Mutual Referral of Thermal Sensation between Two Thermal-tactile Stimuli

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ABSTRACT

When thermal stimulation is applied to one location on the skin and tactile stimulation is presented to another, we perceive the thermal sensation on the latter location as well. While this illusion, known as thermal referral, has been well studied, there is little knowledge on the mutual interaction among multiple thermal-tactile stimuli. We conducted an experiment for verifying the mutual interaction of thermal referral between two thermal-tactile stimuli on forearm and found that there are strong asymmetry between the stimuli locations and between the thermal conditions. The elbow side perceives more thermal referral and synthetic heat (thermal grill illusion) than the wrist side. The warm sensation tends to spread from the periphery toward the center, whereas the cool sensation tends to spread from the center toward the periphery.

Keywords: tactile display, thermo display, thermal grill illusion, thermal referral, tactile-thermal interaction.

Index Terms: H.1.2 [User/Machine Systems]: Human factor—Human information processing.

1 INTRODUCTION

When tactile and thermal stimuli are applied to different locations, the associated thermal sensation is perceived in the part where the tactile stimulus is presented. This phenomenon, a type of thermal illusion, is called thermal referral [1].

In early research, it was reported that thermal referral occurred among three fingers. Green [1] described that when the middle finger was placed on a thermally neutral stimulator and the index and annular fingers were placed on hot (cold) thermal stimulators, the middle finger also felt a warm (cool) sensation. Placing a finger on a stimulator means that a tactile sensation is presented to that finger, which seems a necessary condition for the phenomenon to occur. In addition, he reported that thermal referral could be elicited using two fingers—tactile stimulus to one finger and thermal stimulus to the other—and that this illusion could occur on the forearm as well. Green [2] and Ho et al. [3] reported that the distance between the tactile and the thermal stimuli affects the occurrence rate and quality of sensation of thermal referral.

There were relatively few observations of the contradictory case where hot and cold stimuli were used simultaneously. Green [1] reported that when the middle finger was placed on a cold thermal stimulator and the index and annular fingers were placed on hot thermal stimulators, it was difficult to judge whether the middle finger was hot or cold, and the middle finger perceived synthetic heat (SH). Synthetic heat is a phenomenon that generates the sensation of heat when hot and cold stimuli are located close to each other on the skin [4], which is also known as thermal grill illusion (TGI). This phenomenon often causes pain or a burning sensation [5] [6].

When two contradictory thermal-tactile stimuli (hot and cold) are applied, what are the "mutual" effects? If point A is set cold and point B is set hot, and a tactile sensation is presented to both locations, there would be two simultaneous thermal referrals: cold stimulus transport toward the hot side, and hot stimulus transport toward the cold side (Figure 1). However, previous works did not report these mutual effects. Ho et al. [7] reported that when the middle finger was placed on a neutral thermal stimulator and the index and annular fingers were placed on a hot (cold) thermal stimulators, the middle finger perceive a warm (cool) sensation, and the perceived temperature of the two adjacent fingers decreased (increased) as well. While this can be regarded as a type of subjective conservation of energy, we cannot determine whether there is any mutual interaction of thermal referral between a warm stimulus and a cool stimulus.

This research aims to elucidate mutual thermal referral between multiple thermal-tactile stimuli. In this study, we conducted an experiment to verify the mutual interaction of thermal referral between two thermal-tactile stimuli applied to the forearm.

