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EFFECTS OF RATE OF TEMPERATURE CHANGE ON PAIN PERCEPTION USING A RADIANT HEAT ALGOMETER[1]

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In nine healthy subjects, radiant heat stimuli were applied with an algometer system and systematically varied with respect to 2 parameters: peak temperature and rate of temperature change. The subject's task was to rate both sensory intensity and affective magnitude on visual analogue scales (VAS) for each stimulation.

The results of this experiment showed that the mean ratings of sensory and affective VAS to the temperatures generated by the algometer yielded power functions for the three rates of temperature change in log-log coordinates. This would provide the evidence for ratio scaling properties of the VAS used in this study.

With regard to the effects of the rates of temperature change, subjects rated their pain greater for the slower rate of stimulation than for the faster one despite of the fact that the peak temperature was the same in every rate of stimulation: that is, this indicates that pain perception evoked by the stimulator used in this experiment does not depend only on the temperature. Besides, the mean rating values were linearly related to the total energy the stimulator presented. Then, pain perception is probably determined by the total energy rather than the varied rate of stimulation.

Key words: human experimental pain, radiant heat, rate of temperature change, visual analogue scale.

INTRODUCTION

The measurement of human pain has been attempted by many researchers, but satisfactory quantification has not yet been entirely achieved, as Wolff (1978) has pointed out. The pricking pain threshold has been measured systematically in experimentally induced pain since Hardy, Wolff, and Goodell (1952). But, as Neisser (1959) has pointed out, it is of little value to measure the pain thresholds in untrained subjects, especially in the case of clinical situations. For the researchers who are concerned with the measurement of experimentally induced pain, it is necessary to

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establish the psychophysical relationship between psychological or sensory quantities and physical or stimulus ones. Thus, it is important to find out the measures with the direct scaling methods rather than with the indirect scaling methods such as the pain threshold.

Recently, Price and his colleagues (Price, McGrath, Rafii, and Buckingham 1983 ; Price, Harkins, and Baker 1987 ; Harkins, Price, and Martelli 1986) have attempted to quantify human pain experiences in the laboratory research by using visual analogue scales (VAS). In addition to its simplicity of the procedure, Price et al. (1983) have pointed out that VAS has the following advantages : 1) VAS as the spatial matching paradigm can facilitate attention allocation in untrained subjects. 2) By changing the verbal descriptors on the anchor points of VAS, multiple dimensions of pain can be measured. 3) The psychometric functions derived from VAS construct ratio scales. One of our purposes in this experiment is to examine the validity of VAS as an instrument for assessing experimentally induced pain. Measurements of pain in terms of the stimulus parameters (intensity level, exposure time, stimulus size, etc.) have been taken mainly for the pricking pain threshold since Hardy et al. (1952). From the earlier studies, it has been established that threshold pain is elicited by raising the skin temperature to about 45°C, independently of those variables mentioned above. In neurophysiological studies of pain, it was found that the polymodal nociceptors in the monkey began to fire when the skin temperature was risen to 45°C and above (Croze et al., 1976). These results were obtained by an ascending method of limits which presented heat stimuli of stepwise greater intensity until the pain threshold was reached. In the time method (e.g. Hatayama et al., 1989), however, where reaction time is measured for the pain threshold, the temperature to be reached at was not always 45°C for stimuli of the different rates of temperature change. Croze & Duclaux (1978) found that the faster rate of stimulation resulted in the elevated values in the skin-surface temperatures corresponding to the pain threshold and the pain tolerance. On the basis of the idea that the pain threshold was fixed, they interpreted the temperature rise as an artefact caused by the time lag between the pain sensation and the subject's motor response. The pain reaction time hypothesis was supported by Severin et al. (1985). However, even if the time lag is corrected, pain threshold temperatures for the different rates of temperature change cannot be equal in fact.

