PAIN® 152 (2011) 1068–1073

www.elsevier.com/locate/pain

Attempts to control pain prioritize attention towards signals of pain: An experimental study

Lies Notebaert [a,*], Geert Crombez [a], Julia Vogt [a], Jan De Houwer [a], Stefaan Van Damme [a], Jan Theeuwes [b]

[a] Ghent University, Belgium
[b] Vrije Universiteit, Amsterdam, The Netherlands

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

ARTICLE INFO

Article history:
Received 26 January 2010
Received in revised form 8 November 2010
Accepted 14 January 2011

Keywords:
Pain
Attentional bias
Avoidance
Fear
Anxiety
Hypervigilance
Control

ABSTRACT

Clinical evidence suggests that a persistent search for solutions for chronic pain may bring along costs at the cognitive, affective, and behavioral level. Specifically, attempts to control pain may fuel hypervigilance and prioritize attention towards pain-related information. This hypothesis was investigated in an experiment with 41 healthy volunteers. Prioritization of attention towards a signal for pain was measured using an adaptation of a visual search paradigm in which participants had to search for a target presented in a varying number of colored circles. One of these colors (Conditioned Stimulus) became a signal for pain (Unconditioned Stimulus: electrocutaneous stimulus at tolerance level) using a classical conditioning procedure. Intermixed with the visual search task, participants also performed another task. In the pain-control group, participants were informed that correct and fast responses on trials of this second task would result in an avoidance of the Unconditioned Stimulus. In the comparison group, performance on the second task was not instrumental in controlling pain. Results showed that in the pain-control group, attention was more prioritized towards the Conditioned Stimulus than in the comparison group. The theoretical and clinical implications of these results are discussed.

1. Introduction

Imagine a man suffering from persistent back pain and worrying about the future. He considers possible ways out, visits numerous doctors, and tries several body postures to keep pain under control. He is determined to obtain control over his pain problem. Will he become hypervigilant to pain and pain-related information?

Pain demands attention [12] and often interferes with the accomplishment of valued activities [20]. Therefore it is no surprise that individuals seek pain relief and attempt to get rid of the pain. Initially, trying to control pain is an adaptive coping strategy, and when this strategy is not immediately successful, individuals do not tend to give up quickly, but simply increase effort [42]. However, persistent attempts to solve the pain problem may prove futile and even maladaptive when the pain is a largely insoluble problem, as is often the case in chronic pain patients.

Recent theory suggests that the tenacious pursuit of pain relief may bring along costs at the cognitive, affective, and behavioral levels [1,13,26]. Ironically, attempts to control pain may fuel hypervigilance to pain and increase capture of attention by pain-related information [13]. To date, this argument is largely based on cross-sectional self-report data from clinical studies. For example, persistent attempts to solve chronic pain (measured by the Pain Solutions Questionnaire) are related to self reports of heightened attention to pain and affective distress [11]. Conversely, the willingness to experience pain without the need to control it (measured by the Chronic Pain Acceptance Questionnaire [14]) is positively related to cognitive, social, and physical functioning, and negatively related to attention to pain [25,52]. To our knowledge, there is only one experimental study [8] showing that attempts to remain in control over pain produce attentional costs. However, in that study it was not possible to identify which specific attentional processes [5,34,43] were involved, as only a crude measure of attention was used (task decrement on a secondary task).

The objective of the present study was to investigate whether attempts to control pain lead to an enhanced prioritization of signals of pain. We used an adaptation of a visual search paradigm [31,40] that allows investigating attentional bias to and prioritization of learned signals of pain. In this paradigm, one stimulus is a signal for pain because it indicates that participants might receive a painful electrocutaneous stimulus. Participants had to perform a visual search task in which attention to signals for pain was mea-

* Corresponding author. Address: Department of Experimental-Clinical and Health Psychology, Ghent University, Henri Dunantlaan 2, Ghent B-9000, Belgium. Tel.: +32 9 264 91 05; fax: +32 9 264 64 89.
E-mail address: lies.notebaert@ugent.be (L. Notebaert).

0304-3959/$36.00
doi:10.1016/j.pain.2011.01.020

sured. On a secondary task, intermixed with the visual search task, half of the participants could attempt to control pain. Of particular interest to the current study was whether these attempts to control pain lead to enhanced prioritization of signals of pain in the visual search task.

2. Method

2.1. Participants

Forty-five students of Ghent University participated in partial fulfillment of course credit. After the acquisition phase, 4 participants were not able to correctly identify the pain-related color, and were removed from further analyses. The final sample consisted of 22 participants in the pain-control group (11 males, mean age = 18.9 years, SD = 2.1) and 19 in the comparison group (6 males, mean age = 18.4 years, SD = 1.0). All had normal or corrected-to-normal vision, and reported not to be color-blind. Participants gave their informed consent, and were informed that they could terminate the experiment at any time. No one made use of this option. The study was approved by the ethical committee of the Faculty of Psychology and Educational Sciences of Ghent University.

