Effects of attention on the intensity and unpleasantness of thermal pain

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Summary Both experimental and clinical studies have shown that psychological manipulations, such as hypnosis, behavioral modification and cognitive-behavioral therapy, can reduce reports of pain. Although these are complex procedures, one important variable common to each is direction of attention. We have previously demonstrated in both humans and monkeys a method for monitoring and manipulating attention toward or away from a painful stimulus and have shown that changes in the direction of attention alter the ability to discriminate noxious heat stimuli. The present study assessed whether these changes in discrimination were accompanied by changes in the perception of pain intensity and/or unpleasantness. These data confirm that both the speed and accuracy of detecting changes in noxious heat stimuli are decreased when the subject attends to another stimulus modality. In addition, they show that direction of attention affects the perceived intensity and unpleasantness of painful stimuli in a similar manner. Our previous findings of attention-related modulation of nociceptive neuronal activity in the medullary dorsal horn suggest that these attention-dependent changes in sensory-discriminative and affective components of pain are mediated at early stages of sensory processing.

Key words: Attention; Pain; Sensory intensity; Affect; Discrimination

Introduction

Many studies have shown that psychological manipulations, such as hypnosis, behavioral modification, relaxation training, biofeedback, operant conditioning and cognitive-behavioral therapy, can change the manner in which an experimental subject reports the occurrence of a painful stimulus [2,3,9,13,15–17,25]. Unfortunately, the mechanisms underlying these procedures have been difficult to establish.

One simple variable that is common to most of these psychological procedures is selective attention. Experimental studies designed to specifically manipulate attention show that subjects rate pain lower when they direct their attention away from the painful stimulus [1,18,20,30]. Similarly, patients rate postsurgical pain as more intense when they are required to attend to the pain more frequently [19]. Nevertheless, since threshold, tolerance or global pain ratings are usually used to assess changes in pain, it is not known what aspect of the pain experience is altered by these psychological manipulations. Since pain is now thought to involve both sensory-discriminative and affective-motivational components [21,22,26], it is important to know whether psychological manipulations, such as direction of attention, are altering the perceived intensity of a noxious stimulus or the emotional reaction to receiving such a stimulus.

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Using a psychophysical paradigm based on procedures established in visual research [23], we recently demonstrated a method for monitoring and manipulating attention toward or away from a painful thermal stimulus. Using this method, we have shown that a subject’s ability to discriminate the intensity of painful stimuli is altered by the direction of attention [5]. The goal of the present study is to assess whether these changes in nociceptive discrimination are accompanied by changes in the perceived intensity and/or unpleasantness of pain. A knowledge of which aspects of pain perception are altered by changes in attention could both give us a better understanding of the underlying neural pathways involved in non-pharmacologic analgesic manipulations and help us determine which types of pain problems would be most amenable to such treatments.

Material and methods

Subjects

Four females and 3 males, between 20 and 25 years of age, were paid to participate in this psychophysical experiment. Although the temperatures used in the experiment were within a range that does not damage the skin, subjects were informed that they were free to stop the experiment at any time. They were also given written and verbal explanations of the experimental procedures. Finally, each signed a consent form acknowledging that the experimental procedure and the nature of the noxious stimulus had been explained adequately and affirming his right to withdraw, without prejudice, from the experiment at any time.

Basic task

Subjects were seated in front of a computer screen on top of which was fixed a light stimulus. A 1-cm diameter contact thermode with a base temperature of 37°C was placed on the left side of the subject’s face, just above the upper lip. The thermode was retracted between each trial, and ambient light in the room was kept constant.

Fig. 1 shows a graphic depiction of the discrimination task. The instruction ‘START’ was presented on the computer screen to indicate to the subject that he could begin a trial by pressing the ‘RETURN’ button of the keyboard placed at his right (see bottom left of Fig. 1). Upon initiating a trial, the light above the terminal was illuminated to a clearly detectable level (L1) and the thermode temperature was increased at a rate of 6°C/sec to a temperature (T1) which the subject had previously determined to be distinctly painful, but tolerable for a short period of time. For 2 subjects this temperature was 46°C, and for 5 subjects with higher pain thresholds it was 47°C. After a variable time of 4–9 sec the intensity of Fig. 1. Graphic depiction of the noxious thermal and visual stimulation. When the subject pressed the ‘RETURN’ key after a ‘START’ was displayed on the computer screen, the temperature of the thermode increased from a base of 37°C to 46° or 47°C (T1), depending upon the subject (A), and the light (L1) was illuminated (B). After a variable time (4–9 sec), the temperature increased an additional step between 0.3° and 2.0°C (T2 in A) or the light increased to a second level (L2 in B). The subject was instructed to press the ‘RETURN’ key as soon as he detected this second temperature or light change. The stippled area indicates the period during which a response was considered correct. An auditory cue signalled a correct response; a short series of ‘beeps’ indicated that the subject had failed to press the key during the response window, and no auditory feedback upon response indicated that he had pressed before the occurrence of T2.
either the visual or the thermal stimulus increased another small amount (T2 or L2 in Fig. 1). The subject's task was to press the 'RETURN' button as soon as he detected this second stimulus change. At the beginning of each trial, a message on the screen indicated whether the augmentation would occur in the visual or the thermal modality.