In this experiment, it is assumed that pain sensation does not depend only on the instantaneous temperature of the skin. If pain sensation depends on the skin temperature, the same temperature, despite the different rates of temperature change, will produce the same sensation magnitude. Then, this experiment attempts to examine the effects of the rates of temperature change on pain perception, using VAS procedures.

METHODS

Subjects : Five male and four female healthy undergraduate subjects, ranging in age from 18 to 21 years old, participated in this experiment as paid volunteers. None of them had previously served as *S*s in other psychophysical experiments. Prior to the experiment they were informed that heat stimuli were applied to their skin and that they were free to withdraw from the experiment. All subjects gave us their consent.

Apparatus and stimuli : The presentations of radiant heat stimuli were accomplished by a radiant heat algometer (NYT-55) improved by Nakahama and Yamamoto (1979). This system consisted of two parts : an exposure unit and a control unit.

The stimuli were presented to five spots, on which blackened sticky tapes, 1.9 cm in diam., and thermo-sensors were glued, on the dorsal surface of the left forearm. The initial skin temperature at the thermode-skin interface was 33-34°C, when the stimulus was presented through a radiation window, 8.0 mm in diam., of the exposure unit.

Three intensities of the radiant energy were used : 200, 250 and 300 mcal/sec/cm^2. For each of three intensities, their peak temperatures were at one of 4 temperatures 42, 45, 47 and 49°C. The interstimulus interval was at least 1 min, so that there was a 5 min interval between stimuli applied to the same spot to prevent both suppression and sensitization to painful stimuli and to protect body tissues from injury.

To monitor some temperature change the output amplified through a thermo-amplifier was digitized on-line at 10 msec/point, synchronizing with the onset of the shutter. A microcomputer, NEC PC-9801VM, was used for the control of these equipments.

Procedure : The experiment was performed in an electrically shielded and sound attenuated room. Entering the room, the subject was directed to be seated beside the apparatus, his left arm resting comfortably on a chair. The stimulus side was occluded from the subject's view by a screen.

The experimental procedure was similar to that of Price et al. (1983) with a few exceptions. Visual analogue scales (VAS) were used to assess sensation intensity and unpleasantness evoked by radiant heat. The VAS consisted of 150 mm lines whose endpoints were labeled in Japanese : "no sensation" and "the most intense sensation intolerable any longer" for the sensory dimension and "not bad at all" and "the most unpleasant feeling intolerable any longer" for the affective dimension. In order to clarify the distinction between the sensory and affective dimensions, the same instructions as Price et al. (1983) or Harkins et al. (1986) were used.

The subject was required to mark the sign on the lines, for the two aspects of experimental pain independently, in proportion to the relative perceived intensity. These scales were described on a GRAPHTEC 4030 digitizer in front of the subject and the rating scores were put into the computer.

Experimental design : Each session of the experiment, which consisted of 30 trials (6 practice and 24 test trials), was carried out over 2 days. The first day was served as practice for each subject. The presentation order in which the 24 combinations of intensities (3), temperatures (4) and repetitions (2) were presented was quasi-random. A session lasted about 1 hour.

RESULTS

Skin temperature changes : The pain meter used in this experiment can supply the constant radiant heat energy. However, a temperature rise of skin was not