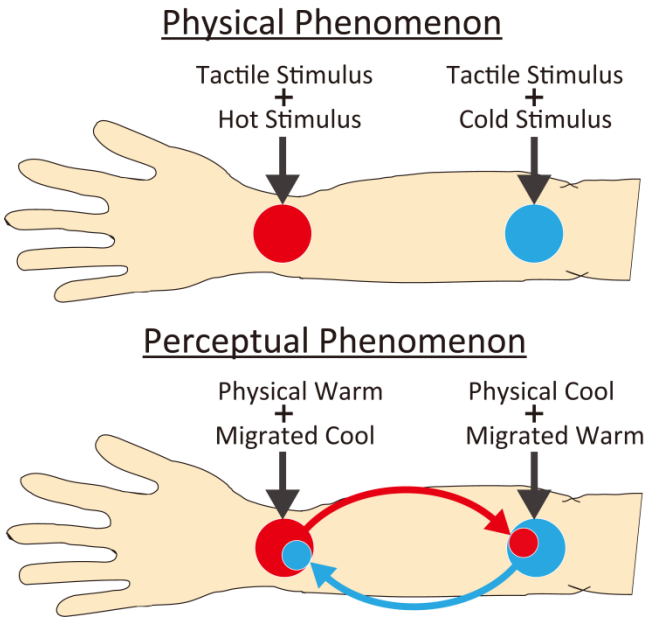

Figure 1: Image of mutual thermal referral between two contradictory thermal-tactile stimuli.

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2 METHOD

2.1 Participants

Six healthy male laboratory members of ages 21–25 years participated in our experiment. Five participants were right-handed, and one was ambidextrous. No participant had any skin disease.

2.2 Apparatus

The experimental system consists of two thermal stimulators (Figure 2). The stimulator comprises a 40 mm ×40 mm Peltier device (TEC1-12703), and a heat sink and fan (Shicoh Engineering, 0410N). The distance between two stimulators was 100 mm, which is much longer than the two-point discrimination threshold of forearm skin [8].

Figure 2: Temperature stimulators composed of a Peltier device and fan.

2.3 Environment

The experiment was conducted in a room maintained at 28 °C.

2.4 Condition

Each stimulator produced three kinds of thermal stimuli: warm (40 °C), cool (20 °C), and neutral (33 °C). Because there were two stimulators, the total number of conditions was nine. Three trials per condition yielded 27 trials in total, conducted randomly.

2.5 Procedure

Participants' right forearms were placed on the stimulators such that their wrist-side borders of forearms were placed on one of the stimulators (Figure 3). Hereafter, we call this stimulator "wrist side stimulator" and the other one as "elbow side stimulator". Twenty seconds after stimulation, the participants lifted their arms off the stimulators and indicated the perceived sensations on the wrist and elbow sides by selecting from seven options ("cool," "cold," "warm," "hot," "burning," "pain," and "nothing"). They were permitted to choose more than one option, except when their first selection was "nothing." For preventing their adaptation to thermal sensation, participants were asked to stroke their right forearms with their left arm and rest for 30 seconds between trials.

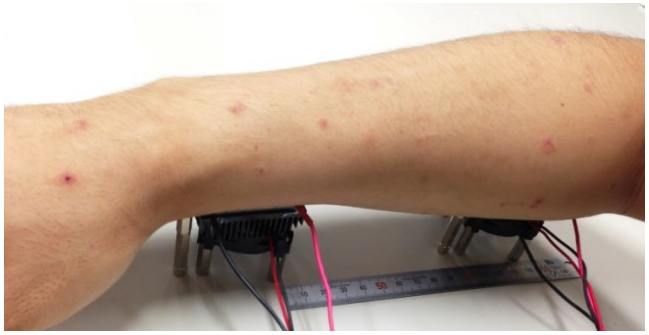

Figure 3: Appearance of the experiment.

3 RESULTS

The results are shown in the following four figures (Figure 4, Figure 5, Figure 6, and Figure 7). The symbol "○-○" in the graphs indicates the types of thermal stimuli that were applied to the wrist side and the elbow side (n: neutral, h: heat, c: cold). For example, "n-n" is the condition that both stimulators were 33 °C, and "h-c" is the condition that the wrist side stimulator was 40 °C and the elbow side one was 20 °C. Figure 4 shows the result of the experiment in which the same temperatures were presented to both the sides ("n-n," "h-h," "c-c"). Figure 5 shows the results of the experiment in which the neutral temperature was presented to the elbow side ("h-n," "c-n"). Figure 6 shows the result for neutral temperature presented to the wrist side ("n-h", "n-c"), and Figure 7 shows the result of the contradictory case in which hot and cold temperatures were presented.

