

Analysis of Paradoxical Phenomenon Caused by Presenting Thermal Stimulation on Three Spots

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Abstract. Thermal referral (TR) and thermal grill illusion (TGI), known as illusions of thermal sensation, have been well studied. In a previous study, an experiment using two thermal-tactile stimulations to the forearm revealed that these illusions simultaneously occurred. In this experiment result, a few subjects perceived a hot stimulation as a cold sensation and/or a cold stimulation as a hot sensation. This paradoxical phenomenon of thermal sensation, which is not discussed specifically in the previous study, could be a fatal problem in the case presenting thermal stimulation on multiple spots intentionally. Therefore, we decided to analyze this paradoxical phenomenon. In this paper, we confirmed that this phenomenon occurs when we present thermal stimulation on two spots and three spots. In comparing the results of thermal stimulation on two spots and three spots, the occurred probability increased on three spots.

Keywords: Thermal sensation · Thermal referral · Thermal grill illusion

1 Introduction

Thermal referral (TR) and thermal grill illusion (TGI) are known as illusions of thermal sensation. TR is a phenomenon in which thermal sensation changes when thermal stimulation is presented to one location and tactile stimulation is presented to another [1–3]. TGI refers to paradoxical sensations of heat and pain resulting from the simultaneous application of interlaced hot and cold stimuli [4, 5].

In a previous study, an experiment using two thermal-tactile stimulations to the forearm revealed that these illusions simultaneously occurred [6]. From the result of this study, we noticed that a few subjects perceived a hot stimulation as a cold sensation and/or a cold stimulation as a hot sensation. This paradoxical phenomenon of thermal sensation, which is not discussed specifically in the previous study, could be a fatal problem in the case presenting thermal stimulation on multiple spots intentionally. Therefore, we decided to analyze this paradoxical phenomenon of thermal sensation.

As a first step (experiment 1), we verified that this phenomenon occurred by presenting thermal stimulation on two spots in a manner similar to the previous study. In the next step (experiment 2), we investigated whether this phenomenon occurred

when we expanded the stimulation from two spots to three spots. Also, we compared the results of experiments in cases of thermal stimulation on two spots and three spots.

2 Thermal Stimulations

In our experiments, hot and cold stimulations are presented by using Peltier devices (size: 40 × 40 mm) and temperature controller sets (VPE-20-5 V, VICS Ltd., Fig. 1). Considering the stability of the temperature stimulation, we sat the devices on a table and asked subjects to put the inside of their forearms on them. Three devices were set 100 mm apart in a row on the table. Each device had contact with the wrist, the center, and the elbow spot of the forearm (Fig. 2). Also, two pillows were prepared for each subject’s wrist and elbow to hold and stabilize his or her forearm.

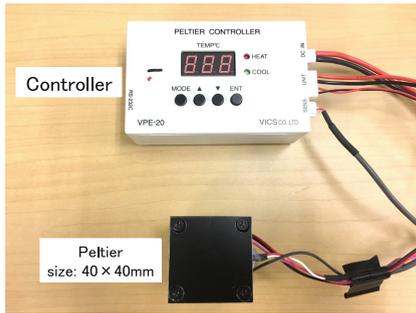


Fig. 1. Device for presenting thermal

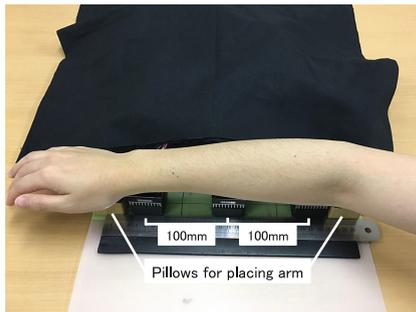


Fig. 2. Experimental scene

Thermal stimulation becomes painful when the temperature is too low or too high (the cold stimulation: 10 °C, the hot stimulation: 45 °C) [7]. We selected 11 °C and 44 °C as the cold and hot stimulations to avoid pain. The experiments were conducted in a room with a constant temperature of 25 °C.

3 Experiment 1: Presenting Thermal Stimulation on Two Spots

3.1 Objective

In the previous study, a few subjects perceived a hot stimulation as a cold sensation and/or a cold stimulation as a hot sensation when a hot stimulation and a cold stimulation were presented simultaneously to two spots on the forearm. In experiment 1, we reevaluated this phenomenon.

