Presentation of Positional Information by Heat Phantom Sensation

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Abstract: In this study, we investigated the "heat phantom sensation" induced by thermal stimulation of two points. Phantom sensations are tactile illusions induced at a point between two or more stimuli, and have been demonstrated to occur in the event of vibration stimulation. However, their induction by thermal stimuli has not been fully investigated. We confirmed the existence of a heat phantom sensation using two heat stimulators, and succeeded in presenting the heat source image at an arbitrary position by changing the temperature ratio.

Key Words: Funneling illusion, Heat sensation, Phantom Sensation, Tactile illusion

1 Introduction

Progress in the field of communications due to the development of information technologies means that people increasingly need to communicate by means other than direct interpersonal contact. Various types of devices have been developed to achieve remote interpersonal communication, most of which are based on visual and auditory modalities. Recent studies, however, have proposed the use of haptic interfaces to communicate between remote users [1], [2]. Most of these have been based on the use of force or vibratory tactile sensations. However, to transmit emotional information, physical properties related to the autonomic nervous system, such as temperature and humidity, are important.

In this study, we investigated temperature sensation, which can be generated using relatively low cost devices.

1.1 Background

Previous studies on temperature presentation have mainly focused on the display of material properties [3], and most of them involved presentation of the sensation to the hand or finger. Our tactile interpersonal communication, however, is not limited to the hands; we can touch the whole body, and temperature displays should thus be designed to achieve whole-body stimulation. However, displays to large areas are associated with increased costs and more bulky systems.

During tactile communication, although a sensation may be felt over a wide area (the ‘display position’), since we can be touched anywhere on the body, the area of the stimulus (the ‘display area’) is not necessarily large, since one cannot touch large areas of our body simultaneously with his/her hands. The requirements of the system are thus summarized as follows:

(1) The display position should be widely distributed.
(2) The simultaneous display area does not need to be large; possibly about the size of a palm.
(3) The system needs to involve as little hardware as possible.

The aim of this study was therefore to present temperature information to an arbitrary position, using a small number of devices.

One possible solution is to use phantom sensation. Phantom sensation [4] (sometimes referred to as funneling [5]), whereby a sensation is generated midway between two stimuli, is known to occur for vibratory sensation. Our question is, whether this phenomenon is also observed by thermal stimuli.

On the other hand, spatial ambiguity of the thermal sense called thermal referral was well known [6], [7]. This phenomenon is observed as follows: if the middle finger touches an object at normal temperature while the forefinger and ring finger touch warm objects, then the middle finger also feels warm. A similar phenomenon can be observed using cold objects. This reported thermal referral can be explained by simple spatial summation. However, no studies have reported the ability to present the stimulation at an arbitrary position, which is an important characteristic of phantom sensation.

Let us call the subjective temperature sensation other than real heat sources, “heat source image”. Analogous to the phantom sensation induced by vibration, we speculated that the position of the heat source image could be controlled by changing the temperature ratio of the two stimuli. We have referred to this phenomenon as heat phantom sensation (h-PhS). This study aimed to confirm this ability to alter the position of the heat phantom sensation.

2 Experimental Setup

Two Peltier elements were used for thermal stimulation. They stimulated two points on the forearm (Fig. 1). The elements were embedded in an acrylic sheet of the same thickness to produce a flat surface, and thus eliminate any effect of contact with the elements on positional perception. Each Peltier element measured 40 mm × 40 mm, with a 90-mm gap between them (130 mm distance between the centers of the heat sources). Three temperature sensors (film thermistors) were used to measure the skin temperature. These were located on each element and in the intervening gap.

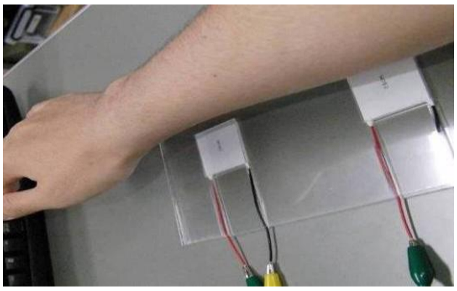


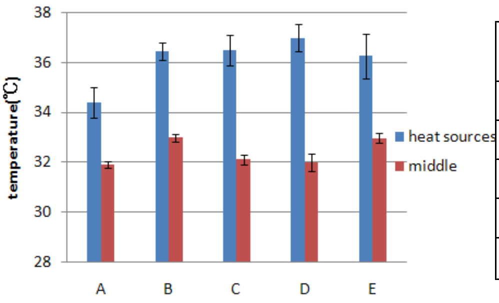
Fig. 1. Two Peltier elements were used to heat the skin. The elements were embedded in an acrylic sheet of the same thickness to produce a flat surface.

3 Perception of heat source image

This experiment was designed to confirm if a heat source image was elicited between the two heat sources, and to investigate the lowest temperature required to produce the funneling illusion.

The participants included five adults (A–E), aged 22–23 years. They have knowledge of funneling by vibration. They were asked if they could feel a heat source image when they put their forearm across the two heat sources. When the temperature of the two heat sources (two temperatures are the same) was increased, all participants reported the sensation of a heat source image. The experiment was repeated five times for each participant. We did not limit response time, and one trial took about 1-3 minutes. Subjects knew the approximate location of the two Peltier elements, but as the elements were hidden by their arms, they could not see the elements during the experiments.