Between each trial, the subject was asked to make 2 ratings about the thermal pain experienced during the previous trial, one concerning the pain intensity and the other concerning the relative unpleasantness of the stimulus. To make the ratings the subject was asked to choose the most appropriate word from each of 2 lists, one containing intensity descriptors and the other containing unpleasantness descriptors [6]. Subjects were familiarized with the lists of words at the same time as they received the instructions about the experimental procedures. At this time each subject rated the meanings of the words on a Visual Analogue Scale, and these ratings, as well as those given by a previous validation group, were used for data quantification [6,11].

**Experimental paradigm**

The experiment was separated into 2 parts, the first part containing one set of 80 trials, and the second containing 2 sets of 80 trials. Part 1 was included to familiarize the subjects with the experimental procedure, as well as to determine each subject's difference threshold for detecting changes in the magnitude of the noxious heat and visual stimuli. A 'descending method of limits' procedure was employed, in which the first trials contained large T2 and L2 stimulus changes, with the stimulus becoming smaller on each trial until the subject could no longer detect the change. This was repeated several times, and visual and thermal trials were alternated. Using the data collected during part 1, we determined a T2 value for each subject which he was able to detect approximately 75% of the time. Table 1 shows the T1 and T2 values finally chosen for each subject. These values were then used for part 2 of the experiment.

Part 2 consisted of 2 sets of 80 trials each, with a short break between the 2 sets. This phase of the experiment was used to determine the effects of attention on both the subject's nociceptive dis-

<table>
<thead>
<tr>
<th>Subject</th>
<th>T1 (°C)</th>
<th>T2 (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT</td>
<td>46</td>
<td>46.7</td>
</tr>
<tr>
<td>LPB</td>
<td>47</td>
<td>47.6</td>
</tr>
<tr>
<td>MCL</td>
<td>46</td>
<td>46.3</td>
</tr>
<tr>
<td>LD</td>
<td>47</td>
<td>47.7</td>
</tr>
<tr>
<td>IT</td>
<td>47</td>
<td>47.8</td>
</tr>
<tr>
<td>CD</td>
<td>47</td>
<td>47.3</td>
</tr>
<tr>
<td>MII</td>
<td>47</td>
<td>47.3</td>
</tr>
</tbody>
</table>

**Data analysis**

For each subject, the percent success for detecting the T2 or L2 stimulus and the median latency of detection for the T2 and L2 stimuli were calculated. The data were analyzed using the Wilcoxon signed rank test for within-subjects comparisons and the Mann-Whitney U-test for between-subjects comparisons.
for making these detections were calculated for each trial type. In addition, numeric values were assigned to each word chosen by the subject to best describe the intensity and unpleasantness of the thermal pain, using previously validated methods [6]. Using these numeric transformations, mean values for intensity and unpleasantness were calculated for each subject during each experimental condition. Data were then analyzed using repeated measures ANOVA and corresponding profile and contrast analyses (SAS Institute Inc., Cary, NC, U.S.A.).

**Results**

For all 7 subjects, nociceptive discriminability was directly related to their level of attention toward the noxious stimulus. Fig. 2A illustrates the relationship between the mean percent of T2 stimuli detected and the 3 experimental conditions designed to alter the subjects' directed attention. The subject's success rates during these 3 conditions were significantly different (repeated measures ANOVA, $F(2, 5) = 5.972, P = 0.047$), with the most stimuli being detected when subjects were correctly cued to attend to the thermal stimulus, and the least when they were falsely cued to expect a visual stimulus. Correspondingly, the speed with which subjects detected the temperature changes (latency$^{-1}$) was significantly different in the 3 conditions (repeated measures ANOVA, $F(2, 5) = 25.899, P = 0.002$), with the subjects' responses being fastest on the correctly signalled trials and slowest on the incorrectly signalled trials (Fig. 2B).

