Exp Brain Res (2011) 208:269–275
DOI 10.1007/s00221-010-2477-y

RESEARCH ARTICLE

The role of spatial attention in attentional control over pain: an experimental investigation

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Received: 4 June 2010 / Accepted: 25 October 2010 / Published online: 10 November 2010

Abstract Distraction is a common method of pain control that is often found to be effective. However, it is still largely unexplored which components of distraction are responsible for its effects. This study investigated the role of the spatial location of task-relevant stimuli in the effectiveness of distraction. Two experiments were performed in which the spatial location of visual stimuli during nociceptive input was manipulated. In a first experiment, we tested whether the reaction to nociceptive information is slower when visual stimuli are presented at a different spatial location than at the same spatial location. In a second experiment, we examined whether the manipulation of spatial location affects the experience of pain. Overall, results indicated that directing attention away from the pain location results in a slower response to painful stimuli and a reduction in pain. It may be concluded that the analgesic effect of distraction is at least partly the result of the spatial location of the distracting information.

Keywords Pain · Attention · Distraction · Spatial attention

Introduction

Distraction, or directing attention away from a painful stimulus, has mostly been found to change the quality and quantity of pain (Bantick et al. 2002; Seminowicz and Davis 2007; Tracey and Mantyh 2007; Van Damme et al. 2010). Most often, studies found a reduction in pain experience (McCaul and Malott 1984; Miron et al. 1989; Petrovic et al. 2000; Tracey et al. 2002; Valet et al. 2004; Van Damme et al. 2008; but see Goubert et al. 2004; McCaul et al. 1992). Directing attention away from pain also dampens the processing of nociceptive input in various brain structures (Bantick et al. 2002; Valet et al. 2004; Villemure and Bushnell 2009), in particular through the activation of prefrontal areas (Bantick et al. 2002; Petrovic et al. 2000; Valet et al. 2004).

A largely unexplored question pertains to the components that are responsible for the analgesic effects of distraction. Many studies have argued that distraction is effective because attention is directed towards a stimulus from another perceptual modality (McCaul and Malott 1984; Miron et al. 1989; Petrovic et al. 2000; Tracey et al. 2002; Valet et al. 2004). This hypothesis, however, is premature since distraction tasks used in previous studies involved both (1) directing attention towards a perceptual modality other than nociception and (2) directing attention towards a spatial location other than the location of the painful stimulus. Therefore, it remains possible that the analgesic effect of distraction is at least partially the result of directing attention spatially away from the pain location. Three arguments indicate that this indeed could be the case. First, people characteristically construct representations of their environment in which information from different senses is integrated according to their relative positions in space (Spence and Gallace 2007). As such, it is likely that when a region of space is cued by a stimulus in one modality, also the processing of a stimulus from another modality appearing in that region will be facilitated. Indeed, it has been demonstrated that the processing of non-painful tactile

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stimuli is improved when their location is cued by visual or auditory stimuli (for a review, see Spence et al. 2004). Consequently, it is reasonable to hypothesize that directing attention away from pain towards another perceptual modality is only possible when distractors are presented in a different location of space. This idea remains to be investigated. Second, it was shown that directing attention towards or away from the location of pain modifies the cortical activity underlying nociceptive processing (Legrain et al. 2009b). Third, some studies indicated that looking away from the location of painful stimulation indeed influences the experienced pain (Dowman 2004; Honoré et al. 1995; Mosely and Arntz 2007; but see Naveteur et al. 2005). However, the results of these latter studies are inconsistent, and alternative explanations for the analgesic effects cannot be ruled out. In particular, excluding placebo effects might be important because directing attention away from the pain is often believed to be effective (Leventhal 1992). Furthermore, studies applied paradoxical instructions (report pain intensity while being instructed to direct attention away from pain), which could have negatively influenced the analgesic effect (Eccleston 1995).

The aim of the present studies, therefore, was to investigate the specific role of the spatial location of task-relevant stimuli in the effectiveness of distraction, taking into account previously discussed methodological problems (Eccleston 1995). In experiment 1, we tested whether the response speed to noxious stimuli was influenced by the spatial location of visual cues. In experiment 2, we tested whether the perception of pain was influenced by sustaining attention away versus towards the location of the task-irrelevant noxious stimuli.

