Tactile Perception of a Water Surface
- Contributions of Surface Tension and Skin Hair -

Michi Sato[1], Junya Miyake[1], Yuki Hashimoto[1] and Hiroyuki Kajimoto[1,2]

[1]The University of Electro Communications
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan
[2]Japan Science and Technology Agency
{michi, junya, hashimoto, kajimoto}@kaji-lab.jp

Abstract. We investigated the tactile perception of a liquid surface that can be clearly felt as a thin line by a hand moving in the liquid. Although this phenomenon was first reported by Meissner in 1859 and is quite well known, the underlying mechanism is poorly understood. This study aimed to clarify how we perceive the boundary between the atmosphere and water as a cutaneous sensation. We found that skin hair plays a major role in the perception on hairy skin, while surface tension does not significantly contribute to perception of a liquid surface. Furthermore, we found that glabrous skin has a smaller role than hairy skin in this sensation.

Keywords: Cutaneous Sensation, Hair Follicle Receptor, Liquid Surface, Tactile

1 Introduction

This study investigated the tactile perception of a liquid surface. The history of liquid surface perception is long. In 1859, Meissner reported that we can clearly feel a liquid surface as a thin ring when a finger is immersed in a vessel filled with mercury [1]. This finding was reinvestigated by Bekesy [2], and has been cited in many reports as proof that human skin can perceive spatial and temporal differences in pressure, rather than pressure itself [3][4][5].

However, it has remained unclear which receptors contribute to the perception of a liquid surface.

In contrast, on a daily basis, we perceive a water surface as a thin line when we take a bath, for example. Water has a much smaller surface tension than mercury, and this perception occurs for any part of body, especially the forearm. Therefore, we must reconsider what mechanism underlies this perception.

In our preliminary experiments, we confirmed that we can clearly feel a water surface when we move our arm up and down through the water (**Fig. 1**). This perception disappears if we stop moving our arm. We also confirmed that mechanoreceptors, rather than thermoreceptors, contribute to this perception because, as the water temperature and body temperature became closer, the sensation became clearer. Although hydraulic pressure is the first candidate, the hydraulic pressure at a water surface is 0. Therefore, it is hard to consider that we perceive a water surface by hydraulic pressure alone.

Starting from these facts, this study aimed to clarify how we perceive the boundary between air and water as a cutaneous sensation, particularly at the forearm.

Fig. 1. Feeling a liquid surface in a tactile manner

2 Experiment 1: Evaluation of the Contribution of Surface Tension

Based on the fact that a water surface is perceived, the contribution of the surface tension was considered as the first candidate for the perception of a water surface. Therefore, we performed an experiment to evaluate the contribution of surface tension to perception.

The experiment was conducted with 17 participants who were separated into two groups of different sequences to avoid bias in the results.

We prepared two vessels filled with different liquids. One contained water (surface tension, 63 mN/m) and the other contained a neutral 2% detergent solution (surface tension, 26 mN/m). The liquid temperatures were set to 34°C, which is the temperature of the skin surface. The participants compared the vividness of liquid surface perception by immersing their forearm into the vessels (**Fig. 2**). The experimental procedure was as follows (**Fig. 2**).

Group A: 8 participants

i. Each participant immersed their right arm in water and their left arm in the detergent solution. They were asked to move their arms up and down.
ii. The participants evaluated the vividness of the water perception from 1 to 5, after setting the vividness of the detergent solution perception as 3 (standard liquid).
iii. After swapping the liquids, the arms were moved up and down again.

iv. The participants evaluated the new solutions as described in (ii).
v. Procedures (i) to (iv) were repeated, but this time the participants evaluated the vividness of the detergent solution perception, after setting the vividness of the water perception as 3 (standard liquid).

Group B: 9 participants
All of the procedures were the same as those for group A, except that each participant started the experiment by immersing their right arm in the detergent solution and their left arm in water.

The results of Experiment 1 are shown in **Fig. 3**. From these results, we concluded that the contribution of the surface tension to sensation is actually quite small (p>0.01).

