ORIGINAL ARTICLE

Experimental pain induces attentional bias that is modified by enhanced motivation: An eye tracking study

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Conflicts of interest
None declared.

Abstract

Background: In this study, the effects of prior pain experience and motivation on attentional bias towards pain-related information were investigated within two visual-probe tasks via eye movement behaviours. It is hypothesized that pain experience would induce stronger attentional bias and such bias could be suppressed by the motivation to avoid impeding pain.
Methods: All participants took part in visual-probe tasks with pictures and words as stimuli that are typically used in studies of attentional bias. They were allocated to three groups: no-pain (NP) group, performing tasks without experiencing pain; pain-experience (PE) group, performing the same tasks following painful stimuli; and pain-experience-with-motivation (PEM) group, undergoing the same procedure as PE group with additional instructions about avoiding impeding pain. Eye movements were recorded during the tasks.
Results: The eye movement data showed that: (1) participants in the PE group exhibited stronger attention bias towards painful pictures than those in the NP group; (2) the attentional bias towards painful pictures was significantly reduced in the PEM group as compared to the PE group. By contrast, the verbal task failed to find these effects using sensory pain words as stimuli.
Conclusion: This study was the first that revealed the impact of acute experimental pain on attentional bias towards pain-related information in healthy individuals through eye tracking. It may provide a possible solution to reduce hypervigilance towards pain-related information by altering the motivational relevance.
What does this study add?: (1) This study revealed the impact of experimental pain on attentional bias in healthy individuals; (2) This study may provide a possible approach of altering motivational relevance to control the pain-induced attentional bias towards pain-related information.

1. Introduction

Existing theory and research on pain have supported that patients with chronic pain selectively attend to pain-related information at the cost of other environmental information, and such hypervigilance might contribute to the development and maintenance of chronic pain (Eccleston and Crombez, 1999; Pincus and Morley, 2001). In recent years, researchers have shown particular interests in the relationship between attentional bias and pain. Although previous studies have revealed a stronger attentional bias in pain patients than in healthy individuals, laboratory studies using experimental pain can seldom replicate the results obtained in clinical settings.

The pain-related attentional bias has been investigated within a dot-probe paradigm, and is defined as faster response to the probe appearing at the same spatial location as pain-related cues. Given that the bottom-up attentional processing involves multiple processes, including attentional orientation, engagement and holding (Allport, 1989), reaction time may be not an effective measure as it only provides a snapshot of attention process. The well-known techniques that measure dynamic temporal responses are the electroencephalography (EEG) and eye tracking method (Yang et al., 2012; Priebe et al., 2015). EEG could depict continuous neural activities corresponding to attentional process (Engel et al., 2001; Thut et al., 2006); eye tracking has the ability to capture dynamics of behaviour (e.g. reading), and is a direct and sensitive tool for detecting eye gaze and visual spatial attention. Thus, the current study attempted to, using eye tracking method, verify whether acute pain experience would induce stronger attentional bias towards pain-related information.

Research has demonstrated that motivational factors affect performance in the pain-related tasks (Van Damme et al., 2008, 2010). Motivation is a theoretical construct that explains why and how human behaviour is activated. Goals play the central role in motivation, because they are direct, proximal regulators of behaviour (Elliot and Covington, 2001). Approach and avoidance are two basic motivational orientations, and task-involved goal manipulations have been commonly used in motivation-related studies (Elliot, 2006; Elliot et al., 2013). For example, Verhoeven et al. (2010) manipulated subjects' motivation by a monetary reward in a distraction task during pain. They found that the task performance was better in the motivated-distraction group compared with the distraction-only group. Schrooten et al. (2012) also revealed that pursuing a concurrent, task-irrelevant goal inhibited the attentional bias towards pain signals. Based on these findings, another aim of our study was to examine how an avoidance motivation affected the pain-related attentional bias.

Studies of attentional bias typically use words and pictures with emotional content as stimuli. Consequently, the present study employed both verbal and pictorial visual-probe tasks (with words and pictures as stimuli, respectively) to examine the pain-related attentional bias. For the verbal task, health catastrophe words were used to control the individuals' vigilance to general threat information. The pictorial task did not employ catastrophe stimuli because it is difficult to match the content of catastrophic pictures with painful pictures. In addition, the psychological factors related to pain, including pain anxiety, fear of pain and pain catastrophizing were assessed by questionnaires, in order to control the differences among groups. The present study attempted to test the following two hypotheses: (1) the eye tracking movement data would reveal stronger attentional bias towards pain-related materials in subjects who experienced experimental pain as compared to those without pain experience; (2) the pain-related attentional bias would be inhibited when subjects were motivated to pursue a goal (i.e. achieving better task performance). We predict that the eye movement indices on attention maintenance are most likely to reveal pain-related attentional bias, because attention towards pain-related information is thought to rely on conscious and elaborate processes (Crombez et al., 2013).