Experiment 1

In experiment 1, we tested whether responses to noxious stimuli are slower when attention is directed away from the pain location by means of visual stimuli in comparison with when attention is directed towards the pain location by means of these stimuli. We used the spatial cueing paradigm (Butter et al. 1989; Spence et al. 1998), which has never been used in its exogenous form with painful target stimuli before.

Method

Participants

Twenty-six undergraduate psychology students from Ghent University who received course credits participated in this experiment (20 women; M_{age} = 18.7 years, SD = 1.0; all Caucasian). Each individual had normal or corrected-to-normal eyesight. Current health status was not assessed. All participants provided informed consent and were free to terminate the experiment at any time. All participants completed the experiment, which took approximately 20 min. The protocol of the experiment was approved by the ethical committee of the Faculty of Psychology and Educational Sciences of Ghent University.

Experimental device

Participants were seated in front of a table, which was equipped with a chin-rest device to maintain the head in a central position. The forearms were positioned symmetrically on the table, both hands resting on a response button. About 10 cm above the table, a black 50-cm-high curved screen was installed, in a distance of 36 cm from the eyes of the participant. At the base of the screen, three LEDs were attached: one central and two lateral (left and right) at approximately 27° from the middle. Participants stretched their arms beneath the screen in such a way that their wrists were exactly at the position of the left and right LED (Fig. 1).

Task and stimuli

The task was programmed and presented by the INQUISIT Millisecond software package (Inquisit 2.06 2008). The task consisted of the presentation of visual cue stimuli and painful target stimuli. Visual cues were LEDs presented to the left or right hand, or centrally between both hands. Painful targets were electrocutaneous stimuli delivered by a constant current stimulator (Digitimer DS7A 1998). Electrocutaneous stimuli consisted of trains of 2-ms pulses with a frequency of 65 Hz and were delivered at the external side of both wrists by two lubricated Fukuda standard Ag/AgCl electrodes (1 cm diameter). Intensity of the electrocutaneous stimulus was 1.00 mA, with an instantaneous rise and fall time.

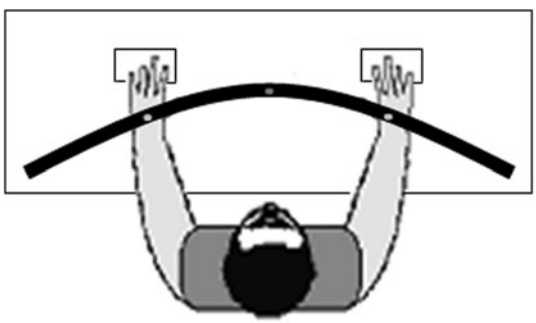

Fig. 1 Schematic illustration of the experimental set-up

Each test trial began with a fixation LED (1,000-ms duration) in the middle of the screen. Next, LEDs were dimmed for 200 ms. Then, one of the three LEDs shone for a duration of 200 ms. This was immediately followed by a pain target on one of both wrists, which lasted 200 ms. Participants were instructed to discriminate the spatial location of the painful stimuli as quickly and accurately as possible by pressing the corresponding response button (left versus right index finger). A trial was completed when a participant responded or 1,500 ms had elapsed.

There were three types of trials: (1) trials in which the target was preceded by the cue at same position (same spatial location trials), (2) trials in which the target was preceded by the cue at opposite position (opposite spatial location trials) and (3) trials in which the cue was presented centrally between both hands (centrally cued trials). To control for potential response biases (responses to the location of cues instead of targets), a number of catch trials were presented. On these trials, the cue was not followed by a target. Participants were instructed to respond to the occurrence of the target stimuli only.

Procedure

During the preparation phase, participants were informed that an electrocutaneous stimulus would be used. They were told that "*most people experience this kind of stimulation as painful and unpleasant*" (Crombez et al. 1998). Subsequently, they provided informed consent. A pair of electrodes was attached to both wrists. The skin at the electrode sites was first abraded with a peeling cream (Nihon Kohden) in order to reduce skin resistance.