2.2. Stimulus material and apparatus

Electrocutaneous stimuli (unconditioned stimuli or US's) were delivered by a constant current stimulator (DIGITIMER, model DS7A; Digitimer Ltd, Hertfordshire, UK), and administered to the inside of the wrist of the nondominant forearm by 2 lubricated Fukuda standard Ag/AgCl electrodes (1 cm diameter). The electrocutaneous stimuli consisted of a series of 38 rectangular pulses (2 ms in duration with an interpulse interval of 6 ms), and had a total duration of 300 ms. The intensity of the US was the maximum intensity that participants were willing to tolerate.

The experiment was programmed using the E-Prime software package (Psychology Software Tools Inc, Sharpsburg, PA, USA) [37]. Participants were seated approximately 60 cm from the screen. There were 2 types of trials, visual search trials and identification trials. The purpose of the visual search task was to measure allocation of attention to threat; the purpose of the identification trials was to manipulate pain control.

2.2.1. The visual search task

A graphical representation of the stimuli in the visual search task can be found in Fig. 1. On each visual search trial, the computer display consisted of a varying number of circles (2.9° diameter) with a colored band (0.5° and black outlined) against a silver background color. These colored circles were spaced equally distant from the midpoint of an imaginary circle (radius of 6° visual angle, center of the screen). The number of circles presented (3, 5, or 7) is the set size. Each colored circle in the display contained a black line segment (extending 1°) in their center. One of the circles contained the target line, the other circles contained distractor lines. The target was either a horizontal or a vertical line segment. The distractors were tilted line segments (22.5° to either side of the horizontal or vertical plane; adopted from Theeuwes [40]). All circles in the display had different colors. There were nine possible colors: pink, blue, turquoise, yellow, green, orange, purple, red, and grey. These colors were matched for intensity and luminance.

There were 3 types of trials (Fig. 1). (1) During *congruent trials*, the target was presented in the color that was linked to the electrocutaneous stimulus (this color is the conditioned stimulus, or CS+); (2) During *incongruent trials*, the CS+ was present but the target was depicted in another colored circle; (3) During *baseline trials*, a target, but no CS+, was present. In order for the pain-related color (CS+) to remain threatening and predictive of the US, we chose the following procedural aspects. First, in order to keep the CS+ threatening, only half of the trials contained the CS+. Second, during each block, 4 trials in which the CS+ was followed by the US were added to avoid extinction [24]. To make sure that participants could not strategically use the CS+ to localize the target, we used the 1/n procedure (where n is set size), so for each set size, the CS+ was not predictive of the target [19]. This means that for set size 3, 1 out of 3 trials in which a CS+ was presented was a congruent trial; for set size 5, 1 in 5 trials was a congruent trial; and for set size 7, 1 in 7 trials was a congruent trial. This way, the target is not more likely to appear in the CS+ than in any of the other colors. A detailed account of the distribution of trials can be found in Table 1. Participants were instructed to focus on the fixation cross at the beginning of each trial. Each trial started with a fixation cross at the center of the screen for a duration of 1000 ms, after which the stimulus display was presented until response. Error feedback was displayed for 500 ms. The intertrial interval was 750 ms. The speed of target identification (whether the line segment was horizontal or vertical) was measured using a 2-button response box. Responses had to be made with the index and middle finger of the dominant hand.

2.2.2. The identification task

On each trial of the identification task, the display consisted of one colored circle that, in contrast to the visual search trials, was presented at fixation, at the center of the computer screen. Other perceptual features were identical to those from a visual search trial. A trial started with a fixation asterisk (1000 ms), after which a stimulus was presented for a duration of 1000 ms or until a response was made. Error feedback was given for 500 ms. All participants were informed that after a fixation asterisk, only one

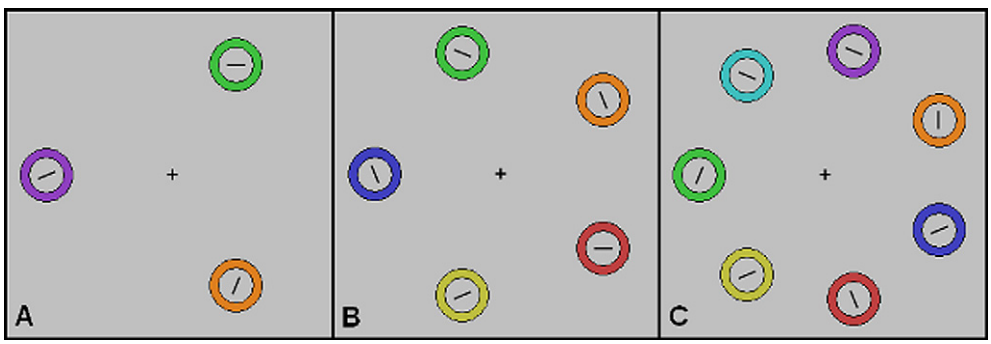

Fig. 1. Examples of the different stimulus displays (not to scale). The red circle represents the CS+. (A) Baseline trial of set size 3 with horizontal target. (B) Congruent trial of set size 5 with horizontal target. (C) Incongruent trial of set size 7 with vertical target.