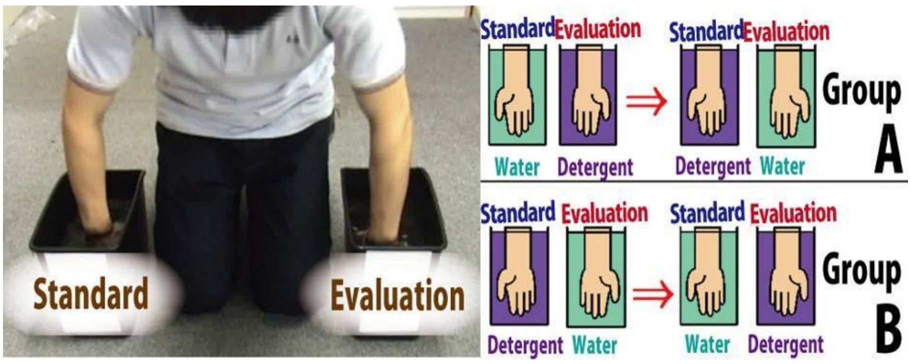

Fig. 2. Setup and procedure of Experiment 1

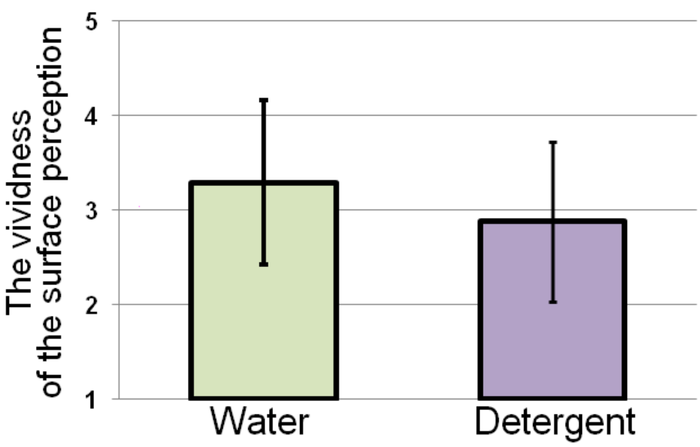

Fig. 3. Comparison of the vividness of the surface perception in Experiment 1

3 Experiment 2: Evaluation of the Contribution of Skin Hair

We considered that skin hair may be another factor behind the perception of a water surface because the hair may be directly moved at the water surface. Therefore, we evaluated the contribution of skin hair to sensation in a second experiment.

The experiment was conducted by 16 participants who were separated into two groups of different sequences, similar to Experiment 1. We prepared vessels filled with water at 34°C. The left arm and the back of the left hand were shaved to lessen the effect of skin hair. Next, the participants compared the vividness of the liquid surface perception by immersing their forearms in the vessels. The experimental procedure was the same as that in Experiment 1 (**Fig. 4**).

The results for Experiment 2 are shown in **Fig. 5**. Hairy skin generated a much more vivid sensation than shaved skin (p<0.01). Therefore, we concluded that the contribution of skin hair to liquid surface perception is actually quite large.

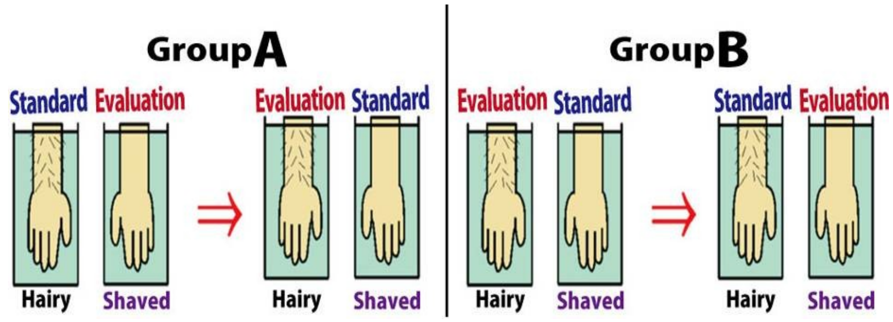

Fig. 4. Procedure for Experiment 2

Fig. 5. The results for Experiment 2 show that skin hair plays a significant role in liquid surface perception