Following the task instructions, the experiment started with 15 practice trials. Afterwards, participants rated the intensity and painfulness of the electrocutaneous stimuli on eleven-point numerical rating scales (0 = 'not at all' and 10 = 'very strongly'). Pain unpleasantness was rated on an eleven-point numerical rating scale (−5 = 'very unpleasant' and +5 = 'very pleasant'). Overall, the participants rated the electrocutaneous stimuli as moderately intense ($M = 4.00$, SD = 1.72), slightly painful ($M = 1.85$, SD = 1.67) and moderately unpleasant ($M = -1.58$, SD = 1.30). The experiment phase consisted of 64 trials (16 same spatial location trials, 16 opposite spatial location trials, 16 centrally cued trials and 16 catch trials).

Data analysis

Mean reaction times (RTs) were analysed using a one-way analysis of variance (ANOVA) with trial type (same spatial location, opposite spatial location, centrally cued) as a within-subject factor. Trials with errors (<2%) and responses faster than 200 ms (anticipations; <1%) and slower than three standard deviations above the individual means for each trial type (misses; <1%) were removed from further analyses. Next, two-tailed *t* tests were used. For ease of comparison with the norms of Cohen (1988), we calculated effect sizes for independent samples using the formula of Dunlap and colleagues (Borenstein et al. 2009). We determined whether Cohen's *d* was small (0.20), medium (0.50) or large (0.80) (Cohen 1988).

Results

ANOVA showed a significant effect of trial type RTs ($F_{(2,24)} = 11.54$, $P < .001$). The comparison of RTs showed that responses were significantly faster on same spatial location trials ($M = 500$ ms, SD = 142) than on opposite spatial location trials ($M = 554$ ms, SD = 154), ($t_{(25)} = 4.16$, $P < .001$, $d = 0.36$; 95% CI: 0.18, 0.53). Furthermore, in comparison with RTs on the centrally cued trials ($M = 541$ ms, SD = 131), RTs were also significantly faster on same spatial location trials ($t_{(25)} = 4.72$, $P < .001$, $d = 0.29$; 95% CI: 0.17, 0.41). These results suggest that RTs to painful stimuli are faster when visual cues occurred at the same spatial location. Finally, there was no difference between opposite spatial location trials and centrally cued trials ($t_{(25)} = 1.342$, $P = .19$, $d = 0.08$; 95% CI: −0.04, 0.20), suggesting no significant cost from visual cues occurring at the wrong location.[1]

Discussion

As expected, we found that responding to pain stimuli was faster when the visual cue appeared at the same location (same spatial location trial) than when the cue was presented at another location (opposite spatial location trial or centrally cued trial). This confirms that the processing of the painful stimuli is modified by the cross-modal direction of spatial attention, in line with findings of previous studies that have investigated the effects of visual cues on the processing of non-noxious tactile stimuli (see Spence et al. 2004). Furthermore, this experiment extends previous research in showing that the modulation of responses to somatosensory stimuli by spatial attention generalizes to nociceptive stimuli. A question left unanswered is whether the manipulation of spatial attention also affects the experience of pain. To answer this question, a second experiment was conducted.

[1] Analyses were also performed including only the women in the sample. Results did not differ significantly from those performed with the complete sample.

Experiment 2

Experiment 2 was designed to test whether directing attention towards or away from the spatial location of pain reduces the experience of pain while keeping attention to the perceptual modality constant. By means of a sustained attention task, attention was maintained on visual stimuli and was spatially manipulated by varying the location of the painful stimulus relative to the location of the visual stimulus. Specifically, participants were instructed to detect subtle dimmings of a LED that were presented at the same location as the pain stimulus (same spatial location trials) or at the opposite location as the pain stimulus (opposite spatial location trials). We hypothesized that pain would be rated as less painful during opposite spatial location trials than during same spatial location trials. Painful stimuli were delivered during a visual sustained attention task, and participants were asked to rate their pain after each trial.