Fig. 2 shows the threshold temperature for the phenomenon. The graph also shows the skin temperature midway between the two points.



	Heat sources (°C)	Middle (°C)
A	34.4	31.9
B	36.5	33.0
C	36.5	32.1
D	37.0	32.0
E	36.3	33.0

Fig. 2. Threshold temperature for producing a heat source image, and skin temperature midway between the two stimulation points in participants A–E

It was confirmed that the heat source image was elicited in all participants. The average threshold temperature was 36.1°C. The temperature midway between the two heat sources was 32–33°C (approximately normal skin temperature), and the heat source image was thus clearly an illusory sensation.

4 Presentation of positional information by h-PhS

This experiment was designed to determine if the position of the illusion could be controlled, as with other PhS. The results of the preliminary experiment showed that an h-PhS was generated at temperatures ≥37°C. Moreover, it is known that heat perception becomes painful at temperatures >43°C [8], [9]. The temperatures of the two heat sources were therefore varied within the range 37–41°C. The temperature combinations are shown in Table 1.

Table 1 Combination of temperatures

Stimulation No.	wrist side (°C)	elbow side (°C)
1	41	37
2	40	38
3	39	39
4	38	40
5	37	41

Stimulations using the different temperature combinations were administered to the participants in random order, and they were asked to identify the position of just the heat source image (Fig. 3). The participants included five adults, aged 22–23 years. The same participants A-D and a new participant F instead of E attended the experiment.

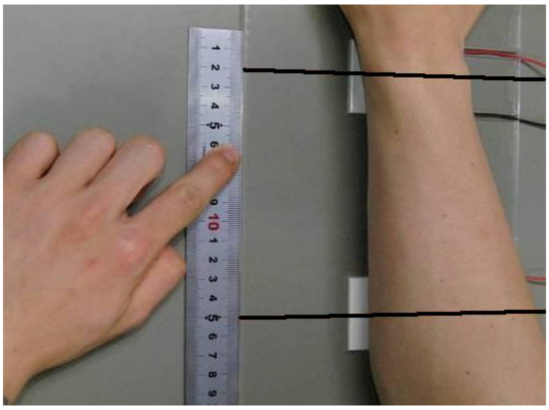


Fig. 3. Participants identified the position of the image

Fig. 4 shows the results of experiment. The two bold lines indicate the central positions of the two Peltier elements. The graph confirmed that the position of the heat source image changed according to the temperature difference between the two heat sources.

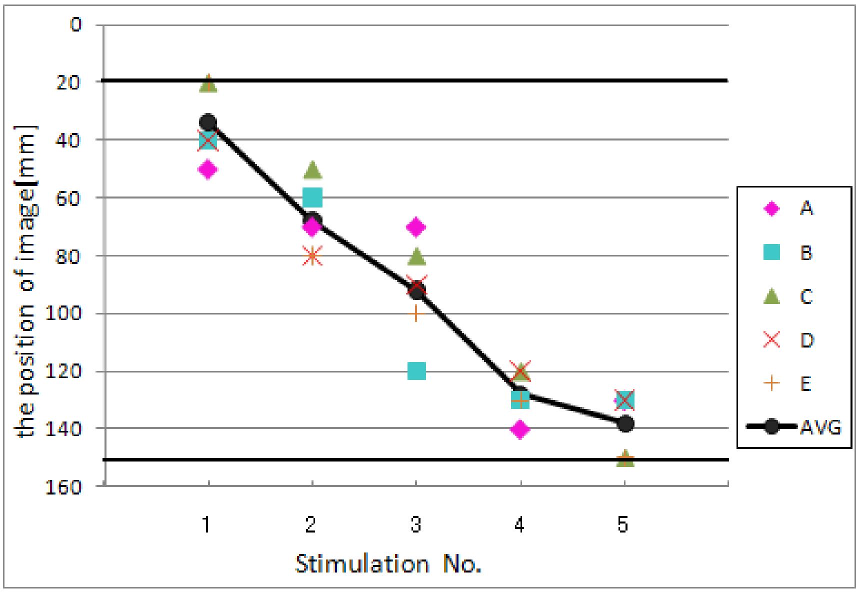


Fig. 4. Perceived position of heat source image in participants A–D and F

5 Conclusions

As described in previous studies, we observed that heat stimulation at ≥37°C applied to two points on the forearm generated a heat source image that was perceived in an area without thermal stimulation.

Although several studies have reported a positional ambiguity effect of temperature perception called thermal referral, they did not demonstrate the ability of the heat source image to be presented at an arbitrary position. On the other hand, we observed that the position of the illusory image could be controlled by changing the temperature ratio.

These results confirm that h-PhS shows the basic characteristics of PhS, and suggest that temperature funneling is based on a mechanism similar to the funneling of vibratory sensations. Further studies are underway to produce spatially distributed temperature sensations using a small number of devices, based on the h-PhS phenomenon observed in this study.

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