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AFFECTIVE DIMENSION OF THERMAL SENSATIONS TO TRANSIENT HEATING[1]

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The present study was done to examine a relationship between thermal sensations and their affective components produced by transient heating of a portion of the subject's forearm selectively stimulated by a pain analyzer. Thermal stimuli of 3- and 6-sec in duration with either 7 or 5 intensity levels were presented in random order, at the rate of one every 45 s, to two 10-Ss groups different in ambient air temperatures (16 and 20 ℃). They were required to assign numbers in proportion to the perceived sensory and affective intensity to the stimuli. Analysis showed that as stimulus intensity increased, the sensory intensity increased also; The perception of affect was characterized by the presence of a bending point in the curve from pleasantness to unpleasantness at high stimulus intensities, the point of which shifted due to stimulus duration and ambient air temperature.

Key words: thermal sensation, hedonic value, magnitude estimation, thermal stimulation.

INTRODUCTION

In previous studies (e.g., Hatayama & Shimizu, 1993; Hatayama, Shimizu, & Ohyama, 1989) were our efforts directed towards finding pain-related factors explaining why pain thresholds with radiant heat stimulation would be often raised during a test period of repeated trials. It is a kind of reaction time method called a single-trial technique (Wertheimer, 1952) which we have paid special attention to as one major measurement taken to determine a threshold of pricking pain produced by radiant heat stimulation.

Although this technique has the advantage of making the threshold measurement possible in only one trial, one of some problems seemed that the measurement relies on a motor response resulting in a delayed reaction time or a higher threshold. The phenomenon of raised pain thresholds might be taken place by thermal imagery (Hatayama, Shimizu, &

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Ohyama, 1989) and deactivation (Yamauchi, Inase, Yoneda, Yamada, Yamamoto, & Tokunaga, 1984).

Another line of reasoning a cause of threshold temperatures raised by using the single-trial technique is based on a simple artefact or a time-lag view which points out that a longer time delay occurs inevitably between pain perception and the subsequent motor response (Croze & Duclaux, 1978). Our attempt (Hatayama & Shimizu, 1993) to validate this view suggested that estimated rises in skin temperature to occur during the time-lag or pain reaction time were too small to explain the raised threshold temperature. Pain reactions could occur to prevent us from body tissue damage when we would find very hard in some reason to maintain a normal internal body temperature with human temperature regulation system.

Much of human temperature regulation, be it homeostatic activity, or thermoregulatory behavior, usually should be made between a liminal sensation of warmth and a pain threshold at which a person reports that heat stimulation feels painful. Marks and Gonzalez (1974) indicated that the thermoregulatory behavior is guided by thermal sensations, particularly their affective components of pleasantness or unpleasantness; they suggested that the thermal sensations would be sensory experiences in which affect is involved. Our previous study showed that magnitude estimates of thermal sensations and unpleasantness might vary to some extent with the rate of temperature change generated from different rates of radiant heat stimulation of human skin (Kudoh, Hatayama, & Shimizu, 1989). For thermal sensations like liminal warm, heat, heat pain there exist specialized afferent fibers (Pertovaara & Kojo, 1985) which are not common to affect. This suggests that the two physiological mechanisms of affect and thermal sensation are more or less different from each other; hence pleasantness and unpleasantness of thermal stimuli should be described by referring to some relationship to thermal sensory dimension. To delineate a predictable relationship between them would be of vital importance to understanding the mechanism to promote activation for heat pain reaction.

A pain reaction to radiant stimulation is considered a thermoregulatory behavior connected with the unbearable heat perception that the person finds extremely unpleasant. Thus we assume that the perception of unpleasantness is an important contributing factor leading to the pain reaction; in this study a special attention was paid to an affective dimension of the thermal sensations.

METHODS

Subjects: Twenty healthy university student volunteers participated in this experiment, ranging in age from 20 to 23 years old. All of them were experimentally naive. They were assigned to two groups of 10 subjects each according to two conditions of ambient temperatures (20° and 10°); In all test sessions, they were dressed in light-weight clothes. An informed consent was obtained before the experiments.

Apparatus: The apparatus used in this experiment was a thermostimulator (Kudo-Denki NYT-9002 pain analyzer) composed of 6 thin metal elements which allowed continuous stimulation of the human skin. Every element was a heating and sensing disc of 8 mm in diameter with its area of 0.5 cm^2, which was a resistant membrane of spirally-shaped copper cord alloyed with nickel. The disc elements working as a heater and sensor were attached to six glabrous skin sites of left ventral forearm to record the temperature as well as to give thermal stimuli during the test. The order of testing these skin sites was counterbalanced over the subjects. An amount of stimulus heat was determined on a total of heat generated by the current applied for a second to the element area. The skin temperature, stimulus energy, and stimulus duration were measured through the display panel of the thermostimulator.