Table 1
Distribution of trials in each of the 4 blocks.

	Set size 3	Set size 5	Set size 7
Congruent	3	3	3
Incongruent	6	12	18
Baseline	9	15	21

stimulus would be presented at the center of the screen, and that they had to press the spacebar when this was the CS+. In the pain-control group, participants were informed that they could avoid the delivery of the US on that trial by pressing the spacebar as quickly as possible with the nondominant hand when the CS+ was presented. They were informed that a fast response would lead to a 90% probability of avoiding pain on that trial, and that a slow response would lead to a 90% probability that the US would be delivered on that trial. This probability factor was included to raise the credibility of the instructions, because actually their reaction had no influence on whether or not a US would be delivered. Whenever another stimulus was presented, no response had to be made. In the comparison group, participants were also instructed to press the spacebar as fast as possible when the CS+ was presented. However, no information was given about the putative instrumentality of these responses. In fact, in both the pain-control group and the comparison group, response speed and accuracy did not influence US probability. All participants were administered an equal number of US's on CS+ trials. Out of the 47 identification trials in each block, the CS+ was presented on 7 trials, 3 of which were followed by a US (and the error feedback "Too slow" was given in the pain-control group).

2.3. Procedure

Upon arrival, the tolerance level of the electrocutaneous stimulus was determined. To increase the threat value of the electrocutaneous stimulus, participants were incorrectly informed that even though most of the electrocutaneous stimuli would be of the selected intensity, the intensity could be increased during the experiment [7]. Participants were explained that "such a strategy was necessary to keep the intensity at tolerance level because participants often habituate towards electrocutaneous stimuli."

Next, participants practiced the visual search task on 15 trials. Electrocutaneous stimuli were not applied during the practice phase. During the subsequent acquisition phase, participants were instructed to find out which color (Conditioned Stimulus, CS+; counterbalanced across participants) was linked to the electrocutaneous stimulus (Unconditioned Stimulus, US). Participants did not have to perform the target identification task during this phase. Colored circles without line segments were presented. To facilitate acquisition, this phase started with 8 trials of set size 1, followed by 4 trials of set size 3, then 4 trials of set size 5, and then 4 trials of set size 7. In half of the trials (that is, in 10 trials, equally distributed over all set sizes), the CS+ was presented. Half of the CS+ trials were followed by the US (50% partial reinforcement schedule), which was presented at CS+ offset. Each participant was administered the same number of trials. At the end of the acquisition phase, participants had to report which color was linked to the US. Participants who did not answer this question correctly were not included in the analyses.

The experiment phase consisted of 4 blocks of 141 trials and was based on a procedure by Vogt and colleagues [51], developed to keep a particular goal activated. In each block, there were 94 visual search trials and 47 identification trials. The order of the trials was determined randomly except for the fact that each series of 3 consecutive trials started with 2 search trials and ended with an identification trial.

After acquisition and at the end of the experiment, participants were requested to report how intense, painful, and frightening the US was (0 = *Not at all*, to 9 = *Extremely*) and how unpleasant (0 = *Very unpleasant*, to 5 = *Neutral*, to 10 = *Very pleasant*) using Likert scales. At the end of the experiment, in order to assess whether conditioning was successful, participants also reported to what extent the US was expected after presentation of the CS+ (0 = *Never*, to 9 = *Always*), and how fearful they were during the presentation of the CS+ (0 = *Not at all*, to 9 = *Very*). In addition, participants reported how much control they felt they had over the presentation of the US in the identification task and the visual search task (0 = *No control*, to 9 = *A lot of control*).

3. Results

3.1. Data trimming

Trials on which a US was presented were not taken into account for analyses because it is likely that the administration of the US interfered with reaction times on these trials. Also, trials with response errors (6.6%) and with outliers (2.6%, defined as reaction times that deviated more than 3 standard deviations from the individual mean of correct responses, calculated for every trial type and set size separately) were removed. We calculated Cohen's *d* and its 95% confidence interval (CI) for relevant terms. For ease of comparison with the norms of Cohen [6], we calculated effect sizes for dependent samples using the formula of Morris and DeShon [28] (see [3]). An effect size of approximately 0.20 is considered a small effect, around 0.50 a medium effect, and 0.80 to infinity a large effect [6]. Standard deviations of the means are reported between brackets.

