Mechanism of Pressure Sensation Generated by Hot Steam

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ABSTRACT

When a hand is held above boiling water, a sensation of pressure is sometimes experienced in addition to the expected thermal sensation. The underlying cause of this phenomenon is currently unclear. Potential candidates for the causal mechanism of this experience include steam, temperature, humidity and tactile receptor activity. In this paper we investigated the underlying mechanism of this novel non-contact tactile experience. To this end, we tested separate aspects of this experience independently. Our results suggest that stimulation of Merkel cells via sweat duct expansion is the principal cause this perceptual phenomenon.

KEYWORDS: Steam, Pressure Sensation, Sweat Duct, Merkel Cell.

INDEX TERMS: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptics I/O; H.1.2 [Models and Principles]: User/Machine Systems—Human factors

1 INTRODUCTION

Conventional tactile presentation devices involve the problem that stimuli cannot be presented without direct contact between the device and the skin, meaning that tactile display apparatus are often relatively cumbersome. The development of tactile presentation techniques that do not require skin contact is an important step toward solving this problem.

Hoshi et al. [1] developed a method of tactile presentation in which ultrasound transducers induce a tactile sensation from a small distance. Using this technique, a sensation of pressure is induced on the skin surface by acoustic radiation. Using a similar approach, Andrei [2] used wind pressure to induce tactile stimulation. However, these systems are still relatively impractical.

We discovered that when a person's hand was slowly placed into steam generated by boiling water, in some cases a sensation of pressure was perceived, in addition to an expected thermal sensation. Participants reported a tactile sensation that felt as if their finger was being lifted. We term this the "Pressure Sensation with Steam" (PSS) phenomenon (Figure 1).

In the current study, we aimed to identify the underlying cause of this phenomenon, in the hope of incorporating it into a new method of simple non-contact tactile presentation for use in future research.

At present, this phenomenon occurs infrequently, and it seems that it is caused only under certain circumstances. This paper attempts to verify the causal factor involved in the PSS.

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Figure 1. Pressure sensation with steam (PSS). When a hand is held above boiling water, a sensation of pressure is sometimes experienced in addition to the expected thermal sensation.

1.1 Preliminary Observations

Our study tested three alternative hypotheses. The first was that the PSS is induced by an actual pressure change caused by steam. The second was that heat itself caused the sensation. The third was that humidity change caused the sensation

For the first hypothesis, we measured air pressure with a pressure sensor (PSM-005KPGW, Fujikura Ltd.). However, our observations revealed that the pressure change was well below the threshold of human pressure sensitivity. Thus, people would not be expected to be able to perceive such a minute change.

To validate this observation, we prepared bottles with different apertures (Figure 2). All the other conditions were the same. If the actual pressure is the cause of the PSS, the sensation should be stronger for smaller aperture, since "steam flow" from inside the container becomes stronger. On the contrary, we observed that the PSS actually became stronger when the aperture was larger. Therefore, the actual pressure change caused by steam flow was not the cause of the phenomenon.

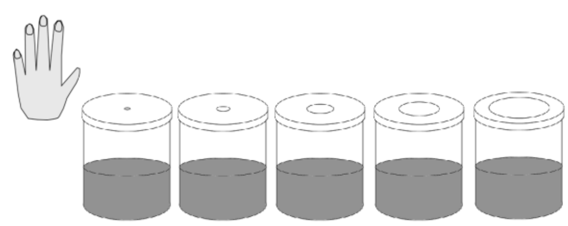

Figure 2. PSS became stronger when bottle aperture was larger. It indicates actual pressure is not the cause of the phenomenon.

For the second hypothesis that heat may caused the PSS, we placed our hands on an infra-red heat source (Figure 3). Although we perceived a much higher temperature than that associated with the steam protocol, no pressure sensation was perceived. According to Stevens et al. [3], the threshold of the pressure sensation rises in tandem with the temperature rise. Based on this knowledge, and our initial observations, we conclude that the PSS is not caused by heat alone.

For the third hypothesis that the humidity change might have caused the sensation, we placed our hands on an supersonic humidifier. It can humidify while no heat was generated. We observed that no sensation was elicited.

Thus, our initial observations indicated that the PSS is not caused by a genuine pressure fluctuation, or by heat alone, or by humidification alone. These findings suggest that the causal factor in PSS induction may be the combined action of steam and heat.