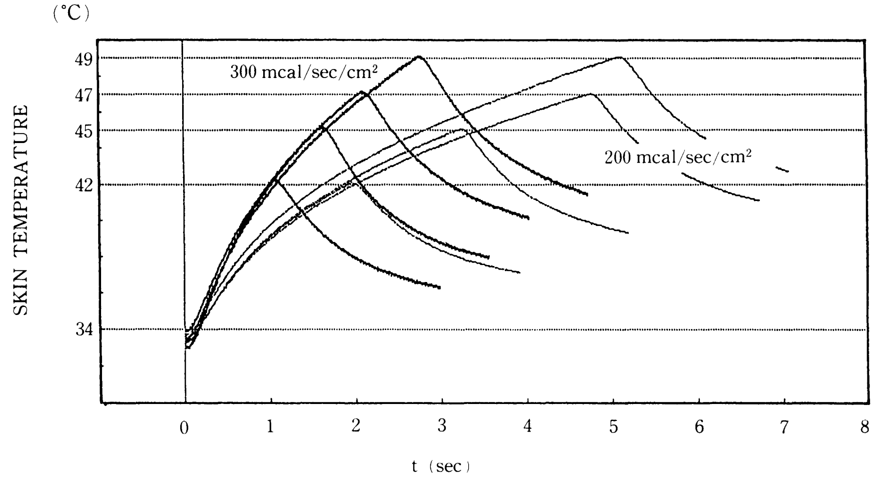

Fig. 1. An example of temperature changes at the thermode-skin interface (for T.S.). Three different intensities were used : 200, 250 and 300 mcal/sec/cm². But the data for 250 were omitted for simplification. Analogue to digital conversion was started on synchronizing with the open of the shutter and continued for 2 sec after the shutter was closed.

Table 1. Mean exposure times and rates of temperature change for each of three intensities.

peak temperature	200 mcal/sec/cm²		250 mcal/sec/cm²		300 mcal/sec/cm²	
	duration (sec)	temperature change (°C/sec)	duration (sec)	temperature change (°C/sec)	duration (sec)	temperature change (°C/sec)
42°C	1.67 (0.27)	5.21 (0.76)	1.07 (0.14)	7.72 (0.75)	0.89 (0.12)	9.69 (1.19)
45°C	2.57 (0.46)	4.44 (0.65)	1.83 (0.18)	6.12 (0.43)	1.30 (0.14)	8.69 (0.82)
47°C	3.89 (0.54)	3.48 (0.39)	2.31 (0.35)	5.71 (0.76)	1.69 (0.24)	7.79 (1.08)
49°C	4.81 (0.47)	3.11 (0.26)	3.32 (0.38)	4.71 (0.45)	2.21 (0.29)	6.95 (0.82)

Note- Values in parentheses represent standard deviations.

linearly related to the constant energy for the thermal properties of tissue (Lipkin & Hardy, 1954). Figure 1 shows a sample of the temperture curves recorded in the experiment. The skin temperature above the initial temperature convexly rose continuously. Table 1 shows the mean exposure times and the rates of temperature change up to reaching one of the four peak temperatures. As shown in Fig. 1, the rate of temperature change for each stimulus intensity changed according to its peak temperature. But, it was observed that there was little difference in their patterns of the temperature rise when the same stimulus intensity was provided. Thus, it appears to be adequate to describe the rate of temperature change (°C/sec) as an independent variable.

VAS measures : Fig. 2 shows the mean relative magnitudes derived from VAS scores as a function of peak temperature. As shown in Fig. 2, both the rating values of sensation intensity and affective magnitude were increased with increased peak temperatures. For each of the two dimensions, an analysis of variance with repeated measures design was performed on the rating scores, the factors being stimulus intensity, peak temperature and subject. For the sensory intensity, main effects of stimulus intensity and peak temperature were statistically significant ($F(2,\ 16)=13.02$, $p<0.01$; $F(3,\ 24)=62.07$, $p<0.01$, respectively). For the affective magnitude, main effects of stimulus intensity and peak temperature and interaction effect, stimulus intensity by peak temperature, were also highly significant ($F(2,\ 16)=19.18$, $p<0.01$; $F(3,\ 24)=110.15$, $p<0.01$; $F(6,\ 48)=4.01$, $p<0.01$, respectively). These results indicate that pain responses as evoked by radiant heat can not only be determined by the temperature, but also influenced by the rate of temperature change.