3.2. Descriptive statistics and manipulation check

The mean tolerance threshold of the intensity of the US was 2.9 [1.6] mA in the comparison group, and 3.3 [4.1] mA in the pain-control group ($t < 1$). Participants rated the US as rather unpleasant (M = 4.3 [2.0]), frightening (M = 5.5 [2.1]), intense (M = 5.8 [1.3]), and rather painful (M = 4.4 [1.9]). They reported being afraid when the CS + was presented on screen (M = 4.8 [2.7]) and quite often expected a US to follow (M = 6.1 [2.2]). There were no differences between groups (all $P > 0.09$) or – regarding the US ratings – between measurement moments (all $P > 0.07$).

The data pattern on the identification trials revealed that our manipulation was successful. Participants in the pain-control group responded significantly faster (M = 418 [121] ms) to the CS+ on identification trials than participants in the comparison group (M = 654 [231]; $t(39) = 3.99$, $P < 0.001$). In addition, participants in the pain-control group had a lower accuracy on identification trials (M = 97.8 [2.4]%) than participants in the comparison group (M = 99.3 [1.1]%; $t(39) = 2.49$, $P < 0.05$). Inspection of the error pattern revealed that the pain-control group made more false alarms (87.2%) than misses (12.8%). In the comparison group there were 44.0% false alarms and 56.0% misses. The McNemar test [27] that compares 2 related proportions indicated a significant difference between error types in the pain-control group ($P < 0.001$) but not in the comparison group ($P > 0.4$). Self reports regarding the feeling of control over the presentation of the US in the identification trials did not reveal the same pattern as the behavioral data, as no difference was found between the pain-control group (M = 4.1 [2.7]) and the comparison group (M = 3.7 [2.9]; $t < 1$). The same was true for self reports concerning control over the US in the visual search task (pain-control group: M = 3.6 [3.2]; comparison group: M = 3.1 [2.5]; $t < 1$). Note, however, that these self-report data were obtained after the experiment phase.

3.3. Visual search data

In a first step, we explored whether our procedure resulted in an attentional bias towards signals of pain. By subtracting congruent from incongruent trials, measured across set sizes, we can see that both groups show a large attentional bias effect: M_{diff} = 434 [203] ms in the pain-control group (t[21] = 10.01, P < 0.001, d = 1.44, 95% CI 1.04–1.84) and M_{diff} = 358 [113] ms in the comparison group (t[19]=13.78, P < 0.001, d = 1.14, 95% CI 0.93–1.34). There was no significant difference in attentional bias between the 2 groups (t[39] = 1.50, P > 0.1). Analyses further revealed that both groups showed difficulty disengaging from the CS+, as indexed by slower reaction times on incongruent trials than on baseline trials: M_{diff} = 108 [92] ms in the pain-control group (t[21]=5.50, P < 0.001; d = 0.25, 95% CI 0.16–0.34) and M_{diff} = 103 [59] ms in the comparison group (t[18]=7.62, P < 0.001; d = 0.36, 95% CI 0.26–0.45). There was no difference in disengagement between groups (t < 1). Analyses further revealed that both groups showed facilitated engagement with the CS+, as indexed by shorter reaction times on congruent trials than on baseline trials: M_{diff} = 326 [153] ms in the pain-control group (t[21]=9.96, P < 0.001; d = 1.35, 95% CI 0.98–1.72) and M_{diff} = 255 [111] ms in the comparison group (t[18]=10.1, P < 0.001; d = 0.81, 95% CI 0.63–0.99). There was no significant difference in engagement between groups (t[39] = 1.71, P = 0.095).

Next, we calculated the search slopes using a linear regression analysis. A search slope is the mean increase in reaction time per additional item in the display [53]. The slope on congruent trials was 51 [60] ms in the pain-control group, and 93 [62] ms in the comparison group. Such a steep search slope is typically observed in tasks where participants adopt a serial search strategy [53]. However, when one stimulus receives attentional priority (eg, an angry face), attention is more often immediately directed to this item in the display, which leads to an attenuation of the search slope [17]. To investigate whether the CS+ is prioritized over the other stimuli, we compared slopes on congruent and baseline trials. The pain-control group showed a prioritization effect since the slope on congruent trials (M = 51 [60] ms) was significantly flatter than the slope on baseline trials (M = 134 [38] ms; t[21] = 6.48, P < 0.001; d = 1.61, 95% CI 0.88–2.34). Also in the comparison group, the slope on congruent trials (M = 93 [62] ms) was significantly flatter than the slope on baseline trials (151 [44] ms; t[18] = 5.46, P < 0.001; d = 1.02, 95% CI 0.59–1.46).