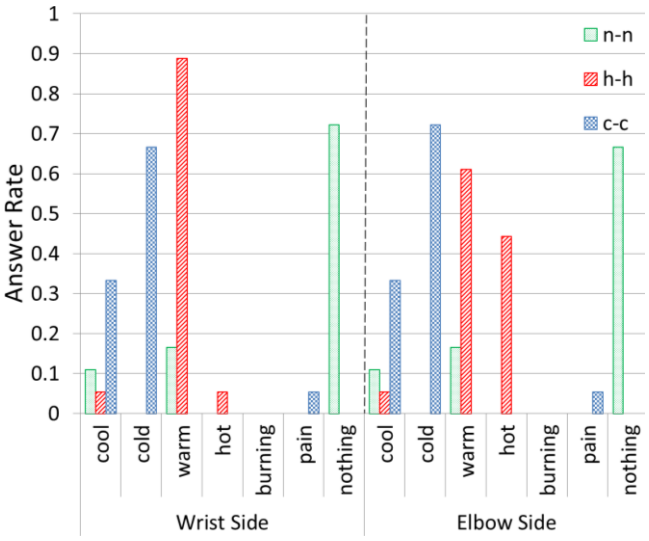

Figure 4: Result of experiment in which the same temperature was presented to both sides.

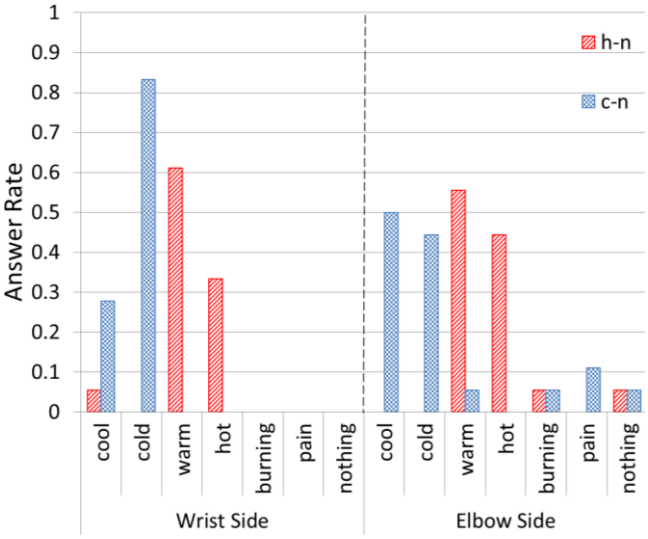

Figure 5: Result of experiment in which neutral temperature was presented to elbow side.

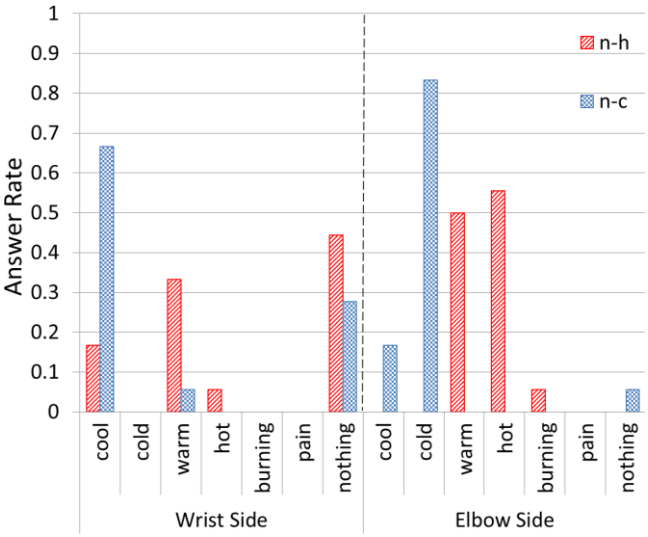

Figure 6: Result of experiment in which neutral temperature was presented to wrist side.