VAS measures as ratio scales : In Fig. 3, the log relative magnitudes for sensation

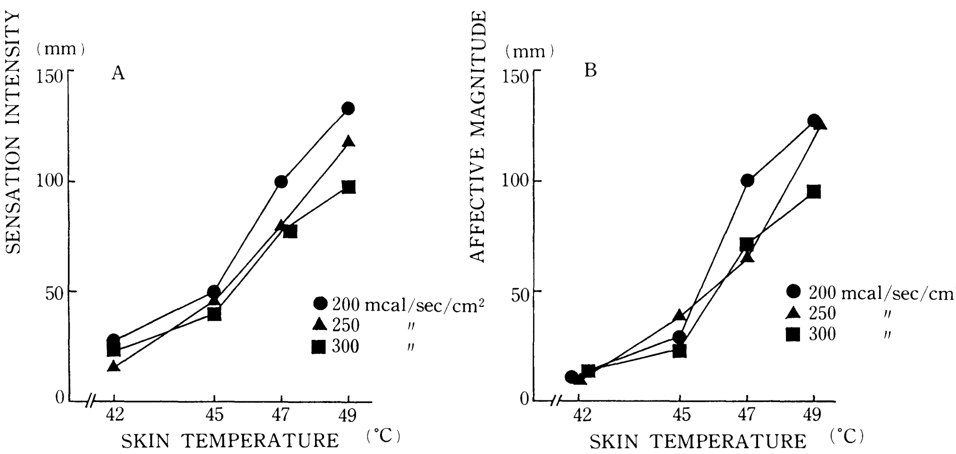

Fig. 2. Mean relative magnitude derived from VAS of the sensation intensity (A) and the affective magnitude (B) were plotted as a function of intensity and peak temperature. Each point is based on 18 observations (9 subjects × 2 repetitions).

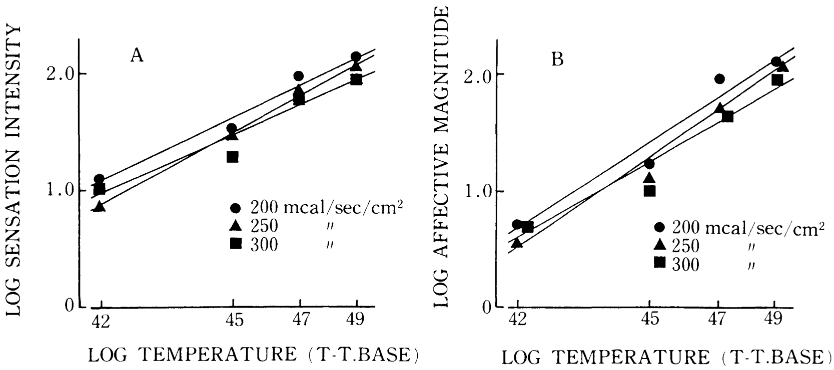

Fig. 3. Log mean magnitude for the sensation intensity (A) and the affective magnitude (B) as a function of intensity and log peak temperature minus baseline temperature. Straight lines represent the best fitting functions determined by the method of least squares.

intensity (Fig. 3A) and affective magnitude (Fig. 3B) were plotted as a function of log peak temperature minus baseline temperature (T-33.9). The mean exponents for the three intensities determined by the method of least squares were 3.9 for sensation intensity and 5.2 for affective magnitude. The correlation coefficients in log-log coordinates were above 0.96 for both dimensions. The functions may be shown as straight lines.

VAS measures as a function of total energy : When the final peak temperature was described as an independent variable, the subjective sensation tended to decrease with increasing the rate of temperature change. However, it was not appropriate to describe the peak temperarure alone as an independent variable because the temporal

