EFFECTS OF THERMAL IMAGERY ON EXPERIMENTAL PAIN USING A CONSTANT RADIANT HEAT

HATAYAMA, Toshiteru
Department of Psychology, Tohoku University
Kawauchi, Sendai 980, Japan

SHIMIZU, Kayoko
College of Medical Sciences
Seiryocho, Sendai 980, Japan

&

OHYAMA, Masahiro
Department of Psychology, Tohoku Gakuin University
Ichinazaka, Sendai 981-31, Japan

The relationship between thermal imagery and thresholds of a pain response was explored by recording reaction time as a measure of the pain threshold, as well as digital pulse volume and heartbeats, on twenty female undergraduates. While a pain stimulus was being presented, subjects in the experimental group were asked to form the same image in their mind as the sensation produced by one of four image cues given beforehand. Two of the image cues were compatible with the stimulus, i.e., radiant heat, and the others incompatible. The present study showed that, as the cues were changed from "hot" to "ice-cold", the thresholds were gradually elevated. Besides, the enhancement of the threshold was found even in the post-test block. The data obtained on finger pulse volume, however, differed from those on the thresholds, that the imagination in the test block had no effect on the pulse volume in the post-test period. It is suggested that the incompatible images play a part to decrease pain sensitivity, and that the enhanced threshold is probably related to the thermal imagery per se rather than to the peripheral skin temperature inferred from the vasomotor measure.

Key words: pain, experimental human pain, thermal imagery, radiant heat.

1) The authors would like to express great appreciation to Prof. M. Yamamoto of the Faculty of Engineering, Tohoku University, for his valuable advice. This study was supported in part by a Grant-in-Aid for Scientific Research (No.02870063) to Emeritus Prof. H. Nakahama of the School of Medicine, Tohoku University.

Received March 23, 1989; accepted June 27, 1989
The present study was aimed at examining the effect of thermal imagery, produced by image cues, on experimental pain responses and, more specifically, at clarifying which of these cues would be effective in delaying a pain response, or would have an analgesic effect.

As Price (1988) indicates, current views on pain have refuted the basic tenet of the specificity theory that there is a linear relationship between intensity of the pain sensation and the extent of injury. This suggests that some factors other than sensory input relevant to pain, especially psychological ones, exert powerful influences upon pain sensation and behavior: motivational and cognitive processes play an important role in pain experiences. This viewpoint has provoked many researchers to devise effective psychological techniques to alleviate clinical pain as well as experimentally induced pain. Among them, cognitive methods have lately attracted considerable attention. These are intended to directly act on thought processes to relieve pain (Tan, 1982). In these approaches, the emphasis is on an underlying notion that a person's experiences related to emotion are primarily modified by his appraisals of the situation concerned. Utilizing some coping skill to produce attention distraction or imagery is thus expected to help some pain patients relieve their pain. In fact, some studies (e.g., Chaves & Barber, 1974; Beers & Karoly, 1979) indicated that some sort of "cognitive strategy" can exert control over a given pain if the subject is required to execute such a strategy.

The use of some imagery strategies has an important meaning for cognitive control methods. One of the experimental procedures often adopted to prove its effectiveness essentially relies on verbal instructions given by the experimenter to cause the subjects to have some mental image. Unfortunately, these are often susceptible to intentional or unintentional distortion and inaccuracy, and result in large individual differences in the extent of vividness of and in the duration of imagery while the subjects use an instructed strategy, as suggested by Spanos, Horton, & Chaves (1975). Considering the methodological difficulties so far, a plan was devised which seemed to strengthen vividness by means of giving the subject an image cue just before presenting a pain stimulus at every experimental trial.

In this study, radiant heat was used as a pain-producing stimulus. In this connection, the image cues were given by thermal stimuli: these consisted of four, ranging from hot to cold, two of which were compatible with the pain stimulus because of the cues with higher temperatures roughly akin to the stimulus. The others were incompatible. If an incompatible stimulus presented to the subject at the same time as the radiant heat can exert some analgesic effect upon pain responses, differing from the compatible expected to act synergistically, this will suggest that the thermal image formed in the mind by the incompatible cue may also have an effect in the same way as the actual thermal stimulus: in this case, the imagery probably serves to elevate a pain threshold.

The task demanded of a subject in the present experiment was to release a response key, which she was required to push just before the beginning of each trial, as quickly as possible when she first felt some pain after the presentation of the radiant heat. Thus, a feature of this task was that the subject assumed a behavioral control over pain experiences, which would cause her to be capable of escaping from the discomfort. In addition, the subjects of the experimental group were distinguished from those of the control in that the experimental group could assume a cognitive control by using an imagery strategy besides the behavioral control.