4 Experiment 3: Validation of the Perception in Glabrous Skin

From the results of Experiment 2, it seems that skin hair plays an important role in the perception of a liquid surface. However, Meissner [1] described that we can clearly feel a liquid surface as a thin ring when a *finger* is immersed in the liquid, not the arm. Half of the skin of a finger is glabrous skin and, therefore, we need to verify whether the perception of water surface occurs on glabrous skin. If this is the case, how clear is it compared with hairy skin? To answer these questions, we performed an experiment that compared the perceptions on hairy skin and glabrous skin of the hand.

This experiment was conducted by five participants. The experimental procedure was as follows and as shown in **Fig. 6**.

i. The backs of the participants' left hands were covered by liquid bandages (Coloskin®, Tokyo-Koshisha Inc.). Their right hands were left uncovered. Both hands were immersed in water.
ii. The participants evaluated the vividness of the water perception by their left hand from 1.0 to 5.0, after setting the vividness of water perception for the right hand as 3.0 (standard perception).
iii. The palms of participants' left hands were covered by liquid bandages. Their right hands were left uncovered. Both hands were immersed in water.
iv. The participants evaluated the vividness of the water perception by their left hand as described in (ii).

The back of the hand comprises hairy skin while the palm comprises glabrous skin. Therefore, when the palm is covered by a liquid bandage, the perception of a water surface is induced by the hairy skin. Conversely, when the back of the hand is covered, the perception is induced by glabrous skin.

Because the number of participants in this experiment was small, we asked the participants to evaluate vividness to a decimal point.

The results are shown in **Fig. 7**. Hairy skin clearly generated a much more vivid sensation than glabrous skin (p<0.01). Nevertheless, glabrous skin provide a small contribution to sensation.

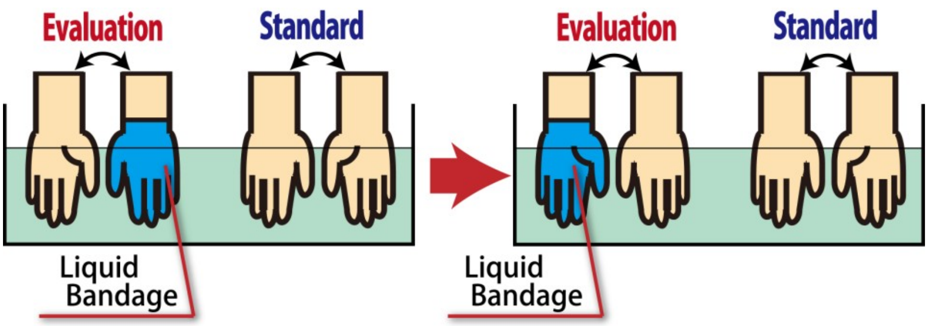

Fig. 6. Procedure of Experiment 3

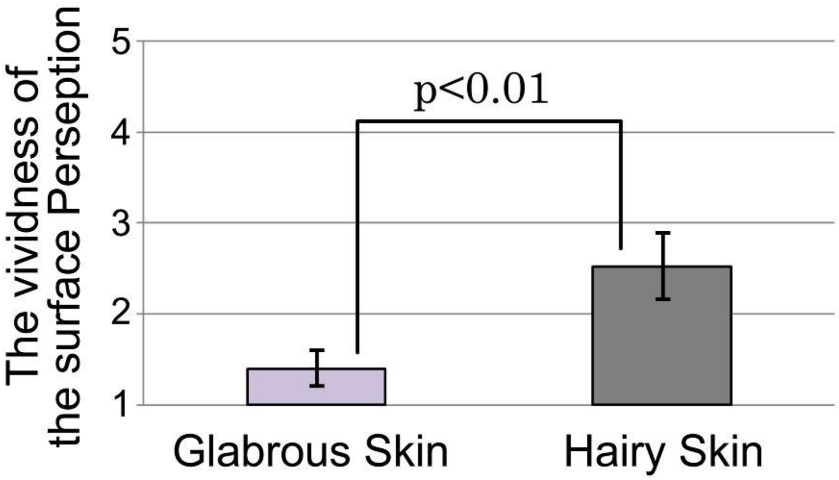

Fig. 7. The results for Experiment 3 show that skin hair plays a significant role in liquid surface perception