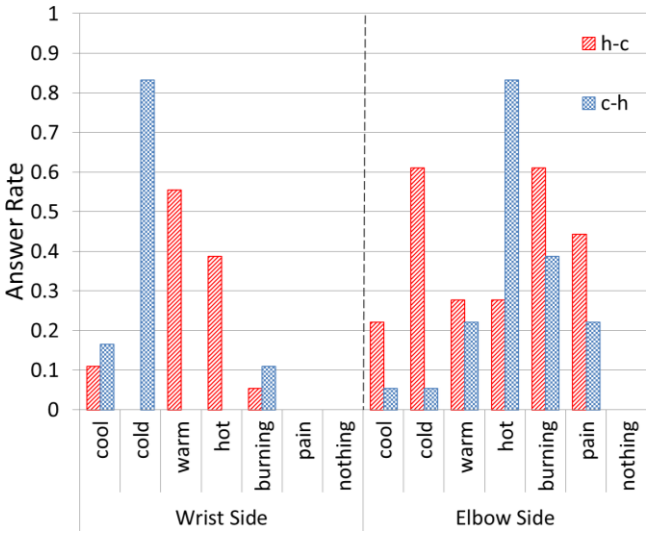

Figure 7: Result of experiment in which hot and cold temperatures were presented (contradictory condition).

In the cases where both stimulators presented the same thermal stimulus, the participants mostly judged the applied stimulus correctly (Figure 4). In the cases where the neutral temperature was presented to the elbow side, the elbow side also perceived the same sensation as the wrist (Figure 5). In the cases where neutral temperature was presented to the wrist, the wrist often perceived the same sensation as the stimulus presented to the elbow side, but it often perceived "nothing" (Figure 6). In the case where hot and cool stimuli were presented, many participants answered "burning" and "pain" at the elbow side (Figure 7), whereas in the case of "h-c," although the cool stimulus was applied to the elbow side, the answers "warm" and "hot" were seen more often than not on the elbow side (Figure 7).

4 Discussion

The experiment confirmed that thermal referral occurred when either the wrist side or the elbow side was presented hot or cold stimulus (Figure 5, Figure 6). "Burning" and "pain," which are typical sensations of SH or TGI, were observed when hot and cold stimuli were presented simultaneously (Figure 7, right). These observations agree with the findings of previous studies.

However, we found strong asymmetry between the elbow side and the wrist side: the wrist side almost did not perceive SH (TGI) (Figure 7, left, Figure 9). This positional asymmetry was also observed in the thermal referral (Figure 8). Comparing Figure 5 and Figure 6, the occurrence rate of thermal referral was quite different at the two locations. The occurrence rate of thermal referral from the elbow side to the wrist side was more than 90% (Figure 5), whereas that in the reverse direction was about 60% (Figure 6).

There is another temperature-related asymmetry. The h-c case yielded more SH (TGI) than the c-h case (Figure 7). This thermal asymmetry was observed in the thermal referral as well. When a temperature stimulus was presented only at the wrist side (Figure 5), thermal referral occurred mainly when the presented stimulus was warm (comparing h-n and c-n). In contrast, when a temperature stimulus was presented only at the elbow side (Figure 6), thermal referral occurred mainly when the presented stimulus was cold (comparing n-h and n-c). In other words, warm sensations tend to spread from the periphery toward the center, whereas cool sensations tend to spread from the center toward the periphery.