Finally, and most importantly, we tested whether attention towards the CS+ was more prioritized in the pain-control group than in the comparison group. To this end, we compared the search slope on congruent trials between the pain-control group and the comparison group. A planned comparison revealed that the slope on congruent trials was significantly flatter in the pain-control group than in the comparison group (t[39] = 2.22, P < 0.05; d = .70, 95% CI 0.06–1.33) (Fig. 2). There was no difference between the 2 groups for the search slope on baseline trials (t[39] = 1.34, P > 0.1) nor for the slope on incongruent trials (t < 1). A detailed account of these data can be viewed in Table 2.

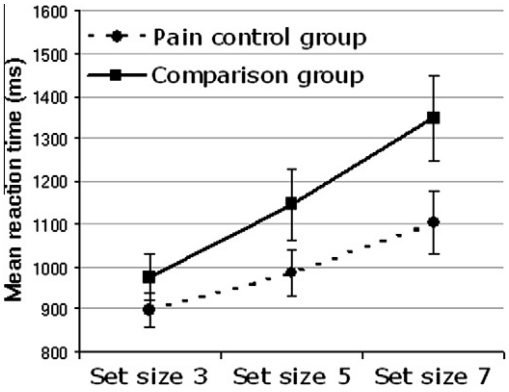

Fig. 2. Mean reaction time and standard error lines for each set size of the congruent trials in the pain control and comparison group.

4. Discussion

This study investigated the extent to which signals of pain prioritize attention when people attempt to control pain. Our results can be readily summarized. First, consistent with previous literature [43,44], attention was biased towards signals of pain. Participants in both groups showed facilitated engagement towards signals of pain, and a difficulty directing attention away from signals of pain. Second, our paradigm allows investigating the extent to which pain-related stimuli are prioritized by attention, because we can assess whether attention is more quickly directed to pain-related stimuli than to neutral stimuli. Results showed that individuals who attempt to control pain reveal stronger prioritization of signals of pain than individuals who do not have this goal. This crucial finding was observed even though the signals of pain in the visual search task have no instrumental value in controlling pain. Thus, installing a goal to control pain in one task seems sufficient to prioritize information that is congruent with that goal, even when this information is not instrumental for the task at hand.

The enhanced prioritization is in line with a recent neurocognitive model of attention to pain [23] that may easily be extended to signals of pain [30]. According to this model, attention is involuntarily captured by salient stimuli in our environment, such as new, rare, or intense events (bottom-up selection). Because pain is intrinsically aversive, it is an eminent candidate for a bottom-up capture of attention [23]. As signals of pain are also salient stimuli, they may activate similar neurophysiological structures such as those activated by pain [33]. Further, although the bottom-up capture is involuntary, it can be modulated by top-down processes [10,15]. When individuals are engaged in the pursuit of a particular goal, they become more sensitive to information that is relevant for the attainment of that goal, and they inhibit the processing of information that interferes with goal pursuit [38]. Hereby, an attentional set related to the pursued goal is formed. This is the mental set of stimulus features that people use to identify goal-relevant stimuli. Stimuli that contain features of this attentional set are likely to attract attention, even when they are not immediately task-relevant [15,51]. In our experiment, the signals of pain were part of the attentional set in both groups, because both groups had to perform the additional task. Thus, we argue that our findings must be explained by taking into account differences in goal characteristics [16]. We suggest that the goal to avoid pain has a high value [45], and that, therefore, individuals in the pain-control group are strongly committed to attain this goal. In line with this idea are the findings that the pain-control group responded faster and made more false alarms on identification trials than the comparison group. The high commitment to the goal to avoid pain then leads to a stronger prioritization of the pain signals in the pain-control group. This explanation is in line with findings of recent studies showing that increasing the value of goals also increases attending to goal-relevant information [21,50].

Our finding extends previous ideas about the origins of hypervigilance and attentional bias to pain-related information. In many clinical models [10,49], pain-related fear is considered the key process for an emergence of hypervigilance to pain. Questionnaire studies [9,18] and experimental studies [41] have corroborated this view. However, this study suggests that attempts to control or avoid pain further fuel this hypervigilance. Hence, not only what

Table 2
Mean reaction times (SD) in ms for each set size in every trial type for both groups.