Method

Participants

Participants were 24 undergraduate students from Ghent University who received course credits for participation (21 women; M_{age} = 19.13, SD = 2.66; all Caucasian). Two participants were removed from this sample due to self-reported medical disorders that might affect the results of the study (anxiety disorder, current back pain). All participants provided informed consent and were free to terminate the experiment at any time. All participants completed the experiment, which lasted approximately 40 min. The study protocol was approved by the ethical committee of the Faculty of Psychology and Educational Sciences of Ghent University.

Apparatus and stimuli

Apparatus and stimulation parameters for visual and painful stimuli were the same as in experiment 1, except for the duration of the electrocutaneous stimulus, which was 10 s in the second experiment.

Visual sustained attention task

The sustained attention task was programmed and presented by the INQUISIT Millisecond software package on an Excel computer (Pentium 4, 2.8 GHz, 512 MB) with a 60-Hz, 17-inch colour monitor. At the beginning of each trial, a central fixation LED shone for 1,000 ms. Immediately after offset of this central fixation LED, either the left or the right LED shone. Occasionally, this LED was completely dimmed for 50 ms. The participants' task was to detect this dimming of the LED by pressing the key of a response device. The time interval between two consecutive LED dimmings varied randomly between 1,000, 1,500, 2,000, 2,500 and 3,000 ms.

Each trial consisted of a baseline phase, a pain phase and a post-pain phase. A trial started with a baseline phase of 13 s, in which participants performed the sustained attention task without pain. During the pain phase, the painful stimulus was introduced, either at the same location or at another location than the visual stimulus. Participants were instructed to continue with the sustained attention task (pain phase). The post-pain phase started with the offset of the painful stimulus, and participants continued with the sustained attention task during an additional 10 s. Each trial lasted approximately 33 s. There were no cues signalling the three different phases.

Self-report measures

Pain intensity was measured by calculating the averaged score on two items (Cronbach's α = .98). Participants were asked to rate maximum pain intensity and average pain intensity (0 = 'not at all' and 10 = 'very strongly'). Pain unpleasantness was measured by means of one numerical rating scale that assessed how unpleasant participants perceived the electrocutaneous stimulus (0 = 'not at all' and 10 = 'very strongly'). Afterwards, an overall pain experience measure was computed by averaging the pain intensity and the pain unpleasantness measure (Cronbach's α = .94).

Procedure

Pre-experimental phase

Participants were not informed about the true purpose of the experiment. To minimize placebo effects, participants were told that *"we were interested in their ability to concentrate on a visual task while experiencing distracters"*. Participants were informed that on each trial, the LED on the left or right side would shine. Their task was to detect each dimming of the LED by pressing as quickly as possible a response device button. Next, participants were informed about the use of an electrocutaneous stimulus. Afterwards, participants provided written informed consent.

During a practice phase, participants performed the sustained attention task once with the LED shining on the left side and once with the LED shining on the right side. The order was counterbalanced across participants. There was no painful stimulus administered during the practice phase. Next, participants were made familiar with the painful stimulus, which was administered once on each wrist.

Participants were asked to rate the intensity and unpleasantness of the painful stimuli afterwards.

Experimental phase

The experimental phase consisted of randomly selected same spatial location trials and other spatial location trials. During same spatial location trials, the painful stimulus occurred at the same location as the task-relevant LED. During other spatial location trials, the painful stimulus occurred at the opposite location as the task-relevant LED. The experimental phase consisted of 12 same spatial location trials and 12 other spatial location trials. After each trial, participants rated pain intensity (average/maximum) and pain unpleasantness of the electrocutaneous stimulus.

Data analysis

Mean reaction times to visual stimuli of the sustained attention task were analysed by means of a 3 (baseline phase; pain phase; post-pain phase) × 2 (same spatial location; opposite spatial location) repeated-measures analysis of variance. Pain ratings were analysed using a two-tailed paired-sample *t* test (same spatial location vs. opposite spatial location). As in experiment 1, effect sizes for independent samples were calculated using the formula of Dunlap and colleagues (see Borenstein et al. 2009).