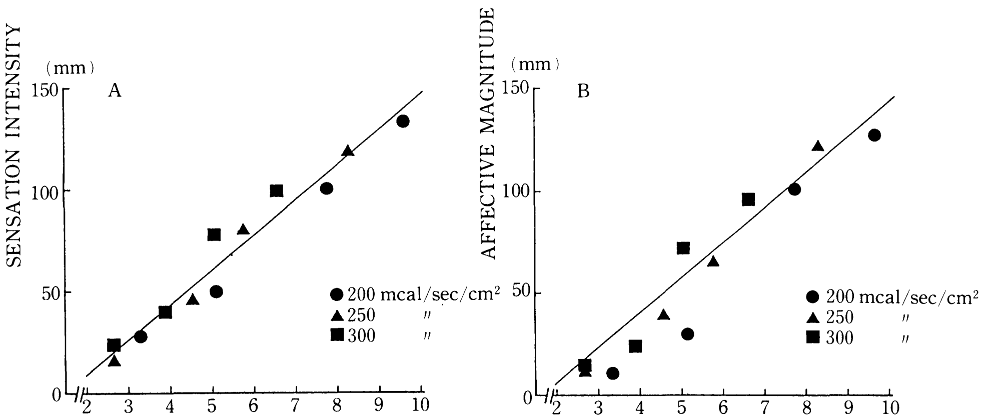

Fig. 4. Mean magnitude for the sensation intensity (A) and the affective magnitude (B) as a function of total energy. Mean magnitudes (Y) for the two dimensions are linearly related to the total energy (X). The equations of the regression lines are: (A) $Y=0.17 \cdot X-25.4$ ($r=0.97$) and (B) $Y=0.18 \cdot X-43.7$ ($r=0.96$).

components accompanied with the stimulus presentation were neglected. Therefore, the mean rating values for the two dimensions were replotted against the total energy the stimulator radiated (stimulus intensity × exposure time), based on the exposure times in Table 1 (see Fig. 4). The correlations between total enery and rating score were 0.97 (Fig. 4A) and 0.96 (Fig. 4B). The linearity might indicate that the effects of the rate of stimulation could be kept at a minimum as the rating scores were expressed as a function of total energy.

Discussion

In general, the subjective magnitude of thermal sensation against the temperature between the initial skin temperature (so-called physiological zero) and the temperature of the stimulus grows the power function (Stevens & Stevens, 1960). In pain perception, it has been known that the power law holds true in the perception of electrocutaneous stimulation (Stevens et al., 1958) and of radiant heat stimulation (Price et al., 1983 ; Harkins et al., 1986). As shown in the results of this experiment, ratio scales were constructed for both sensation intensity and affective magnitude against the distance from the physiological zero. This means that the estimates to radiant heat stimuli derived from VAS are valid and reliable. The tendency that the exponent of the power function for the sensation intensity was smaller than that for the affective magnitude is consistent with earlier findings. This result seems to assure the validity of the data and also imply that the affective estimation to the painful stimulus was crucial for life. The values of the exponent in this study were higher those in earlier studies, which would reflect the differences between the cultural backgrounds.

Suppose the rates of stimulation as dichotomy, it could be concluded that the estimates for the faster rate (300 mcal/sec/cm^2) were smaller than those for the slower one (200 mcal/sec/cm^2). This result coincides with the finding that faster stimulation rates resulted in elevated pain threshold (Croze & Duclaux, 1978 ; Severin et al., 1985). However, the subjects rated both two dimensions higher for the slower rate of stimulation than for the faster one, in spite of the same temperature. Thus, the differences in temperature corresponding to the pain threshold and intolerance, among the different rates of temperature change, may not depend on only an artefact due to the time lag between the sensations and the motor responses to pain. Unless this assumption is correct, sensation magnitude at the same temperature should be equal regardless of rate of temperature change. The fact that sensation magnitude was greater with decreasing the rate of temperature indicates that pain perception does not depend solely on the temperature.

As shown in Fig. 4, when the mean rating values were plotted against the total energy the stimulator presented, the effects of the rate of stimulation were diminished. The linearity of the functions in Fig. 4 may show that pain perception depends on the total energy including the intensive and temporal aspects of the stimulus. This experiment did not deal with the pain threshold directly, but further research will be necessary to examine whether the discussions mentioned above holds true to the pain threshold.

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