	Set size 3	Set size 5	Set size 7	Total	Slope
Pain-control group					
Congruent	898 (188)	985 (249)	1104 (346)	964 (231)	51 (60)
Baseline	953 (193)	1234 (232)	1489 (296)	1299 (248)	134 (38)
Incongruent	1076 (229)	1324 (294)	1560 (364)	1402 (318)	121 (46)
Comparison group					
Congruent	977 (230)	1145 (357)	1351 (433)	1133 (320)	94 (61)
Baseline	1026 (222)	1299 (236)	1631 (356)	1394 (286)	151 (44)
Incongruent	1153 (259)	1369 (286)	1679 (306)	1493 (289)	131 (31)

patients fear about pain, but also how they cope with pain, matters. This indicates that a persistent search for solutions for pain may come along with attentional costs, such as hypervigilance towards pain, in patients with chronic pain [13,26]. An important avenue for further research will be to investigate the attentional dynamics towards pain and pain-related information from a goal perspective [45].

Although attentional bias to pain-related information is well established, the typical effects are relatively small [32]. In our study, the effect size of attentional bias to signals of pain (reaction times on incongruent trials minus reaction times on congruent trials) is large. This may be due to procedural differences with other studies. First, whereas previous studies investigating attentional bias used complex stimuli (like words [36]), we used simple visual stimuli (colors) that may be especially effective in modifying attention [22,46]. Second, we used a classical conditioning procedure with the threat of a painful stimulus at tolerance level. This procedure was aimed at preventing habituation to the electrocutaneous stimuli [7]. Third, the selection of pain-related information may especially emerge in a context of multiple, competing stimuli [10]. Indeed, in comparison with other paradigms such as the exogenous cueing (where only one stimulus is presented [46]) and dot probe paradigm (where 2 stimuli are presented simultaneously [2]), our visual search paradigm displays more elements. In line with previous studies of our laboratory, creating signals for pain using a classical conditioning procedure results in both a facilitated engagement of attention to the CS+ and a difficulty disengaging attention from the CS+, once detected [44]. Compared to these previous findings where effect sizes for engagement were small, we here observed a strong engagement of attention with the CS+. Further results of our study indicate that a facilitation of engagement with the CS+ is best revealed in a context with several competing stimuli since the engagement effect increased with increasing set size. The finding that attempts to control pain influenced only prioritization and not attentional bias in general, might be due to the fact that in both groups, participants selected the intensity of the US at tolerance level. The ratings showed that both groups found the US equally painful and threatening, which might explain why they showed similar facilitation and interference effects. It is thus possible that certain variables only affect prioritization and not attentional bias, and vice versa.

The finding that participants in the pain-control group made more false alarms on identification trials than participants in the comparison group is compatible with another study [4] and can be explained by a "better safe than sorry" strategy [39]. Indeed, there were no adverse consequences in pressing the spacebar when no CS+ was presented. However, missing a CS+ presentation increased the risk of receiving a US. Combined with the finding that the pain-control group was faster on identification trials than the comparison group, this speed-accuracy trade-off suggests that participants in the pain-control group were indeed actively trying to avoid the US.

It is remarkable that enhanced prioritization was found even though the pain-control group did not report feeling more in control over the US than the comparison group. This shows that the enhanced prioritization cannot be explained merely by a difference in the subjective feeling of control. In contrast, these ratings indicate that, specifically, the goal to avoid pain produced more prioritization of pain signals. The reason why the perceived control ratings in the pain-control group are relatively low could be because on identification trials, the CS+ was still followed by a US in 3 out of 7 trials. Participants may have felt that their attempts to avoid the US were not very successful. However, this is not necessarily problematic, since goal frustration is known to activate a goal even stronger [29].

Our study has important clinical implications. First, adopting a goal perspective is clearly useful in investigating how and when attention is biased towards signals of pain. Conversely, a goal perspective may also prove useful in identifying how and when attention to pain-related information can be successfully inhibited [23,45,47]. Second, although we focused upon attentional bias and prioritization in this study, we do not argue for a slavish use of attentional control strategies to minimize this bias. We have shown that attentional bias to signals of pain can be acquired by a classical conditioning procedure. It may, likewise, diminish by using an extinction or exposure procedure [44]. Third, treatments that focus upon accepting pain and relinquishing attempts to control uncontrollable pain may be well suited for reducing hypervigilance to pain and improving daily functioning [26,35,48].

Finally, some limitations to this study must be addressed. First, participants were instructed to show avoidance behavior. Future research should investigate whether other avoidance strategies, such as attentional defocusing, would lead to the same results. In addition, because of the explicit instructions, participants were very conscious of their avoidance behavior. It is yet unclear whether behavior of which people are less aware produces similar attentional effects. Second, since we tested healthy volunteers, we have to be cautious when generalizing these results to clinical samples. Third, there were more male participants in the pain-control group, which may explain the higher variability in the pain tolerance level in this group. However, it must be noted that there was no difference between the groups in the ratings concerning the intensity and painfulness of the US. Future research could investigate the role of gender in attempts to control pain.