Results

Behavioural data

Trials in which no response or an incorrect response was given (11%) were removed from analyses. Furthermore, data were discarded from analyses when response latencies were shorter than 200 ms (anticipations) or larger than three standard deviations above the individual mean per trial type (outliers) (<5%). A 3 (baseline phase; pain phase; post-pain phase) × 2 (same spatial location; opposite spatial location) repeated-measures analysis of variance revealed a main effect of time ($F_{(2,42)} = 5.335$, $P < .01$), indicating that participants were slower during the pain phase ($M = 322$, SD = 44) and post-pain phase ($M = 321$, SD = 41) than during the baseline phase ($M = 310$, SD = 35). Furthermore, a significant interaction effect of time and spatial location was found, $F_{(2,42)} = 6.987$, $P < .01$. This interaction was further explored by means of 3 paired-sample *t* tests (same spatial location vs. opposite spatial location). The paired-sample *t* test on the mean reaction times during the pain phase revealed a significant effect of spatial location ($t_{(21)} = 2.942$, $P < .01$, $d = 0.26$; 95% CI = 0.08, 0.43), indicating that participants were significantly faster in identifying dimmings at same spatial location trials ($M = 315$ ms, SD = 44) than in identifying dimmings at other spatial location trials ($M = 327$ ms, SD = 46). The paired-sample *t* tests on RTs during the baseline phase and post-pain phase revealed no significant effect of spatial location (*t*s < 1.14).

Pain ratings

Analyses for pain ratings were performed on data from trials with no more than 20% of the dimmed LEDs missing during electrocutaneous stimulation (17%). By doing so, only trials are analysed in which participants' attention was directed towards the expected location, excluding trials in which participants were not engaged in the sustained attention task. As expected, the analyses on overall pain experience revealed that participants rated the pain significantly lower at other spatial location trials ($M = 3.96$, SD = 1.62) than at same spatial location trials ($M = 4.29$, SD = 1.68) ($t_{(21)} = 2.677$, $P < .05$, $d = 0.20$; 95% CI = 0.05, 0.34).[2]

Discussion

Behavioural results show that participants are slower to perform the sustained attention task when performed at a location other than the pain than when performed at the same location as the pain. Behavioural results also reveal that participants' performance on the sustained attention task is slowed down during and following the presence of pain. Furthermore, results show that the experience of pain was modified by the direction of spatial attention. Participants perceived the electrocutaneous stimulus as significantly less painful when the visual stimulus was presented at a different location than the painful stimulus in comparison with the situation when the visual stimulus was presented at the same location as the painful stimulus.

General discussion

The aim of this study was to investigate the role of spatial attention in the effectiveness of directing attention away from painful stimuli. This was accomplished by the presentation of task-relevant visual stimuli relative to the pain location during a distraction task. In sum, behavioural data confirm that directing attention away from the location of painful stimuli slows down responding to these stimuli. Furthermore, the manipulation of the location of distractive

[2] Analyses were also performed including only the women in the sample. Results did not differ significantly from those performed with the complete sample.

stimuli relative to the location of painful stimuli resulted in a significant reduction in the pain experience.

Behavioural results confirm our first hypothesis and show that participants' responses to noxious stimuli are facilitated by directing attention towards the noxious stimuli in comparison with when their attention is shifted away from the pain location. These findings are consistent with previous findings in cross-modal research which indicated that directing attention towards the location of a tactile stimulus by means of stimuli in other sensory modalities (visual or auditory) facilitates detection of this stimulus (see Spence et al. 2004). The current findings extend the results of earlier research in generalizing previous cross-modal findings with non-painful somatosensory stimuli. Most importantly, this indicates that attention can be successfully manipulated towards or away from the location of painful stimuli by presenting stimuli in a different modality at, respectively, the same or another location than the one of the painful stimulus.