Method

Subjects

Twenty-six female student volunteers participated in this experiment. Six of the 26 were excluded from the study because they were 1.0 s or over in the standard deviations of pain reaction times at pre-test. The results refer to the remaining 20 subjects (mean age 19.8 yrs.) who were experimentally naive. None of them were regularly on medicines or reported any history of cardiovascular disorders.

They were divided into two groups of 10 subjects each according to a randomized schedule: an experimental group using a
thermal imagery strategy, and a control group not to be given any image cue. All subjects were paid for their participation.

Apparatus

The subject was tested individually in a comfortable armchair in an electrically shielded room. All apparatuses were installed outside the space (2.0 by 3.0 meters) for a subject, whose space was provided by dividing the room with a curtain. The presentations of pain stimulus were accomplished by a radiant heat algometer (NYT-55), based on the Hardy-Wolff-Goodell model improved by Nakahama and Yamamoto (1979). In addition to measuring the pain response, physiological recordings of two autonomic indexes, digital pulse volume and heartbeat, were made by a Fukuda model FD-31P cardiograph: a DC input of this was connected to a Fukuda PT-300 photoplethysmograph with a time constant of 2.0 s, containing a light-emitting element and a CdSE.

Procedure

Immediately upon entering the room, the subject was directed to be seated and to put on goggles with translucent plastic inserted in them for the purpose of helping her strengthen her concentration on radiation from the algometer. Then, round black stickers, 1.9 cm in diam, to ensure the absorption of radiant heat were attached to six stimulus spots in her right dorsal forearm. These spots were paired in two longitudinal rows distal to the site of the elbow joint at intervals of about 5 cm. The distance from the elbow to a pair of the spots proximal to the elbow joint was about 7 cm and the distance between the two pairs was about 5 cm. Setting up the spots in this way enabled us to avoid the delivery of the radiant heat in succession to an identical stimulus spot. The stimulus intensity was a constant 200 mcal/\text{s}/cm$^2$ heat, which was presented through a round radiation window of the pain meter, following the preheating sequence predetermined by Nakahama and Yamamoto (1979).

A photoplethysmograph was clipped to the third phalanx of right index finger to detect finger pulse volume (PV). The ECG skin electrodes were placed on the right arm and the left leg to make the ECG recording using standard lead II.

The experimental session consisted of the following blocks preceded by four warm-up trials which were omitted from analysis.

Pre-test. After the preparations for data recordings were completed, the subject was instructed to press the microswitch key for response with her left index finger when the start of a trial was signalled, and to release the key as quickly as she began to feel pain. The time delay from the heat presentation to turning the key off was measured at every trial through the timer unit of the algometer and served as the measure of pain threshold. Such a method of measurement is called the “Time Method” here. During this block, the subject was given 5 trials with at least 70 s of the intertrial interval.

Test. After completing the pre-test, an experimental treatment of 20 trials consisting of 4 imagery manipulations was administered to the subject of the experimental group. This block was different from the pre-test only in that she was given one of 4 image cues just before the beginning of each trial. The subject was then asked to form the same image in her mind as the sensation produced by the cue. An icy bag filled with ice (I), and a cool breeze (C), warm air (W) and a hot wind (H) blown up to the left forearm from the nozzle of a hairdrier were used as the cue stimuli, adjusted to a temperature of approximately 0, 25, 45 and 65 degrees centigrade respectively. These cues were presented for about 10 s to the dorsal surface of the forearm in random order, and any cue was designed to be used 5 times in the end throughout this experimental block.

Post-test. This block was the same as the pre-test. The subject was simply asked to turn the response key off as soon as she felt pain.

The image cues in the test block were given only to the experimental group. Thus the procedure for the control group was identical to that for the pre-test throughout the three blocks. The interblock interval was approximately 3 min, and the total duration of this experiment was on the order of 70 min or less.

The design was a 2 by 4 split-plot factorial, with Image (presence vs. absence) as the randomized factor and Cue (ICE-COLD, COOL, WARM and HOT) as the repeated measure-
The data of pain thresholds for statistical testing were those of averages calculated for each subject in the pre- and post-test, and in each cue condition during the test block. The plethysmographic finger PV was hand scored with vernier callipers in terms of systolic pulse magnitude in mm. This was then converted to the value of mV/V, which is that of pulse volume per unit blood flow quantity 1V. In this way, these 14 successive points were sampled from 3 s before the radiant heat presentation. On the basis of the data obtained, the PV measure was computed as follows: First, the mean of 3 PV values just before the radiation was found in order to utilize it for the baseline of a trial. Second, a minimal PV value after the heat stimulus onset was detected and a response value was obtained through averaging this value and the nearest 2 values before and after it, and then the response magnitude per trial was calculated by subtracting this response value from the baseline concerned. The averages worked out in each block for every subject were used as raw data for statistical testing. All test trial and post-test trial levels were expressed as a percentage of the mean pre-test level.

