Effect of illusory thermal sensation on hardness perception
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We examined whether simultaneous illusory thermal sensations can influence the perception of hardness. By applying thermal stimuli on the index and ring fingers, we elicited referred thermal sensation on the middle finger, to which only hardness stimuli was applied without affecting the thermal properties of the peripheral receptors. Seven participants underwent a two-alternative forced-choice task on the perceived hardness of rubber pieces with various hardness values. The results show that the participants found samples to be harder under the cold condition. This phenomenon implies that the illusory thermal experience induces a tactile illusion in which warm (cold) material is perceived to be soft (hard).

Key words: hardness perception, referred thermal sensation, multisensory perception

In the last decade, we witnessed considerable progress in multisensory interaction studies but still know little about the interactions between cutaneous sensations. This research stagnation may be ascribed to the difficulties in clarifying whether the interactions between cutaneous sensations are caused by the modulation of the central nervous system or by variation in the sensitivity of peripheral receptors.

To resolve this difficulty, we may gain some insight from the illusory thermal sensations induced by tactile inputs. A typical case is the referred thermal sensation; for example, when the index and ring fingers are placed on a warm (cold) material and the middle finger is placed on a neutral thermal material, participants will feel warmth (coldness) in all three fingers (Green, 1977). In this case, the participants undergo various thermal experiences on the middle finger despite the fact that there is no physical thermal difference on that finger.

By using a referred thermal sensation, we conducted an experiment to examine whether simultaneous thermal sensation can bias the perception of hardness. The aim was to measure the effects of a genuine tactile hardness stimulus without causing an actual thermal difference in the peripheral receptors at the site of stimulus. Further, any modulation of hardness perception would provide experimental evidence for the existence of an interaction between thermal and mechanical information in the central nervous system, where the illusory thermal sensation is known to be generated.

Method

Participants. Seven normal healthy adults (four women and three men) aged between 27 and 35 years participated in the experiment. They had no abnormalities in their tactile or thermal sensory systems. They all reported that they were right-handed.

Apparatus. The experimental apparatus, comprised the comparison and standard stimulus sets. The former included the comparison hardness stimulus, which was touched by the middle finger, and a pair of thermal stimuli, which were placed on both sides of the comparison hardness stimulus and were thus touched by the index and ring fingers. The comparison hardness stimulus was a 6-mm-thick silicone rubber piece of size 30 × 40 mm with a JIS-A hardness of 10, 20, 30, 40, 50, 60, or 70 (Shin-etsu Chemical Co., Ltd.); the thermal stimuli were bakelite (Sumitomo Bakelite Co., Ltd.) pieces of the same size. A comparison stimulus of different hardness was

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used in each trial. The standard stimulus set comprised the same components except that the hardness of the rubber piece in the middle (standard hardness stimulus) was fixed to JIS-A 40. The standard and comparison stimulus sets were positioned on left and right sides, respectively, and thus the six stimuli were aligned horizontally. The surface temperatures of the stimuli in the standard set and that of the comparison hardness stimulus in the comparison set were kept at around 34°C by a circulating thermostatic bath (PCC7000, Tokyo Rikakikai Co., Ltd.). The surface temperature of the thermal stimuli in the comparison set was controlled by another circulating thermostatic bath (CO 2-A, Nihon Techno Service Co., Ltd.) to around 42°C, 34°C, and 24°C.

Procedure. Each participant underwent three sessions with different thermal conditions (Warm (42°C), Neutral (34°C), and Cold (24°C)). The order of the sessions was counterbalanced. The participants were instructed to gaze at a fixation point 30 cm away from the tactile stimuli, which were curtained to eliminate visual cues. Before each trial, the participants were instructed to place the fingers of the dominant hand on the standard stimuli to maintain the skin temperature at around 34°C. In each trial, the participants touched the standard and comparison sets sequentially. At the start of each trial, the participants were alerted by a 1-s beep, at the end of which, they raised their fingers off the standard set. And after a 0.5-s interstimulus interval (ISI), a 0.1-s beep prompted them to touch the standard set briefly. After 0.5 s interval, the identical sound sequence was presented to prompt their fingers to touch the comparison set. They then reported whether the comparison hardness stimulus was harder or softer than the standard hardness stimulus. The hardness of the comparison hardness stimulus was varied according to the double-staircase method. The point of subjective equality (PSE) was calculated by averaging the last five (out of ten) reversal points of each staircase series.

At the end of each session, the participants were asked to estimate the temperature of the comparison hardness stimulus with JIS-A hardness 40 relative to that of the standard stimulus at 34°C.

| Table 1 | Mean and standard error of point of subjective equality (PSE) of hardness. |
|---------|-----------------|-----------------|-----------------|
|         | Thermal condition | Warm | Neutral | Cold |
| mean PSE | 45.7            | 39.4            | 32.6            |
| Standard error of mean | 3.3             | 1.7             | 2.8             |
| n=7 (JIS-A hardness) |

Results and Discussion

First, to determine whether the thermal variation on the index and ring fingers influenced the temperature perceived on the middle finger, we conducted a one-way analysis of variance with the thermal condition (3) as the within-subject factor for the temperature judgment. The analysis revealed a significant main effect for the thermal condition (F(2, 12) = 8.30, p<.01). This result confirms that referred thermal sensations were produced in our experiment.

Table 1 shows the average and standard error of the mean PSE under each thermal condition. To determine whether variation in the thermal stimulus on index and ring fingers influenced the perception of hardness on the middle finger, we conducted a one-way analysis of variance test with the thermal condition (3) being the within-subject factor for the PSE of hardness judgment. We found a significant main effect for the thermal condition (F(2, 12) = 8.65, p<.01). This result indicates that the participants found the same sample to be harder under the cold condition.

Taken together, the results clearly demonstrate that the illusory thermal experience induces a tactile illusion by which a warm (cold) material is found to be soft (hard). The thermal illusion is not caused by sensitivity adjustment of peripheral receptors but by modulation of the central nervous system. Therefore, the tactile illusion observed in this study can only be attributed to an interaction between the thermal and tactile senses occurring in the central nervous system.

Reference