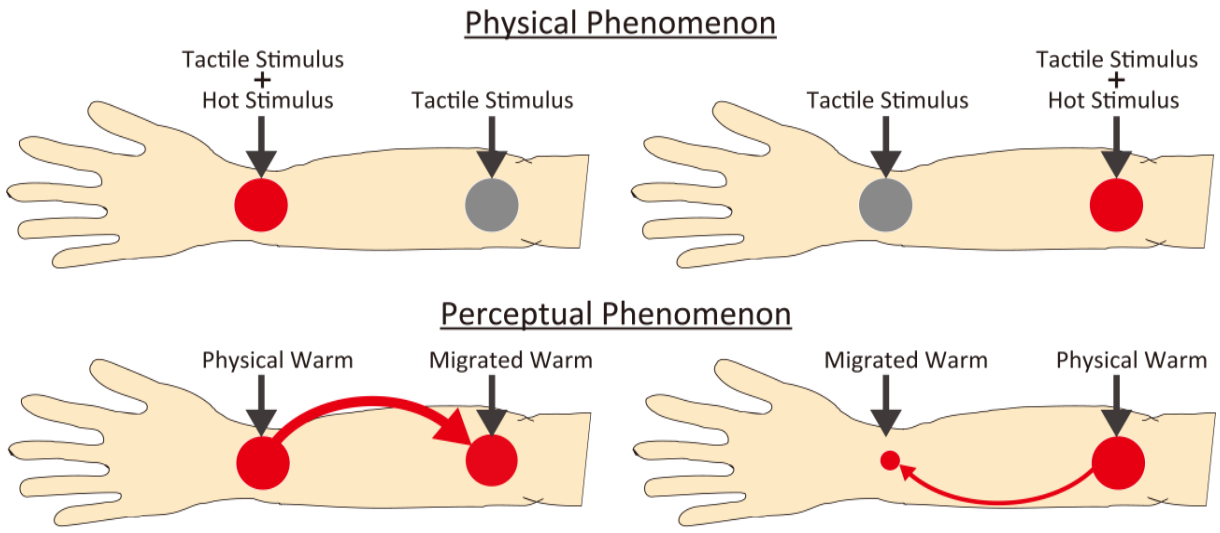

Figure 8: Asymmetry of occurrence rate of thermal referral between the elbow side and the wrist side. The hot stimulus on the wrist side induced thermal referral to the elbow side, while the same stimulus on the elbow side almost did not.

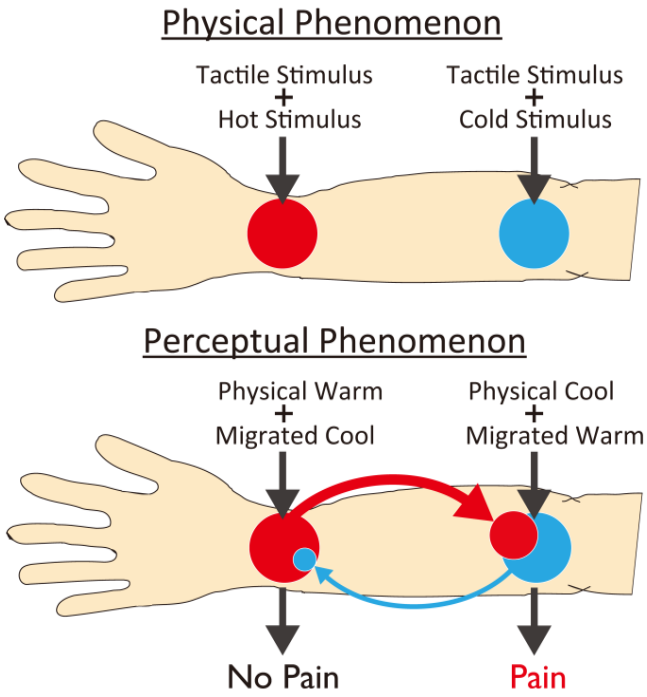

Figure 9: Asymmetry of occurrence rate of SH (TGI) between the elbow side and the wrist side in which hot and cold temperatures were presented (contradictory condition). The pain sensation was elicited almost at the elbow side, and combination of hot stimulation to wrist side and cold stimulation to elbow side induced clearer SH (TGI) than the opposite condition.

Although the reasons underlying these asymmetries are less obvious and warrant further research, their presence possibly suggests the mechanism of observed SH (TGI) elicited by two hot and cold stimuli presented at remote locations (Figure 7). There are two possible mechanisms. One is "referral first, SH (TGI) second," i.e., thermal sensation migrates to one side, and this migrated sensation and the physical thermal stimulation create a sensation of pain. The other possible mechanism is "SH (TGI) first, referral second," i.e., SH (TGI) is generated by two remotely located hot and cold stimuli, and this pain sensation itself funnels toward the elbow side. In other words, it is "pain referral." From the above observations, the positional and thermal asymmetries of the thermal referral and the SH (TGI) have quite similar trends, suggesting that thermal referral plays major role in the observed SH (TGI), thus supporting the first hypothesized mechanism.

5 Conclusion

This study aims to elucidate the mutual interaction of thermal referral between two thermal-tactile stimuli. An experiment using two thermal-tactile stimuli presented to the forearm revealed that while thermal referral and SH (TGI) were observed in agreement with previous literatures, there are positional and thermal asymmetries. The elbow side perceives more thermal referral and SH (TGI) than the wrist side. The warm sensation tends to spread from the periphery toward the center, whereas the cool sensation tends to spread from the center toward the periphery. Further research on these asymmetries is needed, which will be the basis of future thermal display of the entire body.

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