Procedure: Two stimulus durations of 3 and 6 sec were used under the room temperatures of 16 ± 1 and 20 ± 1℃, a lower and a normal temperature condition respectively; one condition was applied in a different test day from the other. For the 3 sec duration, the stimulus intensity consisted of 7 levels of 100, 150, 200, 250, 300, 350, and 400 mW; for the 6 sec duration, 5 levels of 100, 150, 200, 250, and 300 mW. In a test session each stimulus was presented three times at the rate of at least one every 45 sec. If the subject stated that his thermal sensation still remained on the forearm after the completion of a test trial, further 30 to 60 sec was added to the time period of the intertrial interval.

The testing room was dimly lit. Subjects were seated in a semi-reclined position of an EEG chair with armrests on which they put their left forearm with the ventral part at the top; the chair was set up in a room space separated from a set of apparatus. All of the disc elements were fixed to the forearm with thermal insulation made of styrene foam 6-mm thick in order to protect from flow of heat and movement of the air by convection currents. After a rest period of 5 min, 4 training trials were followed by 36 test measurements. We applied visual analog scales to estimate the perceived sensory and the affective intensity to transient exposures of thermal stimulation.

RESULTS

Figure 1 shows the average estimates of sensory magnitude at the exposure time of 3 sec for all subjects as a function of thermal stimulus intensity expressed in the heat capacity, mW. These were geometric means that were calculated every stimulus intensity from the sum total of medians of sensory magnitude estimates to each intensity for all subjects. According to the Stevens' power law, we transformed the original data of heat capacity and sensory magnitude into logarithm, from which transformed values the regression lines were obtained of sensory magnitude on thermal intensity. The index and correlation coefficient at the normal ambient temperature were $n = 1.88$ and $R = 0.979$, respectively; Those at the lower temperature were $n = 1.03$ and $R = 0.996$. In the stimulus intensities below 200 mW the sensory magnitude values were higher at the lower temperature than at the normal, while in the intensities above 200 mW they were higher at the normal temperature. Although there was a similar tendency to changes in sensory magnitude at the exposure time of 6 sec as well (Fig. 2), the differences between both conditions of ambient temperature became smaller ($n = 1.41$ and $R = 0.990$ at the normal temperature and $n = 1.08$ and $R = 0.879$ at the lower); This resulted from the increased sensory magnitude in the intensities below 200 mW at the normal.

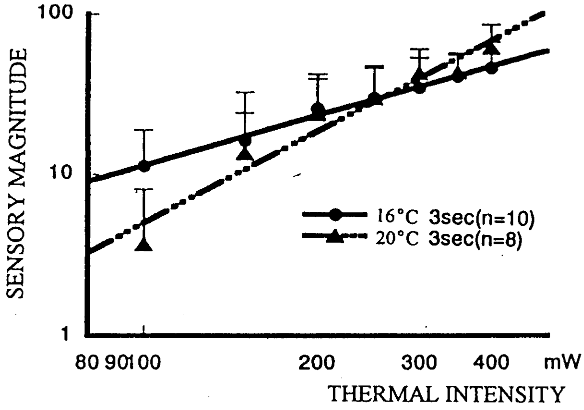

Fig. 1. Average magnitude estimates of thermal sensation. The parameter is ambient air temperature. The stimulus exposure was 3 sec in duration.

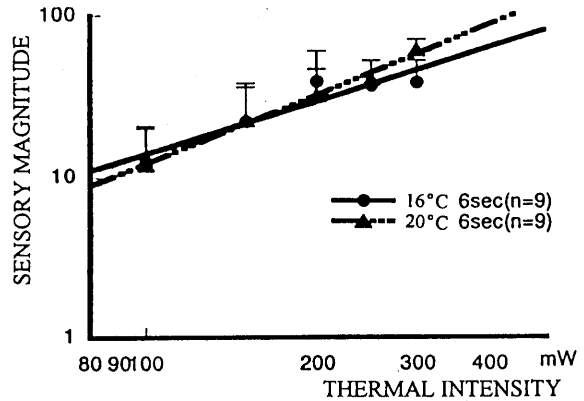

Fig. 2. Average magnitude estimates of thermal sensation. The stimulus exposure was 6 sec in duration.

The pleasantness and unpleasantness values accompanying thermal sensation were also calculated in the same way as sensory magnitudes: geometric means obtained every stimulus intensity from the sum total of medians of magnitude estimates to each intensity for all subjects. The bipolar rating scale used was constructed of the hypothesized affective dimension of pleasant-unpleasant, specified by the two opposing poles with the scale itself laid out between them: When a subject felt pleasant, he marked the point from the neutral, 0, to the right pole, +100, and marked from 0 to the left pole, -100, when feeling unpleasant. Figure 3 and Fig. 4 illustrate mean magnituede estimates of affect in response to thermal stimuli of 3 sec and of 6 sec in duration, respectively.