3.2 Condition

In experiment 1, the hot and cold stimulations were presented to two of the three spots and a null stimulation, which was neither hot nor cold, was presented on the remaining spot of the forearm. This null stimulation was set to 32 °C because the indifferent temperature (when humans do not feel hot or cold sensations) is known to be between 30 °C and 36 °C. In our preliminary experiment presenting this null stimulation on three spots (the wrist, the center, and the elbow), we confirmed that none of 10 subjects feel hot and/or cold.

The center of subject’s right forearm was placed on the Peltier device as shown in Fig. 2. At the same time, the remaining two devices had contact with the wrist and the elbow of the forearm. After a 20-second interval of placing his forearm on the devices, the subject was asked to describe the sensation he perceived (hot, null, or cold) at each of the three spots. We also asked whether the subject felt pain at any of the spots. A series of the 12 combinations (Table 1) was presented in random order. The subjects included 10 males in their 20 s to their 30 s.

Table 1. Answer rate of temperature and pain sensations in each pattern when thermal stimulation is presented on two spots (subjects = 10)

Stimulation Location	Answer Pattern				Pain	Answer Pattern				Pain	Answer Pattern				Pain	Answer Pattern				
	Hot	Null	Cold	Pain		Hot	Null	Cold	Pain		Hot	Null	Cold	Pain		Hot	Null	Cold	Pain	
Wrist	H	80%	20%	0%	10%	C	10%	0%	90%	10%	H	80%	20%	0%	0%	C	0%	0%	100%	10%
Center	H	70%	30%	0%	10%	C	0%	20%	80%	20%	C	30%	10%	60%	30%	H	60%	30%	10%	0%
Elbow	N	70%	30%	0%	0%	N	0%	80%	20%	0%	N	20%	50%	30%	0%	N	90%	10%	0%	0%
Wrist	H	70%	30%	0%	0%	C	0%	0%	100%	0%	H	70%	20%	10%	0%	C	0%	0%	100%	10%
Center	N	70%	30%	0%	0%	N	0%	20%	80%	0%	N	20%	40%	40%	20%	N	20%	80%	0%	0%
Elbow	H	90%	10%	0%	10%	C	0%	10%	90%	0%	C	0%	20%	80%	10%	H	100%	0%	0%	0%
Wrist	N	40%	60%	0%	0%	N	0%	80%	20%	0%	N	70%	30%	0%	0%	N	20%	40%	40%	0%
Center	H	70%	30%	0%	10%	C	0%	20%	80%	0%	H	40%	30%	30%	10%	C	10%	30%	60%	20%
Elbow	H	90%	10%	0%	10%	C	0%	0%	100%	0%	C	10%	0%	90%	10%	H	70%	10%	20%	10%

※Patterns in the table indicate that the stimulation was presented on the wrist, the center, and the elbow spot in order from the top
 ※H, N, C indicate the type of presentation stimulation (H: Hot stimulation, N: Null stimulation, C: Cold stimulation)

3.3 Procedure

The experimental procedures were as follows:

- (1) Measure the center position of the forearm.

- (2) Set the temperature and wait until the temperature is stabilized.
- (3) Put the subject's forearm on the devices and wait for 20 s.
- (4) Determine the subject's sensation on each of the three spots.
- (5) Provide sufficient intervals (more than 2 min) to eliminate the effects of temperature change on the skin.
- (6) Steps (2) to (5) are repeated 12 times.

If the subject wanted to redo procedure (4), then we provided a sufficient interval and repeated the same trial.

3.4 Result and Discussion

The results are shown in Table 1. The letters "H", "N", and "C" in the table indicate the presented hot, null, and cold stimulations, respectively. These characters are described in the order of the wrist, the center, and the elbow. The values in Table 1 show the answer rate of the temperature and pain sensations perceived at each spot. The dotted values are the correct answers, and the double underlined values indicate the opposite answers.

- (i) When only the hot or the cold stimulation was presented, the subjects correctly answered the presented stimulation.

In the patterns (HHN, HNH, NHH, CCN, CNC, NCC) that present the same thermal stimulations (e.g., hot and hot/cold and cold), the subjects perceived the presented thermal stimulation accurately. However, the null stimulations were substantially affected by the neighboring thermal stimulation (TR phenomenon).

- (ii) When both hot and cold stimulations were presented, a few subjects gave opposite answers.

In the patterns (HCN, HNC, NHC, CHN, CNH, NCH) that present the opposite thermal stimulation, especially in the patterns (HCN, NHC, CHN, NCH), the answer rate that correctly perceived the presented thermal stimulation became lower than the result of (i). A few subjects commented that "I could not feel some of the hot/cold spots" or "Perceived the temperature reversely to the presented stimulation." Particularly in the center spot of HCN and NHC, the occurrence of the paradoxical phenomenon of thermal sensation was 30%. Most of the null stimulations were under the influence of the neighboring stimulation (TR phenomenon).