Figure 3. PSS was not observed by radiation heat.

2 Experiment 1: Evaluation of the contribution of thermesthesia and moisture

We sought to test the proposal, based on our initial observations that the PSS is caused by a combination of steam and heat. As such, we investigated whether thermesthesia, pressure receptors, or humidity were involved in inducing the PSS (Figure 4).

To test the involvement of thermesthesia in inducing the PSS, we put participants into thermesthesia generated beforehand by applying capsaicin, and saw if the PSS occurred. Our hypothesis was that if themesthesia is involved, the PSS would become weaker if themesthesia was saturated beforehand.

To test whether humidity is involved in PSS, moisture was removed from the hand by applying dehydrated ethanol prior to the experiment. As dehydrated ethanol absolves water, this process causes the skin to become dry.

Participants were five adults (four male and one female) aged between 21-24 years. Before the experiment, the PSS phenomenon and the experimental protocol were explained. A subsequent training period of 30 minutes was conducted, to allow participants to learn the required appropriate hand motion. The procedure was as follows.

(1) Induction of thermesthesia
Capsaicin was painted on one hand while nothing was done to the other. Both hands were placed into the steam, and if the PSS was perceived, participants were asked to compare it between each hand. The conditions were then reversed and the same evaluation was conducted (i.e. the other hand was tested).

(2) Moisture removal
Dehydrated ethanol was applied to one hand while nothing was done to the other. Both hands were placed into the steam and if the PSS was perceived, participants were asked to compare the sensation in both hands. The conditions were reversed and the same evaluation was conducted.
As skin temperature decreases with the application of ethanol, the evaluation was conducted after the temperature of the hands had equalized.

Figure 4. Experiment procedure. On one hand, capsaicin was painted or moisture was removed. Both hands were placed into the steam to see the difference.

2.1 Results

The results of the experiment are shown inTable 1.

No perceptual change was caused by inducing thermesthesia before the application of steam. On the other hand, when the moisture of the hand was removed beforehand, the magnitude of the PSS clearly changed. Almost all participants reported that the pressure sensation became stronger following the removal of the moisture.

Table 1. Effect of different skin treatments on the PSS."No" means no difference. Addition of thermesthesia gave no effect on the PSS, while moisture removal enhanced the PSS.

	Participant				
	A	B	C	D	E
Addition of thermesthesia	No	No	No	No	No
Moisture removal	Yes	Yes	No	Yes	Yes

These results suggested that the PSS is not caused by thermesthesia. Rather, the findings suggest that the pressure sensation is more likely caused by the activity of Merkel cells, a mechanoreceptor known to be responsible for pressure sensation. We found that moisture plays important role in PSS induction. As one of the primary sources of the moisture on the skin is the sweat gland, we speculated that there may be a mechanism that links sweat gland function to the activity of mechanoreceptors.

3 HYPOTHESIS: INFLUENCE OF SWEAT DUCT

Based on the results of our first experiment, we next examined the structure of the skin to shed further light on possible mechanisms of the PSS, investigating whether a known relationship exists between sweat glands and mechanoreceptors.

It is established that the sweat duct passes through subcutaneous tissue, dermis, and epidermis. The Merkel cells that perceive pressure gather next to the sweat gland at the epidermis-dermis boundary[4][5] (Figure 5).

Because of the spatial proximity of Merkel cells and sweat duct, we hypothesized that the sweat duct may expand because of the heat involved in steam, and that Merkel cells become stimulated by this expansion. The infrared heater did not cause the sensation of the PSS (see preliminary observations, Section 1.1), but this may have been due to differences in the mechanism of heat transfer. The infrared heater transmits heat by radiation, whereas steam directly transmits heat to the sweat duct. Furthermore, steam has a high heat transfer coefficient compared to other heat transfer mediums. Rapid sweat duct expansion caused by steam seems likely to stimulate Merkel cells, thus inducing a sensation of pressure.

Applying ethanol to dehydrate the hand surface substantially reduced the PSS threshold. We speculate that this occurred because the sweat in the sweat duct was removed, allowing the steam to enter the sweat duct and transmit heat.