The lower ambient temperature led to higher pleasant values at the exposure time of 3 sec than those at 6 sec; Fig. 3 showed that as stimulus intensity increased, the pleasantness of the sensation increased to a maximum between 200 and 300 mW, and then declined to neutrality, after which the affective response changed into negative direction at the intensity, 400 mW. At the stimulus duration of 6 sec, as shown in Fig. 4, higher pleasant values were obtained under the normal ambient temperature; the change of affect to the negative direction occurred at the intensity of 300 mW.

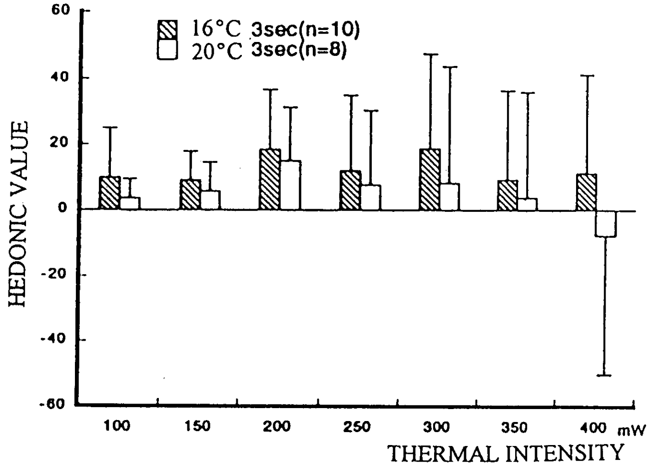

Fig. 3. Average hedonic values in response to thermal stimuli of 3 sec in duration.

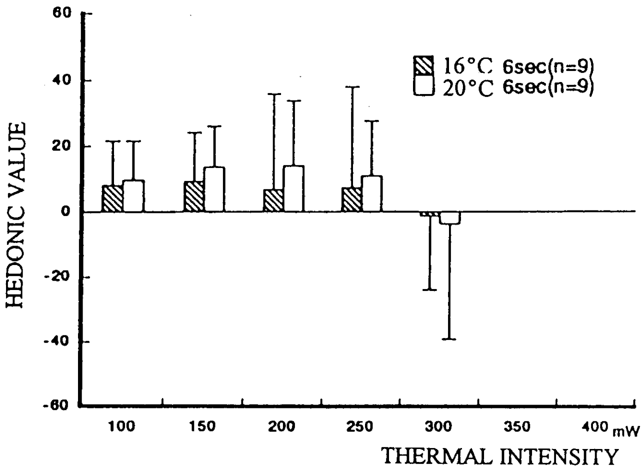

Fig. 4. Average hedonic values in response to thermal stimuli of 6 sec in duration.

Discussion

The results of sensory magnitude suggested that the lower the stimulus intensities under the lower ambient air temperature, the greater the magnitude would be, and the prolonged exposure time would reduce the effect of both ambient temperatures. Further, the exponents seemed to be determined by ambient air temperatures and stimulus duration: With lowering ambient air temperature and lengthening exposure time, the exponents may tend to decrease in value though under lower ambient temperatures they remain relatively constant regardless of the length of exposure time; This implies that the perception of thermal stimulation might be affected by temporal summation under the condition of lower ambient temperatures.

There was not a linear correspondence between sensory and affective magnitude estimates. Under the ambient air conditions in the present study, as the stimulus intensity was increased from 100 mW, the thermal stimulation became more and more pleasant, with positive hedonic value reaching a peak when the intensity was at a higher point that can be varied according to the degree of temporal summation: The longer stimulus duration would move the point to the lower level of stimulus intensity. Further increase in stimulus intensity caused a decline in positive hedonic value towards neutral base line, and then the stimulus was rated as unpleasant. Marks and Gonzalez (1974) suggested that such "perception of unpleasantness may serve to warn the organism of possible pain... ...that will result if the heat stimulus continues". Thus, the bending point in the curve from pleasantness to unpleasantness is probably proximate to the threshold of pain reaction.

The present study suggested that the positive hedonic reactions would be at least determined by the two factors of independent variables: one is the ambient air temperature and the other the exposure time. Under the lower temperature, the *S* tends to evaluate a stimulus in lower intensities as having a more positive hedonic value than that in higher; Then, it is the exposure time which would determine the extent of stimulus intensity to bring about such a positive affective reaction. In short, the temporal summation would be an important factor to have an effect on the hedonic tone.

On the other hand, our results showed that there was little difference in sensory magnitude estimates between the two ambient air temperatures. Thus, changes in hedonic values are probably produced by some different mechanism from the temporal summation making an increase in sensory magnitude. A mechanism of that kind may be closely related with that relevant to producing some thermo-regulatory reaction subsequent to a change in hedonic tone into negative affect occurring near pain reaction threshold; This implies that the thermo-regulatory reaction would be produced through the escape mechanism that is warned by a signal of negative affect, and functions to prevent an organism from tissue damage.

This study suggested that some interaction between peripheral somatosensory system and emotion-arousing system would underlie thermo-regulatory behavior that was led to the production of pain-relevant escape reaction.

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