Directing attention away from the location of painful stimuli results in a reduction in the pain experience. Effect sizes, however, indicate that the effect of directing attention spatially away from the pain location on the pain experience is rather small ($d = 0.20$). Several factors may explain why our manipulation of spatial attention only has small effects on overall pain experience, in comparison with traditional distraction studies. First, participants were kept unaware of the true purpose of the experiment (pain reduction), minimizing the potential influence of placebo effects (Benedetti 2006; Vase et al. 2002). Second, painful stimuli used in this study were of long duration. Although the use of painful stimuli of a long duration (10 s) is more ecologically valid, this could have led to reduced analgesic effects of spatial attention on the pain experience. Because pain automatically draws attention (Eccleston and Crombez 1999), it seems reasonable that attention has more opportunity to shift towards the painful stimuli during longer pain stimuli than during painful stimuli of short duration. However, all the same, the overall result of the present experiments indicates that spatial attention is effective at reducing pain experience, independently of other attentional variables such as intermodal selective attention.

Several underlying mechanisms can be put forward to explain the influence of the spatial location of distracting stimuli on distraction effectiveness. A first plausible underlying mechanism is a mechanism of 'gain control' on neural responsiveness. As it was similarly explained for the effect of attention in the visual and auditory modalities (see Hillyard et al. 1998), Legrain et al. (2002) proposed that the responses of neurons underlying the processing of a nociceptive input are modified, i.e. amplified when attention is directed towards, and inhibited when attention is discarded from the stimulus, leading to facilitated versus suppressed processing of sensory inputs. In our experiments, the facilitation/inhibition of noxious stimuli could have been induced by the activation of multimodal neurons by the visual cues. Indeed, neurophysiological and neuropsychological research has shown that cross-modal effect of spatial attention could be due to the existence of neurons responding to stimuli from different modalities (Maravita et al. 2003). Recently, it was suggested that nociceptive stimuli could also be processed, at least partially in multimodal cortical areas (Mouraux and Iannetti 2009). Second, the influence of the spatial location of visual stimuli on distraction effectiveness could also be explained by the fact that participants' behaviour is goal-directed during the performance of the sustained attention task (Van Damme et al. 2010). To reach their goal (i.e. good performance on the sustained attention task), participants needed to focus their attention on the location that is relevant for their goal (i.e. the location of the LED that is lit). This focussing at a specific location could benefit the processing of other events at this location (i.e. an electrocutaneous stimulus presented at same location) and be at cost of events at other locations (i.e. an electrocutaneous stimulus presented at other location).

Some issues deserve further consideration. First, in these experiments, only a moderately intense pain stimulus was used. Since previous research has shown that more intense and threatening pain draws more attention and interrupts one more easily from an ongoing task (Crombez et al. 1998; Van Damme et al. 2004), it remains unclear whether spatial distraction would also reduce the pain experience when the pain is more intense. More systematic research on the effects of pain intensity on distraction effectiveness is recommended. Second, pain and negative cognitions during the task were rated retrospectively. Although this might have resulted in memory biases (Redelmeier et al. 2003), it has been argued that post-pain ratings administered shortly after the exposure to pain are valid alternatives for online measurement (Koyama et al. 2004). Moreover, measurement during the task might even be more problematic as it might interfere with distraction manipulations (Eccleston 1995). Third, electrical stimulation as used in these experiments activates both nociceptive and non-nociceptive afferents. Our results might therefore not be specific for pain. Further research is needed to resolve this issue, for instance by using stimuli that exclusively stimulate the nociceptive afferents. However, evidence is accumulating that the processes underlying nociception are largely shared with those underlying perception of the other perceptual modalities (e.g. Mason 2005; Mouraux and Iannetti 2009; Legrain et al. 2009a). A scientific endeavour may then not be to identify specific attentional processes for pain but rather to find the environmental or cognitive factors that increase versus decrease nociceptive processing. Fourth, the present

research was conducted in pain-free undergraduate students using experimental pain stimuli. Therefore, one should be cautious in generalizing these results to both other non-clinical populations and clinical populations. Finally, it should be noted that we failed to screen for prior pain conditions in experiment one, which may have reduced the power of the analyses.

Despite these limitations, the present findings expand our understanding of the underlying mechanisms of distraction by demonstrating that focusing attention to information in other sensory modalities might be optimized when the distracting information is presented at another location than the pain location.

Acknowledgments The authors thank Katleen Gardinael for her help in the data collection. Preparation of this paper was partly supported by Grant BOF/GOA2006/001 of Ghent University and FWO project G.017807. There are no conflicts of interest that may arise as a result of this research.

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