papillae and the epidermal ridges are important to increase the sensitivity of tactile sensation [2]. Also, Gerling et al. reported an enhancing effect of the fingertip for edge detection [3]. Thus, there are many facets to the structure of human skin and structural models of human skin have been developed with various methods [4][5]. Recently, these findings were used to develop artificial tactile sensors [6].

On the other hand, external structures, notably hair, also play an important role. Sato [7] clarified the phenomenon by which water surfaces are perceived by hair. Water flow bends hair, exciting hair follicle receptors (Figure 1).

This mechanism can be considered as a type of impedance transformation mechanism, similar to the "tactile contact lens" proposed by Kikuuwe et al.[8]. In the tactile contact lens, small deformations are expanded by a lever mechanism, whereas in human hair, small air/water flow is translated to skin deformation by a lever mechanism. In both mechanisms, the mechanical lever structure converts external mechanical energy to a dynamic range that is appropriate for human perception.

In this study, we propose a tactile enhancement structure that mimics the mechanism by which human hair follicles detect sensation (Figure 2). The matrix of artificial hairs is driven by minute stimulation from the external world, transferring a magnified force to the skin surface. The device allows users to feel a normally unnoticeable water surface, which is known to be important for swimmer training [9] (Figure 3). We then describe an experiment to verify the function of the device.

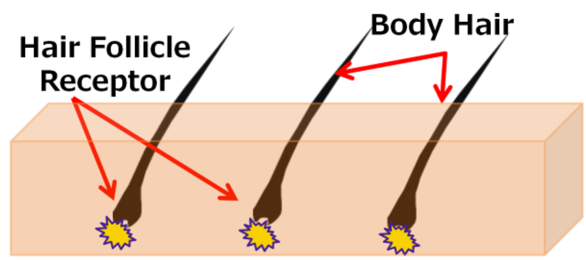

Figure 1. Structure of the hair follicle receptor.

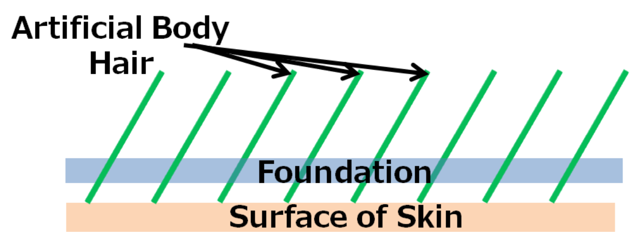

Figure 2. Proposed mechanism for sensing with artificial body hair.

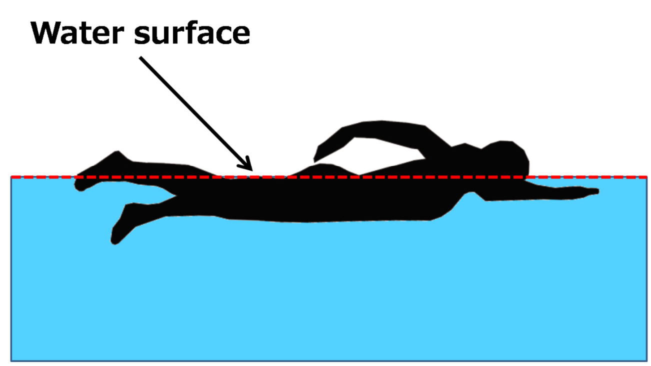

Figure 3. Perceiving the water's surface is important in swimming.

2 Proposed Mechanism

A model of the proposed mechanism is shown in Figure 4. The model is composed of an artificial body hair and a foundation. The hair penetrates the foundation, and one end of the hair touches the skin, creating a lever mechanism and applies a shear force to the skin, with the foundation serving as a supporting structure.

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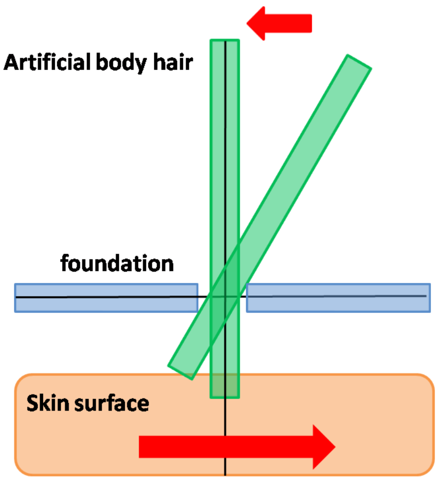

Figure 4. Model of proposed mechanism.