2. Materials and methods

2.1 Participants

Sixty-five adults (31 men, mean age = 22.15 years) participated in this experiment. Participants were recruited from local universities through advertisements posted on the websites. Inclusion criteria were as follows: (1) normal or corrected-to-normal vision; (2) age 18 years or more; (3) no any forms of chronic pain or psychiatric disorders; (4) naïve to the purpose of the research. All of them finished the whole procedure of the experiment. Ethics approval for this study was granted by the Research Ethics Committee of the Institution of Psychology, Chinese Academy of Sciences.

2.2 Questionnaire measures

The following questionnaires were used for assessing state and trait anxiety, pain-related anxiety, pain catastrophizing and fear of pain.

The Chinese version of the State-Trait Anxiety Inventory (STAI) is 40-item self-report measure of state and trait anxiety (Shek, 1988) Participants rated each item on a 4-point Likert scales. Possible scores range from 20 to 80 separately for state and trait subscale. Higher scores represent more frequent and intense feelings of anxiety. The Chinese version of STAI has a satisfactory internal consistency (Cronbach's alpha = 0.89).

The Chinese version of the 20-Item Pain Anxiety Symptoms Scale (ChPASS-20) was used to assess

four dimensions of pain anxiety, including avoidance, fear, cognitive anxiety and physiological anxiety (Wong et al., 2012). Participants rated each items on a 5-point Likert Scale. All ChPASS-20 subscales demonstrate acceptable-to-good internal consistency (Cronbach's alpha: 0.72 ~ 0.92).

The Chinese version of the Pain Catastrophizing Scale (PCS) is a 13-item self-report questionnaire consisting of three subscales: rumination, magnification and helplessness (Yap et al., 2008). Participants indicated the degree to which they experienced catastrophic thoughts or feelings during pain episodes using a 5-point scale. Internal consistency of Chinese version of PCS is 0.927 and test–retest reliability is above 0.9.

The 30-item Fear of Pain Questionnaire III (FPQ III) consists of Severe Pain, Minor Pain and Medical Pain subscales (McNeil and Rainwater, 1998). Participants rated items from 1 = 'not at all' to 5 = 'extreme' to indicate the level of fear if they are exposed to different painful situations. The FPQ possesses high internal consistency. The Chinese version of FPQ III used in the experiment has been translated, tested by the research group of Southwest University, Chongqing, China (Yang et al., 2013). The three-factor solution was replicated with the exception of dropping items 4, 18, 22 and 27, which failed to load, double-loaded or loaded on a conceptually dissimilar factor (Yang et al., 2012). The alpha for this 26-item FPQ is 0.873 in the research sample.

2.3 Apparatus and materials

The PATHWAY Pain & Sensory Evaluation System with CHEPS (Contact Heat Evoked Potentials) thermode was used to administer thermal stimuli and explore pain tolerance level. The PATHWAY is a computer-controlled system in which a set of stimuli is emitted. The CHEPS thermode (27 mm in diameter) was attached to the forearm of participants. A Limits Method was used, with which the temperature of thermode was raised from baseline temperature (32 °C) at a constant rate (1 °C/s) until participants pressed keyboard to stop it.

Visual stimuli were presented with an 18-inch CRT monitor with a 1024×768-pixel resolution and an 85-Hz refresh rate. Eye movement data were recorded via an SR-research Eyelink1000 eye tracker system running at 1000 Hz, with recommended settings for cognitive experiments (Stampe, 1993). A height-adjustable chinrest was used to avoid head movements. The SR-Research Experiment Builder was used for programming and running the task.

The pictorial task used 10 black-and-white photo pairs as experimental stimuli, each pair consisting of a painful photo and a non-painful photo (see Fig. 1A). All photo pairs depicted familiar situations in daily life. The difference between two photos in each pair was containing painful components or not (e.g. a pair of photos of hammer striking on a hand or on a nail, where the hand struck by hammer was a painful component). Each painful versus non-painful photo pair was displayed four times. Other 10 non-painful photo pairs were used in filler trials, and each pair was displayed twice. The photos were adopted from Jackson et al. (2005). The word task used 12 sensory pain-neutral and 12 health catastrophe-neutral word pairs as experimental stimuli and 12 neutral-neutral word pairs as fillers. The words were selected from the study of Yang et al. (2012), and were equated for the total number of Chinese character strokes and frequency of occurrence in the Chinese language. Pain-neutral and catastrophe-neutral word pairs were displayed twice, and neutral-neutral pairs were displayed only once.