Results
Pain Reaction Times
The average RTs representing pain thresholds for each of the compatible and the incompatible images were calculated at the test block as well as at the pre- and post-test for every subject. The data of the control group without imagery manipulations were the averages of trial data corresponding to the test trials by means of different image cues.

The mean RTs and standard deviations (in parentheses) for each condition of experimental treatments were 5.8(1.5), 5.1(1.9), 4.9(1.5) and 4.5(1.7)s for the image-I, -C, -W and -H, while those for the control group were 5.0(0.9), 4.8(0.5), 4.9(0.8) and 4.8(1.0) respectively. No statistically significant difference was found among variances in these conditions.

An analysis of covariance, computed upon the pain thresholds, revealed significant effects for groups when the pre-test was covaried ($F(1/17) = 5.72, p<0.05$), conditions of image ($F(3/54) = 14.14, p<0.01$), and the Groups × Conditions interaction ($F(3/54) = 7.67, p<0.01$). Newman-Keuls procedure for multiple comparisons indicated that the significant differences among image conditions at the $p<0.05$ level or below were seen solely in the experimental group, not in the control. The mean pain threshold for the incompatible image-I was significantly higher than the thresholds for the compatible image-W and -H as well as that for the pre-test. The mean value for the post-test was significantly higher than that for the image-H and for the pre-test.

Fig. 1 presents the mean percent RT in each of the 4 image conditions and in pre- and post-test blocks for both groups of subjects. This figure suggests that different images to some extent may exert some influence on pain sensation, so as to bring about different RTs, and that this manipulation can also have an effect on the RTs of the post-test. In fact, the pre-post difference was highly significant in the experimental group ($t = 4.22, df = 9, p<0.01$).

Separate trend analysis was then conducted on each of both groups to further examine the data plotted. For the experimental group with imagery manipulation, a quadratic component was recognized to be significant ($F(1/45) = 5.07, p<0.05$), whereas the data in the control group showed no significant trend. This
confirmed that the image cue with the lower temperature condition would increase the pain threshold and at the same time, such an effect of manipulation would be carried over into the post-test block.

These results suggest that imagery manipulations taken in the experimental group probably play an important role in threshold variations relevant to pain sensation. Then, an effect of such a manipulation appears to be heightened in the cue stimuli discriminable easily from the subject’s skin temperature, especially in the image-I.

Here an issue to be clarified is whether this increment in the pain threshold is not simply related with an adaptation effect due to repetitive stimulation of the specific skin spots, but really closely related with the image control. If such an adaptation is the case for the increment in threshold at the post-test, the adaptation for the radiant heat stimulation is expected to take place gradually with continued trials of the test block. This was examined by means of the following: the pain RT data of the control group, and the finger PV data described later.

The data in the control group were rearanged in order of trials, and the extent to which the pain thresholds simply varied as a function of the number of trials was reexamined. The measurements were divided into six blocks with five trials as a block. Here, the first block and the sixth were the pre- and post-test respectively. The mean RTs and SDs (in parentheses) from the first to the sixth, in order, were 4.7 (1.0), 4.8 (0.9), 4.9 (0.9), 4.9 (0.8), 4.9 (0.8) and 4.8 (0.9) s. The result for a one-factor ANOVA with repeated measurements showed no significant difference among these averages. It was therefore found that without any imagery manipulation the threshold variations were smaller, and that there was no significant effect of stimulus repetition.

**Finger Pulse Volume**

Each group consisted of nine subjects for which the plethysmographic data could be utilized without any trouble on scoring.

Fig. 2 illustrates the mean PV scores, i.e., response magnitude, in each of the image conditions for subjects of both groups. The PV data showed that in the experimental group the scores tended to be gradually raised as the image cues were changed from the ice-cold to the hot, whereas there was no consistent tendency to vary in the response magnitude of the control group. The two-way ANOVA with repeated measures indicated that though the difference in the magnitude scores between both groups was not statistically significant, there were a significant main effect of Images and also a significant Groups (2) × Images (4) interaction (Images : $F(3/48) = 5.54, p<0.01$; Groups × Images : $F(3/48) = 2.95, p<0.05$).

The feature of the imagery manipulation was further tested by examining whether these changes of the response magnitude had any effect on the PVs even after completion of experimental treatments. As shown in Fig. 3,

![Image 1](image1.png)

![Image 2](image2.png)

**Fig. 2** Response magnitude changes of the four image cues. Response magnitude was the difference score in PVs (see text).