Acknowledgments

This research was funded by a Special Research Fund (BOF) and grant BOF/GOA2006/001 of Ghent University. Stefaan Van Damme was supported by the Fund for Scientific Research Flanders (Belgium) and by an IASP Early Career Research Grant. There are no conflicts of interest that may arise as a result of this research.

References

[1] Aldrich S, Eccleston C, Crombez G. Worrying about chronic pain: vigilance to threat and misdirected problem solving. Behav Res Ther 2000;5:457–70.
[2] Asmundson GJG, Carleton RN, Ekong J. Dot-probe evaluation of selective attentional processing of pain cues in patients with chronic headaches. Pain 2005;114:250–6.

[3] Borenstein MJ, Hedges L, Higgins JP, Rothstein HR. Introduction to meta-analysis. Chichester, UK: Wiley; 2009.
[4] Brandtstädter J, Voss A, Rothermund K. Perception of danger signals: the role of control. Exp Psychol 2004;51:24–32.
[5] Bundesen C. A theory of visual-attention. Psychol Rev 1990;97:523–47.
[6] Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, NJ: Erlbaum; 1988.
[7] Crombez G, Eccleston C, Baeyens F, Eelen P. When somatic information threatens, catastrophic thinking about pain enhances attentional interference. Pain 1998;75:187–98.
[8] Crombez G, Eccleston C, De Vlieger P, Van Damme S, De Clercq A. Is it better to have controlled and lost than never to have controlled at all? An experimental investigation of control over pain. Pain 2008;137:631–9.
[9] Crombez G, Eccleston C, Van den Broeck A, Goubert L, Van Houdenhove B. Hypervigilance to pain in fibromyalgia: the mediating role of pain intensity and catastrophic thinking about pain. Clin J Pain 2004;20:98–102.
[10] Crombez G, Van Damme S, Eccleston C. Hypervigilance to pain: an experimental and clinical analysis. Pain 2005;116:4–7.
[11] De Vlieger P, Van den Bussche E, Eccleston C, Crombez G. Finding a solution to the problem of pain: conceptual formulation and the development of the pain solutions questionnaire (PASOL). Pain 2006;123:285–93.
[12] Eccleston C, Crombez G. Pain demands attention: a cognitive-affective model of the interruptive function of pain. Psychol Bull 1999;125:356–66.
[13] Eccleston C, Crombez G. Worry and chronic pain: a misdirected problem solving model. Pain 2007;132:233–6.
[14] Fish RA, McGuire B, Hogan M, Morrison TG, Stewart I. Validation of the Chronic Pain Acceptance Questionnaire (CPAQ) in an internet sample and development and preliminary validation of the CPAQ-8. Pain 2010;149:435–43.
[15] Folk CL, Remington RW, Johnston JC. Involuntary covert orienting is contingent on attentional control settings. J Exp Psychol Hum Percept Perform 1993;18:1030–44.
[16] Förster J, Liberman N, Higgins E. Accessibility from active and fulfilled goals. J Exp Soc Psychol 2005;41:220–39.
[17] Frischen A, Eastwood JD, Smilek D. Visual search for faces with emotional expressions. Psychol Bull 2008;134:662–76.
[18] Goubert L, Crombez G, Van Damme S. The role of neuroticism, pain catastrophizing and pain-related fear in vigilance to pain: a structural equations approach. Pain 2004;107:234–41.
[19] Jonides J, Yantis S. Uniqueness of abrupt visual onset in capturing attention. Percept Psychophys 1988;43:346–54.
[20] Karoly P, Ruehlman LS. Psychosocial aspects of pain-related life task interference. an exploratory analysis in a general population sample. Pain Med 2007;8:563–72.
[21] Kiss M, Driver J, Eimer M. Reward priority of visual target singletons modulates ERP signatures of attentional selection. Psychol Sci 2009;20:245–51.
[22] LeDoux J. Fear and the brain: where have we been, and where are we going? Biol Psychiatry 1998;44:1229–38.
[23] Legrain V, Van Damme S, Eccleston C, Davis KD, Seminowics DA, Crombez G. A neurocognitive model of attention to pain: Behavioral and neuroimaging evidence. Pain 2009;144:230–2.
[24] Mackintosh NJ. The psychology of animal learning. New York: Academic Press; 1974.
[25] McCracken LM, Carson JW, Eccleston C, Keefe FJ. Acceptance and change in the context of chronic pain. Pain 2004;109:4–7.
[26] McCracken LM, Vowles KE, Gauntlett-Gilbert J. A prospective investigation of acceptance and control-oriented coping with chronic pain. J Behav Med 2007;30:339–49.