5 Discussion and Conclusions

In Experiment 1, we compared two liquids with different surface tensions. The results showed that there was almost no difference between the perceptions of these two liquids, despite the two-fold difference in their surface tensions. From these results, we concluded that the contribution of the surface tension to liquid surface perception is quite small.

In Experiment 2, we compared hairy skin with shaved skin. The results showed that the perception of a water surface became indistinct and almost disappeared when the skin was shaved. Therefore, we concluded that the contribution of skin hair to liquid surface perception is quite large.

Based on these observations, we sought to identify which types of receptors contribute to the sensation of liquid surfaces.

As the contribution of skin hair is dominant, we considered that hair follicle receptors may be involved. This consideration is supported by the following facts. First, the perception of a water surface became vivid when the arm was moved and indistinct when the arm was rested. These observations suggest that RA-type receptors are involved. Second, there are only two types of RA receptors (Pacinian corpuscles and hair follicle receptors) in hairy skin (Meissner corpuscles do not exist in hairy skin [6][7][8]). Third, the spatial resolution of Pacinian corpuscles is quite large, and a "thin line" perception by Pacinian corpuscles seems unreasonable.

This raised another question. Meissner first observed the water surface perception by a finger, which contains both hairy and glabrous skin. Thus, which skin type contributes most in the finger?

In Experiment 3, we compared glabrous skin and hairy skin of the hand. The results showed that the hairy skin generated a much more vivid sensation than the glabrous skin. Although glabrous skin provided some sensation, it was quite small relative to hairy skin. Thus, this sensation was considered to be due to Meissner corpuscles instead of hair follicle receptors.

In other words, although the perception of a liquid surface was first mentioned by Meissner, the perception was not primarily generated by the Meissner corpuscles, but rather by hair follicles, on the arm and fingers.

References

[1] Meissner. G.: Untersuchungen über den Tastsinn. Zeitschrift fur rationelle Medicine. (1859)

[2] von Bekesy, G.: Sensory Inhibition. Princeton University Press, Princeton, 115–117 (1967)

[3] Kenshalo, D.R.: The Cutaneous Senses. In: Kling, J.W., Riggs, L.A. (eds), Woodworth and Schlosberg's Experimental Psychology, vol. 3: Sensation and Perception, 3rd Ed. Holt, Rinehart and Winston, New York (1972)

[4] Katz,D., trans. by Krueger L. E.: The World of Touch. Lawrence Erlbaum, 213 (1989)

[5] Srinivasan, M.A., Dandekar, K.: An Investigation of the Mechanics of Tactile Sense Using Two-Dimensional Models of the Primate Fingertip. Trans. ASME J. Biomech. Eng. 118, 48–55 (1996)

[6] Bolanowski, S.J., Gescheider, G.A., Verrillo, R.T., Checkosky, C.M.: Four Channels Mediate the Mechanical Aspects of Touch. J. Acoustic. Soc. Am. 84, 1680–1694 (1988)

[7] Gescheider, G.A., Bolanowski, S.J., Pope, V., Verrillo, R.T.: A Four-channel Analysis of the Tactile Sensitivity of the Fingertip: Frequency Selectivity, Spatial Summation, and Temporal Summation. Somatosensory Motor Res. 19, 114–124 (2002)

[8] Miyaoka, T.: Mechanoreceptive Mechanisms to Determine the Shape of the Detection-Threshold Curve Presenting Tangential Vibrations on Human Glabrous Skin. Proceedings of the 21st Annual Meeting of the International Society for Psychophysics, 211–216 (2005)