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Interaction between stimulus intensity and perceptual load in the attentional control of pain

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The interaction between intensity of nociceptive stimuli and cognitive load in a concomitant task is still a challenging and complex topic. Here, we investigated the interaction between top-down factors (i.e., perceptual load), induced by a visual task, and bottom-up factors (i.e., intensity of nociceptive stimuli that implicitly modifies saliency of input). Using a new experimental paradigm, in which perceptual load is varied while laser heat stimuli of different intensities are processed; we show a significant interaction between intensity of nociceptive stimuli and perceptual load on both pain ratings and task performance. High perceptual load specifically reduced intensity ratings of high intensity stimuli. However, under this condition, task performance was impaired, regardless of interindividual differences in motivation and pain catastrophizing. Thus, we showed that pain ratings can be reduced by increasing the load of attentional resources at the perceptual level of a non–pain-related task. Nevertheless, the disruptive effect of highly intensive nociceptive stimuli on the performance of the perceptual task was evident only under high load.

1. Introduction

The interaction between the processing of task-unrelated but salient painful stimuli and task-related nonpainful stimuli underlines the bidirectional relationship between pain-induced attentional capture (and interruption of cognitive functioning) and decreased pain perception due to the demands of a non–pain-related task [1,25,30,32]. On 1 hand, several studies have suggested an interruptive function for pain indicated by a decline in task performance (e.g., increased reaction times [5,7,21]), probably mediated by the salience of painful stimuli [19,20]. On the other hand, performance of concurrent tasks during noxious stimulation results in reduced pain intensity or unpleasantness ratings [4,10,11,23,36,38], partially depending on general task demand, motivation, goals, and other contextual factors [32,36,37]. However, only a few studies have investigated the interaction between the demands of a non–pain-related task and the intensity, and therefore salience, of nociceptive stimulation. Moreover, the results of these studies show some inconsistencies. Although some studies have reported no interaction of intensity of painful stimulation and task load [26], others have demonstrated that task demand interacts with the level of painful stimulation [4], but also that intensity of noxious stimulation affected task performance, specifically that increased intensity leads to reduced task performance [5].

Accounting for these inconsistent findings, a neurocognitive model of attention to pain specifies the role of task load (amount of attention demanded by the task) and task set (task relevant stimulus features) in the top-down attentional modulation of pain that results in an increased neural representation of task-relevant, and inhibition of task-irrelevant, stimuli [18]. With respect to the bottom-up attentional modulation of pain, the model also emphasizes the importance of stimulus saliency and of the shared perceptual features of nociceptive and task relevant stimuli (attentional set). In addition the model describes the role of executive functions that control the interference induced by distracters [17]. The model thus proposes a dynamic balance of top-down and bottom-up mechanisms: to avoid intrusive effects by painful stimuli, attention must be engaged to a completely non–pain-related task (set); this engagement must be effortful (load condition); and must be controlled by executive functions to prevent interference from distracters (executive control). In addition, perceptual load theory [15] suggests that the processing of non–task-relevant distracters is greater under low perceptual load (because attentional [processing] resources are not exhausted) than under high perceptual load, due to there being no additional processing resources available for the processing of competing information. However,

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to our knowledge, no study has concurrently modulated both perceptual load and intensity of noxious stimulation.

The present study investigates the interaction of intensity of phasic nociceptive stimuli and perceptual load and its effects on pain ratings and behavioral performance. We hypothesized that increased perceptual load imposed by a visual task would reduce resources for the processing of painful stimuli. This should result in reduced pain ratings and reduced pain-related impairment of task performance.

2. Methods

2.1. Subjects

Twenty-two healthy subjects (7 male and 15 female; mean age = 23.05 years; SD = 3.64 years) participated in this study. All subjects were right-handed, displayed normal pain thresholds, and had normal or corrected to normal vision. Prior to the experiment, we checked participants' history for pain syndromes and the use of analgesics by means of a short questionnaire. Participants with a history of chronic pain, use of analgesic medication, or neurological disorders were excluded from the study.