[27] McNemar Q. Note on the sampling error of the differences of correlated proportions of percentages. Psychometrika 1947;12:153–7.
[28] Morris SB, DeShon RP. Combining effect size estimates in meta-analysis with repeated measures and independent-groups designs. Psychol Methods 2002;7:105–25.
[29] Moskowitz GB. Preconscious effects of temporary goals on attention. J Exp Soc Psychol 2002;38:397–404.
[30] Mouraux A, Iannetti GD. Nociceptive laser-evoked brain potentioals do not reflect nociceptive-specific neural activity. J Neurophysiol 2009;101:3258–69.
[31] Notebaert L, Crombez G, Van Damme S, De Houwer J, Theeuwes J. Signals of threat do not capture, but prioritize attention: a classical conditioning approach. Emotion, in press.
[32] Pincus T, Morley S. Cognitive processing bias in chronic pain: a review and integration. Psychol Bull 2001;127:599–617.
[33] Ploghaus A, Tracey I, Gati JS, Clare S, Menon RS, Matthews PM, Rawlins JNP. Dissociating pain from its anticipation in the human brain. Science 1999;284:1979–81.
[34] Posner MI, Petersen SE. The attentional system of the human brain. Annu Rev Neurosci 1990;13:1627–31.
[35] Richardson EJ, Ness TJ, Doleys DM, Banos JH, Cianfrini L, Richards JS. Catastrophizing, acceptance, and interference. laboratory findings, subjective report, and pain willingness as a moderator. Health Psychol 2010;29:299–306.
[36] Roelofs J, Peters ML, Zeegers MPA, Vlaeyen JWS. The modified stroop paradigm as a measure of selective attention towards pain-related stimuli among chronic pain patients: a meta-analysis. Eur J Pain 2002;6:273–81.
[37] Schneider W, Eschman A, Zuccolotto A. E-Prime user's guide. Pittsburgh: Psychology Software Tools Inc; 2002.
[38] Shah JY, Friedman R, Kruglanski AW. Forgetting all else: on the antecedents and consequences of goal shielding. J Pers Soc Psychol 2002;83:1261–80.
[39] Smeets G, de Jong PJ, Mayer B. If you suffer from a headache, then you have a brain tumour: domain-specific reasoning 'bias' and hypochondriasis. Behav Res Ther 2000;38:763–76.
[40] Theeuwes J. Cross-dimensional perceptual selectivity. Percept Psychophys 1991;50:184–93.
[41] Van Damme S, Crombez G, Eccleston C. The anticipation of pain modulates spatial attention: evidence for pain-specificity in high pain catastrophizers. Pain 2004;111:392–9.
[42] Van Damme S, Crombez G, Eccleston C. Coping with pain: a motivational perspective. Pain 2008;139:1–4.
[43] Van Damme S, Crombez G, Eccleston C, Koster EHW. Hypervigilance to learned pain signals: a componential analysis. J Pain 2006;7:346–57.
[44] Van Damme S, Crombez G, Hermans D, Koster EHW, Eccleston C. The role of extinction and reinstatement in attentional bias to threat: a conditioning approach. Behav Res Ther 2006;44:1555–63.
[45] Van Damme S, Legrain V, Vogt J, Crombez G. Keeping pain in mind: a motivational account of attention to pain. Neurosci Biobehav Rev 2010;34:204–13.
[46] Van Damme S, Lorenz J, Eccleston C, Koster EHW, De Clercq A, Crombez G. Fear-conditioned cues of impending pain facilitate attentional engagement. Neurophysiol Clin 2004;34:33–9.
[47] Verhoeven K, Crombez G, Eccleston C, Van Ryckeghem DML, Morley S, Van Damme S. The role of motivation in distracting attention away from pain: an experimental study. Pain 2010;149:229–34.
[48] Viane I, Crombez G, Eccleston C, Devulder J, De Corte W. Acceptance of the unpleasant reality of chronic pain: effects upon attention to pain and engagement with daily activities. Pain 2004;112:282–8.
[49] Vlaeyen JWS, Linton SJ. Fear-avoidance and its consequences in chronic musculoskeletal pain: a state of the art. Pain 2000;85:317–32.
[50] Vogt J, De Houwer J, Crombez G. Multiple goal management starts with attention: Goal prioritising affects the allocation of spatial attention to goal-relevant events. Exp Psychol, in press.
[51] Vogt J, De Houwer J, Moors A, Van Damme S, Crombez G. The automatic orienting of attention to goal-relevant stimuli. Acta Psychol 2010;134:61–9.
[52] Vowles KE, McCracken LA, Eccelston C. Patient functioning and catastrophizing in chronic pain: the mediating effects of acceptance. Health Psychol 2008;27:S136–43.
[53] Wolfe J. Visual search. In: Pashler H, editor. Attention. London, UK: University College London Press; 1998.