- (iii) A few subjects perceived pain sensation on the center spot.

From the results of this experiment, we confirmed that the influence of the TR phenomenon made the null stimulation inaccurate. Furthermore, the thermal stimulation was not necessarily perceived accurately, and even paradoxical perception could occur.

4 Experiment 2: Presenting Thermal Stimulation on Three Spots

4.1 Objective

In experiment 2, we evaluated the incidence of paradoxical phenomenon of thermal sensation when thermal stimulation was presented on three spots on the forearm.

4.2 Condition and Procedure

In experiment 2, the hot or cold thermal stimulation was presented on three spots. The null stimulation was not used. Eight combinations of hot and cold stimulations on the three spots (Table 2) were presented to the subjects in random order. Other experimental conditions and procedures were the same as those in experiment 1.

Table 2. Answer rate of temperature and pain sensations in each pattern when thermal stimulation is presented on three spots (subjects = 10)

	Answer Pattern					Answer Pattern					Answer Pattern					Answer Pattern				
	Hot	Null	Cold	Pain		Hot	Null	Cold	Pain		Hot	Null	Cold	Pain		Hot	Null	Cold	Pain	
Wrist	H	90%	10%	0%	0%	H	80%	10%	10%	10%	C	0%	10%	90%	0%	H	60%	10%	30%	0%
Center	H	100%	0%	0%	20%	H	70%	0%	30%	0%	C	30%	10%	60%	10%	C	40%	10%	50%	40%
Elbow	H	100%	0%	0%	0%	C	30%	0%	70%	0%	H	80%	10%	10%	10%	H	90%	0%	10%	0%
Wrist	C	10%	10%	80%	0%	C	0%	0%	100%	0%	H	60%	40%	0%	10%	C	10%	10%	80%	10%
Center	C	0%	20%	80%	0%	H	70%	10%	20%	30%	C	30%	10%	60%	40%	H	60%	0%	40%	20%
Elbow	C	0%	0%	100%	10%	H	90%	0%	10%	0%	C	20%	0%	80%	0%	C	50%	0%	50%	10%

※Patterns in the table indicate that the stimulation was presented on the wrist, the center, and the elbow spot in order from the top
 ※H C indicate the type of presentation stimulation (H: Hot stimulation C: Cold stimulation)

4.3 Result and Discussion

The results are shown in Table 2.

- (i) When only the hot or the cold stimulation was presented, the subjects correctly answered the presented stimulation.

Similar to the result of experiment 1 (i), in the patterns (HHH, CCC) that present the same thermal stimulations, the subjects perceived the presented thermal stimulation accurately.

- (ii) When two identical thermal stimulations were aligned side by side, a few subjects perceived the presented stimulation reversely.

Similar to the result of experiment 1 (ii), in the patterns (HHC, CHH, HCC, CCH), which present two of the same thermal stimulations side by side, the answer rate that correctly perceived the presented thermal stimulation was lower than the result of (i).

- (iii) When the hot and cold stimulations were aligned alternately, half of the subjects reversely perceived the presented stimulation.

In the patterns (HCH, CHC) that present the thermal stimulations alternately, the incidence of paradoxical phenomenon of thermal sensation increased more than the result of experiment 1 (ii) and the result of experiment 2 (i) and (ii); 40% in the center spot of HCH and CHC, and 50% in the elbow spot of CHC.

(iv) Some subjects perceived pain sensation at the center spot.

Particularly, in the patterns (CHH, HCC, HCH) that aligned the hot and cold stimulations side by side, more subjects perceived pain sensation than the result of experiment 1 (iii).

From these results, we found that the paradoxical phenomenon of thermal sensation also occurred in experiment 2. In addition, we found that increasing the number of spots of thermal stimulation increased the incidence of paradoxical phenomenon of thermal sensation and TGI.

5 Conclusions and Future Work

In experiment 1, we confirmed that paradoxical phenomenon really occurs when we present thermal stimulation on two spots. In experiment 2, we evaluated the incidence of paradoxical phenomenon of thermal sensation when thermal stimulation is presented on three spots on the forearm. As a result, this phenomenon occurred in the patterns that alternately present thermal stimulation with a probability of 50%. In comparing the results of two spots and three spots, the incidence increased on three spots.

In the future, we want to investigate why this paradoxical phenomenon of thermal sensation occurs by changing some parameters, such as presentation temperature and positions, to determine how we can avoid this.

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