3 EXPERIMENT: EVALUATION OF PARTICIPANTS' SUBJECTIVE PERCEPTION OF THE SURFACE OF WATER

3.1 Experimental device

We made a prototype device that mimics the structure of body hair and the hair follicle receptor, using silicone (Shinetsu Silicone KE-109-A/B), and plastic optical fibers (Mitsubishi Rayon, Eska, ϕ =0.50 mm) (Figure 5). The optical fibers penetrate the sheet and touch the skin. The fibers must swing freely, with the silicone sheet surface serving as a supporting surface. Thus, the supporting surface must be as thin as possible. The surface of the silicone foundation works as a pivot. Due to the length ratio of outer and inner parts of the fiber, minute external force applied to the outer part is magnified and transmitted to the skin surface. (Figure 6)

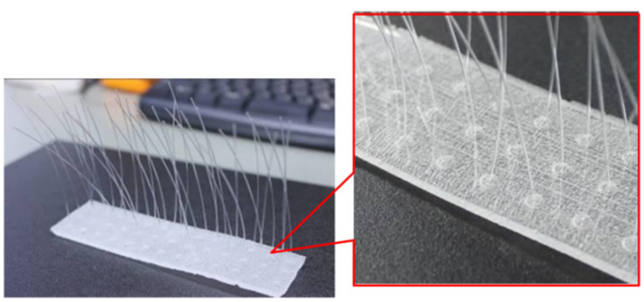

Figure 5. Experimental device.

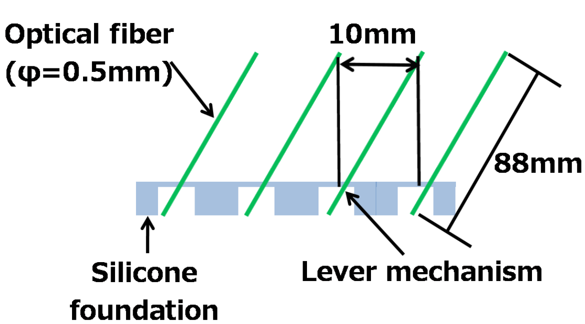

Figure 6. Cross-sectional view of the device.

3.2 Experiment

We defined participants' subjective perception of the surface of water as 'water surface perception'. We carried out an experiment to verify that our device enhanced water surface perception. What we want to compare is a natural hair from bare skin and an artificial hair from our device. However, there is a possibility that the silicone foundation part of the device might affect the sensation, possibly by reducing sensation.

To eliminate this effect, we divided the experiment into two steps. One was to compare skin covered by the experimental device and skin covered by the silicone foundation (we called the silicone foundation alone a standard stimulus). The other was to compare bare skin and skin covered by the silicone foundation (Figure 7).

The experimental procedure was as follows:

(1) On one arm, the participant mounted the silicone sheet (standard stimulation). On the other arm, the participant's arm was either bare or mounted with the experimental device. Both sheet and device were mounted with Velcro tapes.

(2) Both arms were soaked in water for 30 seconds to equilibrate skin temperature.

(3) Participants moved their arms vertically ten times in time with a metronome (60 beats per minute) (Figure 8).

(4) Participants indicated water surface perception of the experimental arm, compared with the standard arm (standard stimulation). Participants indicated sensation by marking an analog scale (Figure 9).

The experiment was carried out with 14 participants (between 21 and 25 years old, 10 males and 4 females). To eliminate order effects, participants were divided into two groups, and the right and left arms were alternated in half of the participants (Table 1). Water temperature was kept at 34°C to eliminate the effect of temperature perception [7]. To remove visual cues, participants were blind-folded before each trial. Before filling in the analog scale questionnaire, participants' arms were obscured by a plate to hide the device. Four trials were conducted for each participant.

Figure 7. Experimental conditions

Figure 8. Photograph of the experiment

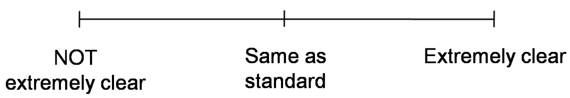

Figure 9. Analog scale.

Table 1. Example of trial procedure.

Trial	Left arm	Right arm
1	Silicone sheet	Bare skin
2	Silicone sheet	Device installed
3	Bare skin	Silicone sheet
4	Device installed	Silicone sheet

3.3 Results

Figure 10 shows the result of the experiment. Vertical axis represents the clarity of water surface perception. There is a significant difference between bare skin and skin covered with our device ($p<0.01$). The results suggest that participants were able to perceive the water surface much more clearly when using the experimental device. All 14 participants commented that although the quality of sensation caused by the device was different from that of bare skin, greater clarity of sensation was experienced when using the device.

The result of bare skin was almost equal to 0, indicating that the effect of the silicone foundation was negligible.

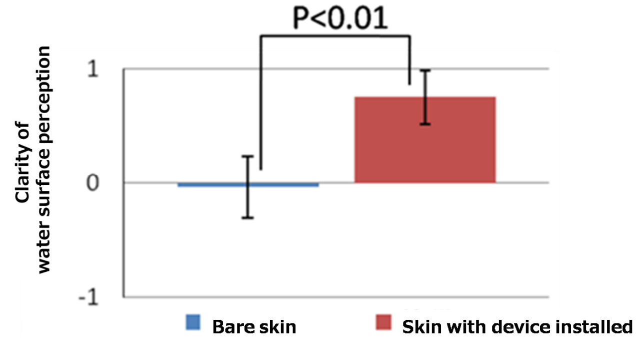

Figure 10. Results of experiment

4 Conclusion

In this paper, we present a tactile enhancement structure similar to the hair follicle receptor, and we describe how it affects water surface perception. The proposed device was evaluated based on the clarity of water surface perception. The results suggest that perception was enhanced by the device, compared with bare skin alone.

In the future, we will optimize the design of this device, focusing on parameters such as length of the artificial hair and material composition.

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