In addition to painful stimuli being more detectable when subjects attended to the thermal modality, subjects' ratings of both the intensity and unpleasantness of the painful stimuli were influenced by the attentional state. Fig. 3 shows that subjects rated both intensity and unpleasantness of the painful stimuli higher on correctly signalled than on falsely signalled trials (repeated measures ANOVA, $F(2, 5) = 5.972, P = 0.047$).
TABLE II
ANALYSIS OF VARIANCE OF CONTRAST VARIABLES

<table>
<thead>
<tr>
<th>Type</th>
<th>Thermal cue (correct) vs. neutral cue</th>
<th>Visual cue (false) vs. neutral cue</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Thermal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% success</td>
<td>(F(1,6) = 5.40, P = 0.059)</td>
<td>(F(1,6) = 8.59, P = 0.026)</td>
</tr>
<tr>
<td>Speed</td>
<td>(F(1,6) = 4.90, P = 0.069)</td>
<td>(F(1,6) = 23.55, P = 0.003)</td>
</tr>
<tr>
<td>Intensity</td>
<td>(F(1,6) = 0.77, P = 0.414)</td>
<td>(F(1,6) = 25.53, P = 0.002)</td>
</tr>
<tr>
<td>Unpleasantness</td>
<td>(F(1,6) = 0.09, P = 0.948)</td>
<td>(F(1,6) = 25.04, P = 0.002)</td>
</tr>
<tr>
<td><strong>B. Visual</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% success</td>
<td>(F(1,6) = 3.68, P = 0.104)</td>
<td>(F(1,6) = 11.11, P = 0.016)</td>
</tr>
<tr>
<td>Speed</td>
<td>(F(1,6) = 0.64, P = 0.454)</td>
<td>(F(1,6) = 7.83, P = 0.031)</td>
</tr>
</tbody>
</table>

ANOVA, \(F(2,5) = 13.541, P = 0.010\) and \(F(2,5) = 11.736, P = 0.013\), respectively.

When data from the neutral condition are considered, the results suggest that subjects weighed their attention in favor of detecting an impending thermal stimulus, rather than splitting their attention between thermal and visual stimuli, although these two events had an equal probability of occurrence. The percent detection, response speed, and intensity and unpleasantness ratings for this neutral condition were more similar to those observed in the correctly signalled condition than to those of the incorrectly signalled condition. Table II shows the results of ANOVA analysis of contrast variables. For each response measure on thermal trials, there was a significant difference between the neutral and falsely cued conditions. However, for none of the response measures was there a significant difference between the correctly cued and neutral conditions. These differences were particularly profound for the intensity and unpleasantness ratings (Table IIA).

This suggestion of preferential attention toward thermal stimuli during the neutral condition is supported by data relevant to detection of the visual stimuli (L2). As in the thermal task, the ability to detect luminosity changes was influenced by the direction of attention (Fig. 4A), with a significant condition effect for the percent of stimuli detected (repeated measures ANOVA, \(F(2,5) = 6.84, P = 0.037\)). The subjects’ accuracy for detecting these visual stimuli was significantly greater \((P = 0.016)\) when their attention was correctly directed toward the visual stimulus, as compared with the neutral condition (Table IIB, visual cue vs. neutral cue). However, there was little difference in the subject's accuracy between the neutral condition and that in which they were cued to attend to the thermal stimulus (Fig. 4 and Table IIB, thermal cue vs. neutral cue), thus indicating again that the subject’s attention during the thermal neutral condition was preferentially weighted toward increasing his chances of detecting an impending change in thermode temperature. Results of response speed show a similar tendency. Although Fig. 4B illustrates a trend for subjects to
respond to the visual stimuli with differential speeds during the 3 conditions (repeated measures ANOVA, $F(2, 5) = 3.270, P = 0.124$), and contrast analyses reveal a difference between the correct and neutral conditions ($P = 0.031$), there is no such trend between the neutral and false conditions (Table II).

In addition to revealing that perceived intensity and unpleasantness, as well as stimulus discriminability, are influenced by the subject’s attentional state, our data also suggest that experimental heat stimuli may produce pain with a relatively low affective component compared to its intensity. Fig. 3 shows that the mean ratings of intensity were higher than those of unpleasantness for noxious heat stimuli in all 3 conditions. However, a repeated measures MANOVA using the 2 scales (intensity and unpleasantness) and 3 conditions (correct, neutral, false) revealed only a trend toward a scale effect ($F(1, 6) = 3.972, P = 0.093$).