**Fig. 3** Pre-post differences in response magnitude.
neither group was different from the other between the pre- and the post-test.

**Discussion**

The data obtained from the test block required to hold one of the thermal images showed that the image-I and the image-C which were thought of as incompatible with the effect of radiant heat stimulation both lowered the experimentally induced pain sensation, whereas the compatible images, image-H and -W, little affected it.

The effects of these two kinds of imagery strategies appear to be impressive in the incompatible images. Although the image-H and -I, which were elicited by the greater intensities of cue stimuli within the same sort of imagery strategy, produced somewhat larger effects on pain thresholds than their counterparts, the image-W and -C respectively, the differences were not significant between the image cues which let the subject adopt the same sort of strategy. It was revealed, after all, that the pain threshold tended to be decreased correspondingly as the image cues were changed from the incompatible to the compatible.

Another finding was that the mean pain threshold in the post-test were significantly higher than those in the pre-test. This possibly presents a question about whether increased RTs at the post-test were actually brought about by a psychological intervention with an imagery strategy during the test block or resulted from sensory adaptation as a function of the number of cue stimulus presentations.

In this respect, the present study suggested that the RT increment at the post-test which was found in the experimental group, was probably not attributed to sensory adaptation, since the data for the control showed no consistent changes in the RTs during the test. In addition, the data for response magnitudes of PV also supported this view indirectly. That is, out of image conditions the response magnitudes were the smallest in the image-I, and as the temperature of cue stimuli were raised, these magnitude values tended to be increased too. This magnitude variation thus appears to be just the opposite of the results of pain thresholds. This may cause us to make an inference that the imagery procedure applied just before a trial probably exert some influence on the skin temperature of the forearm stimulated. But on the other hand, the post-test data in the experimental group showed that there was a difference between the two measures of pain RT and PV: The response magnitude of PV declined towards the level of control group at the post-test, while the pain threshold was increased at the post-test where the imagery procedure was not available. From the PV data it is inferred that the peripheral skin temperature in the experimental group, whose temperature might be raised by the imagery procedure, would have dropped down at the post-test. Thus, it is probably reasonable to consider that the variation in pain threshold seen in the experimental group mainly resulted from the psychological intervention through the cognitive control strategy, and not from changes in the skin temperature.

Tan (1982) pointed out that no definitive statement supporting the consistent efficacy of a cognitive intervention, in other words, the insistence that the use of imagery strategies is more effective for pain control than that of procedures in which no obvious imagery is employed, can be made yet. In the present study too, all of the image cues were not always effective in increasing pain thresholds. The results of the present study indicated that it was probably the incompatible image cues which had worked best for the increment in the pain threshold at the post-test. On the contrary, the imagery manipulation did not take part in lowering the threshold even when a compatible cue was used. This suggests that such a manipulation itself has another effect on pain sensation: the effect of taking the subject’s attention away from the heat stimulation, and thus the attention distraction prevented the threshold from decreasing lower than the level of the control group. That is, it might be assumed that imagery manipulations with any image cue have only an "inhibitory" effect on pain sensation, because there is a possibility that they cause the subject’s attention to be distracted from the heat stimulation in addition to a "net" effect of them. Thus, one of the
problems to be considered in future experiments is to clarify to what extent the attention distraction accompanying the imagery manipulation can have to do with an increase in the threshold.

Thus far, as seen in Melzack and Wall's (1982) statement that cognitive methods involved with distraction of attention is effective only if the pain is steady or rises slowly in intensity, it appears to have been the explicitly held view that the pain sensations produced by radiant heat are able to be little modified by cognitive methods. However, the present study suggests that there is a possibility that some sort of imagery technique is able to control the pain in the sense of increasing the threshold of pain reaction. We supports the view of Wolff and Goodell (1943) that cognitive factors may modify the pain threshold and the manner of reaction to pain produced by radiant heat.

Finally, one thing to keep in mind is the methodological issue coming out of a notable feature of the "Time Method" used in this experiment; i.e., the subjects had their behavioral control of escaping from the loaded radiant heat by releasing the response key. Recent researches on behavioral control have often pointed out that subjects capable of using such a control report less anxiety or fear as they anticipate receiving shock (Bowers, 1968; Szpiler & Epstein, 1976), loud noise (Gatchel & Proctor, 1976), or the administration of some kind of intelligence test (Stotland & Blumenthal, 1964); thus, these researches suggest that the subjects who believe they have some behavioral control will show reduced arousal compared with those not allowed to have it. If this is the case, a psychological mechanism involved in cognitive coping strategies seems to play an important role in determining autonomic responses. More information is needed on a detailed elucidation of the specific cognitive processes that may mediate pain-related autonomic responses.

References