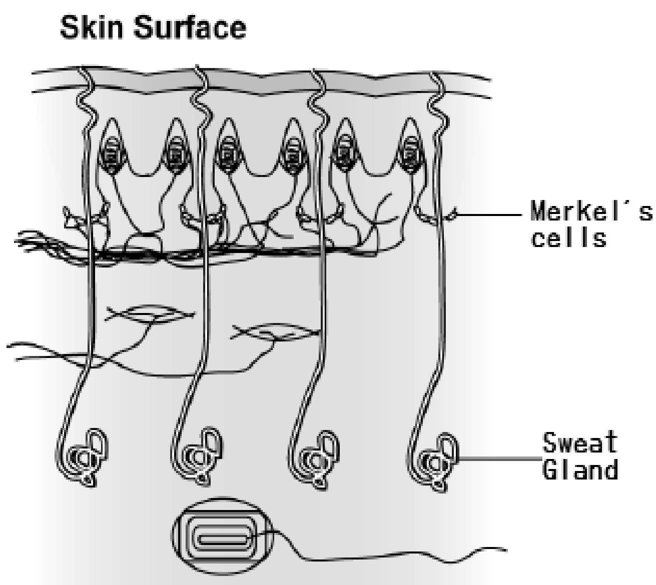

Figure 5. Position of Merkel cells and sweat ducts. As the sweat duct passes by the Merkel cells, it is highly possible that sweat duct affected by steam, or the steam itself affects Merkel cells.

4 EXPERIMENT 2: VERIFICATION OF THE EFFECT OF SWEAT DUCT

To test whether the sweat duct is necessary for inducing the PSS, we changed its state by controlling perspiration (sweat), and examined for changes in PSS induction.

4.1 Experimental conditions: Control of perspiration

Three experimental conditions were as follows.

(1) Suppression of Sweat gland activity
An antiperspirant spray containing chloro-hydroxy aluminum was applied to one hand. Nothing was done to the other hand. Both hands were placed in steam, and participants were asked to compare the sensation between them.

(2) Promotion of sweating by warming
We tested the effects of placing one hand in a sealed box and warming the air inside with a far-infrared heater, until sweat was produced. Nothing was done to the other. Both hands were placed into steam, and sensation was compared between them.

(3) Addition of moisture to hands
Urea ointment was used to add moisture to the skin of one hand. Nothing was done to the other. Both hands were placed into steam, and sensation was compared between them.

4.2 Result

Participants felt a pressure sensation clear only when sweat gland activity was suppressed by antiperspirant spray (1). The sweating by warming (2) lessened the magnitude of the PSS, and urea ointment (3) removed the PSS entirely.

These results are consistent with the notion that the presence of sweat inside the sweat duct removes the PSS. These findings support our hypothesis that the PSS is caused by the action of steam causing heat, which generates pressure through the sweat duct.

5 CONCLUSION

This study revealed a new phenomenon, that hot steam can generate a sensation of pressure, in the absence of genuine perceivable tactile stimulation. Our results indicated that the causal factor in generating the PSS is to the heating of the sweat gland, which generates a perceivable sensation of pressure.

Based on the present findings alone, we cannot conclude decisively whether heat directly affects Merkel cells, or, alternatively, if expansion caused by the heat is the causal factor in Merkel cell activation. We can, however, propose the phenomenon as a new simple experimental method for generating the perception of pressure in humans, without direct physical contact.

In future research, we hope to develop this method into a small experimental apparatus for generating non-contact pressure.

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REFERENCES

[1] Hoshi, T., Iwamoto, T., Shinoda, H.: Non-contact Tactile Sensation Synthesized by Ultrasound Transducers. Proc. 3rd Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp.256-260, 2009.

[2] Sherstyuk, A.: Haptic Wind. Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology, ACM International Conference Proceeding Series, page 352, 2008.

[3] Stevens, J.C., Foulke, E., Patterson, M.Q.: Tactile Acuity, Aging, and Braille Reading in Long-Term Blindness. Journal of Experimental Psychology: Applied，2(2), pp.91-106, 1996.

[4] Mountcastle, V.B.: The Sensory Hand Neural Mechanisms of Somatic Sensation. Harvard University Press, pp.41-44, 2005.

[5] Kandel E. R., Schwartz J. H., Jessel T. M.: Principles of Neural Science, McGraw-Hill, 2000.