Discussion

Results of the present study confirm our previous findings that both the accuracy and speed of detecting changes in the magnitude of noxious heat stimuli are similarly influenced by cues signalling stimulus probability [5]. These changes that we observed in the subjects’ performance are similar to those reported by others who have used this type of behavioral paradigm to investigate the effects of attentional state on visual perception [23]. Thus, changing stimulus probability in order to alter the subjects’ response strategies appears to be a simple but powerful model for controlling attentional state; monitoring the accuracy and latency of the subjects’ responses supplies a sensitive measure of the paradigm’s success in directing the subjects’ attention to the various stimulus modalities.

In addition to confirming the validity of the attentional paradigm, our data show that changes in directed attention can alter both the perceived intensity and the unpleasantness of a painful stimulus. When a subject focuses his attention on noxious heat stimuli, they are perceived as both more intense and more unpleasant than when he directs his attention elsewhere. Further, the experimental pain stimuli used in the present study tended to be rated by the subjects as relatively less unpleasant than intense; this finding is not surprising, as subjects were informed that they could terminate the stimuli at any time and that the stimuli would not damage the skin.

Nevertheless, even in this situation where the affective reactions were low, both intensity and unpleasantness were altered by attention. Finally, when subjects were instructed to attend concurrently to the visual and noxious thermal stimuli (neutral condition), they appeared to direct their attention preferentially toward the painful stimulus, and both the intensity and unpleasantness of that stimulus were the same as when the subjects directed their attention exclusively to it. This suggests that, unless an individual actively directs his attention away from a painful stimulus, that stimulus will dominate over those that are not painful.

The fact that the sensory and affective pain responses were modulated in a parallel manner by direction of attention (see Fig. 3) suggests that changes in the subject’s perceived unpleasantness of the stimulus are at least partially a consequence of alterations in the perceived intensity of the stimulus. This finding is supported by several studies which have shown a concomitant reduction in unpleasantness following a manipulation (such as electroacupuncture [28], high doses of morphine [29], or fentanyl [27]), which reduces the perceived intensity of pain. It is interesting to note, however, that some manipulations, such as diazepam [10], low doses of morphine [29], and warning signals [25], can rather selectively reduce the emotional response to experimental pain.

The finding that intensity and unpleasantness dimensions of pain are similarly altered by changes

* Unpublished data from our laboratory indicate that the relationship between intensity and unpleasantness varies among experimental stimuli. While noxious heat pulses show a relatively low unpleasantness/intensity ratio (0.65), ischemia shows a high ratio (1.54).

** One previous study [12], showing a fentanyl-induced selective reduction in pain intensity, contradicts these other reports.
in attention is consistent with an interpretation that these effects are occurring at an early stage of sensory processing. Such an idea is substantiated by neurophysiological data. Studies in monkeys trained to perform tasks in which their attention is directed to either visual or noxious thermal stimuli show that nociceptive neurons in the medullary dorsal horn (the trigeminal homologue to the spinal dorsal horn) are more responsive to noxious thermal stimuli when the monkey is attending to those stimuli than when he is attending to a visual stimulus [4,14].

Previously Price et al. reported that when subjects rate the intensity and unpleasantness of various noxious and non-noxious thermal stimuli, the perceived intensity is the same whether or not the subject receives a warning that the upcoming stimulus is to be painful; in contrast, the subjects rate the unexpected painful stimuli as relatively more unpleasant than those that are signalled and thus expected [25]. In the present study, direction of attention was manipulated by signalling to the subject the modality of the next stimulus change to be detected. Yet we found that when subjects expected a change in the noxious heat stimulus (correctly signalled condition) they rated the pain as more unpleasant than when they did not expect it (incorrectly signalled condition). The apparent inconsistency of these findings with those of Price et al. [25] is probably due to the fact that in our study a noxious stimulus was presented on every trial (i.e., T1) and only a small change in the intensity of this stimulus (T2) was expected or unexpected. Since the subjects had been instructed to rate the overall intensity and unpleasantness of the painful heat throughout the trial (i.e., T1 and T2 together), any effects of expectancy were probably outweighed by changes in attention.

Some psychological treatment strategies, such as behavioral modification and hypnosis, have been shown to be effective in reducing patients’ complaints of chronic pain as well as their dependence on analgesic medication [8]. Although these approaches undoubtedly reduce the unpleasantness of pain and the affective response to the painful condition, the important question remains: do these psychological manipulations reduce the actual sensation of pain [7]. The present psychophysical data, along with our previous finding of dorsal horn nociceptive neurons modulated by directed attention [4], indicate that psychological state can indeed alter the sensation produced by brief experimental pain stimuli. These data suggest the possibility that psychological interventions may also reduce pain sensation within a clinical setting.

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References