2.2. Pain stimulation

Pain was induced by laser stimulation using a thulium doped yttrium-aluminium-gamet (*YAG*) laser (Themis, Starnberg, Germany). Its emitted radiant pulse was computer controlled and had a wavelength of 2 μm, spot diameter of 6 mm on the skin, and duration of 1 ms. Stimulus intensity and individual stimulus thresholds were obtained through a psychophysical pre-test by applying 3 series of stimuli with ascending and descending intensities to the dorsum of participants' left hand. Stimulus intensity was rated using a modified numerical ratings scale (NRS) ranging from 0 ("no pain, no sensation at all") to 10 ("worst imaginable pain") with additional anchors at 1 ("just perceived, but not painful"), 2 ("clearly perceived, but not painful, warm sensation"), 3 ("slightly painful"), 4 ("perceived painful sensation"), 5 ("moderately clearly painful"), 6 ("highly painful, but tolerable"). This scale is nearly similar to that which we used in earlier studies [28], with the exception that we introduced (due to the low intensity) 2 ratings for nonpainful stimulation. Although we were interested only in investigating ratings representing nonpainful up to highly painful but tolerable stimuli (rating 6), we created a scale (see also Buhle and Wager 2010 [4]) up to a maximum of 10 to have the possibility to assess also extreme ratings that were beyond our intended rating range. We chose laser stimuli within the calibration session that met the following criteria: low laser intensity, I1, in order to evoke a warm, but not painful sensation (NRS = 2); moderate intensity, I2, to induce a low pain sensation (NRS = 3.5); and high intensity, I3, to be perceived as inherently painful (NRS = 5). Threshold determination revealed the following average threshold intensities: I1 (low/warm but not painful intensity): mean = 376.79 mJ, SD = ±69.2 5 mJ, NRS = 2; I2 (moderate, slightly painful intensity): mean = 497.44 mJ, SD = ±96.64 mJ, NRS = 3.3; I3 (high, painful intensity): mean = 604.05 mJ, SD = ±89.75 mJ, NRS = 5.1. Using 3 different laser stimulus intensities, we implicitly manipulated the stimulus salience. We propose that stimuli producing highly painful sensation are more salient than moderately painful stimuli. Similarly, moderately painful stimuli should be more salient than nonpainful (warm) stimuli [6].

2.3. Perceptual task

The perceptual load task, which had 2 different levels of load, was based on a visual search paradigm [12]. Subjects got the instruction to discriminate between 2 possible target symbols in a display of several visual distracters (set size 8) (Fig. 2). The 2 target symbols were both rotated letters "C" with either a 90° counterclockwise or 90° clockwise rotation (Fig. 2). We operationalized the level of perceptual load by varying the degree of target–distracter similarity. Thus the complexity (type) of the distracters depends on the condition. In the low perceptual load condition, the distracters were letters "O". Thus, it was easy to discriminate the nontarget letter "O" from the target letter (rotated "C") in low perceptual load conditions. In the high perceptual load conditions, the distractors were letters "C" that were presented rotated, but in a different rotation compared with targets (Fig. 2). Thus, it was more difficult to discriminate the target letters in the high-perceptual load condition (target "C"s between other, nontarget "C"s) compared with the low-perceptual load condition (target "C"s between nontarget "O"s). This manipulation of perceptual load conforms to the description by Lavie (2005) of heightening perceptual load by making perceptual identification more demanding or difficult on attention [13]. The set size of 8 items was constant across the 2 task loads.

2.4. Experimental procedure

Before the experiment, all participants received information about the procedure of the experiment and provided written informed consent for participation. The study was approved by the Ethics Committee of the Friedrich Schiller University.

Before the main experiment, there was a training session to familiarize participants with the experimental procedures. During the experiment, participants sat in a comfortable chair while watching visual stimuli on a 24-inch screen from a viewing distance of 70 cm. Protective goggles were worn to avoid eye injury from laser irradiation, and ear plugs were worn to avoid any perception of noise evoked from the laser stimulator. The goggles also limited the field of view of participants. Because of the structure of the trial (Fig. 1), it is unlikely that participants saw their hands during laser stimulation, but we cannot fully exclude this possibility.

Participants performed a perceptual detection task while simultaneously receiving painful or non painful laser-heat stimuli. Each trial (Fig. 1) began with a fixation cross presented for 4400 to 6400 ms, followed by the visual stimulus (perceptual task) presented for 600 ms. A 1-ms laser stimulus with 1 of 3 intensities I1 to I3 was applied to subjects' left hand simultaneously with the start of the perceptual load task. Subjects had to solve the task and perform a speeded button press to indicate which target (clockwise or counterclockwise rotation) was presented. Manual responses were given by the left index and ring finger, which were placed directly above the response buttons. The assignment of the response buttons was counterbalanced across participants. After presentation of the perceptual task stimulus, a visual pattern mask [9] was presented for 200 ms followed by a fixation cross with a variable presentation time between 3200 and 5200 ms. Thereafter, a numerical rating scale (NRS) ranging from 0 to 10 was displayed for 3000 ms, which prompted the subject to rate the intensity of the preceding laser stimulus. With a sliding window, the subject pressed a button to move along the scale from 0 to 10 to choose the appropriate intensity. Subsequently, the next trial commenced. Between any 2 laser stimuli, the laser beam was manually displaced by ~1 cm along a proximal distal line on the dorsum of the left hand to avoid burning the skin. The whole experiment took 45 min.

For data analysis, a 3 × 2 factorial design was used with the factors Stimulus Intensity (I1, I2, I3) and Perceptual Load (low load, high load). Each of the 6 conditions contained 20 trials. In addition, 20 null-events showing a fixation cross without any laser stimulation were randomly intermixed. Because of the overall length of the experiment, the whole experimental session was divided into