2.4 Visual-probe tasks and pain tolerance measurement

Eye movements were recorded in a pictorial visual-probe task as well as a verbal task. Each trial of pictorial task began with a black dot presented in the centre of the screen (drift check). After ensuring that participants fixed their eyes on the dot, the experimenter started the display of stimuli. A pair of pictures (9 cm height, 13 cm width) was presented for 4000 ms, one on the left side of the dot and the other on the right. The distance between the edges of two pictures was 6.8 cm. Immediately after the pictures disappeared, the target letter 'p' or 'q' appeared in one of the two locations. Participants were requested to press the corresponding 'p' or 'q' on the keyboard as accurately and quickly as possible. The probe letter disappeared immediately after a response was recorded or after a 2000-ms delay. In congruent trials, the target letter appeared in the location of the previous pain-related picture or word (including health catastrophe word) of the pair; in incongruent trials, it appeared in the location of the neutral ones. The verbal visual-probe task was similar to the pictorial one except that the stimuli were word pairs (2 cm height and 3 cm width, and 20 cm distance between them) that were displayed for 2000 ms. The pictorial task consisted of 40 trials and 20 fillers (with same, neutral photos in each location), and the word task consisted of 48 trials and 12 fillers. Target location (left or right) and identity ('p'
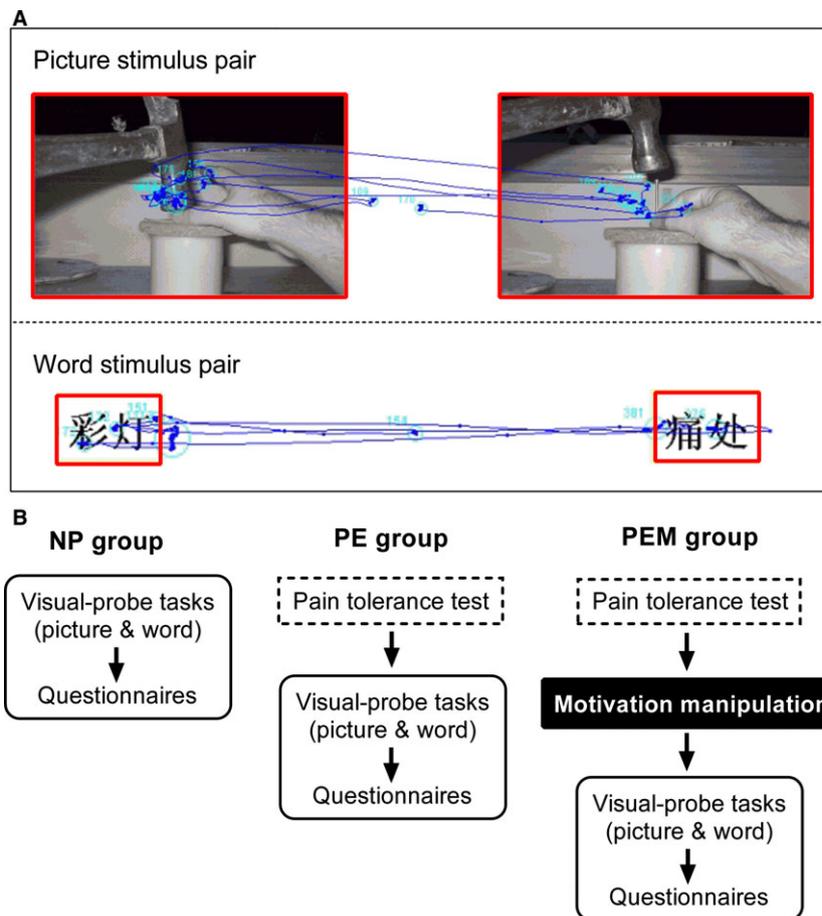
Figure 1 Experimental design. (A) Examples of pictorial pair and verbal pair with superimposed eye movement. Red frames delimit areas of interest (AOI). Light blue numbers and circles show fixation duration (ms) and location, respectively. Deep blue lines present saccades. (B) Experimental procedures for the three groups. NP, no-pain; PE, pain-experience; PEM, pain-experience-with-motivation.

or 'q') were fully counterbalanced across pictures or words. The order of pictorial task and word task was balanced across participants.

Acute pain experience was produced by pain tolerance measurement. A contact heat thermode was applied onto the forearm of participants. The pain tolerance was assessed in three trials. The temperature of thermode increased at rate of 1 °C/s from baseline temperature 32 °C. Participants were asked to close their eyes during the assessment procedure. They were assured that the temperature would not exceed the safe temperature (50 °C). They press 'Y' on the keyboard to stop temperature rising when they cannot endure pain any more. Pain tolerance level was calculated by averaging the response temperatures over the three trials.

The pain tolerance measurement served at least two purposes in this study: (1) for the pain-experience groups, it provided a prior painful experience while avoiding participants aware of the hypothesis

tested in the experiment, i.e. the effect of acute pain experience on attentional bias; (2) for the motivation group, it provided a criterion for possible punishment (although never applied) when the goal was not attained.

2.5 Groups and procedure

Participants were randomly allocated to three groups: no-pain (NP) group ($n = 21$), pain-experience (PE) group ($n = 21$), and pain-experience-with-motivation (PEM) group ($n = 23$). All of them signed the informed consent form after arriving at the laboratory.

All participants took part in the visual-probe tasks with pictures and words as stimuli. The PE group received pain tolerance test before the tasks. The PEM group underwent the same procedure as PE group, except for receiving additional instructions about being stimulated painfully if the task

performance was poor (i.e. motivational manipulation). They were told that the computer would automatically evaluate their performance based on reaction accuracy and speed. If their scores were lower than the average level, CHEPS would administer a safe, but painful stimulus with certain intensity close to their tolerance level. The CHEPS thermode was attached to their left ankles during the tasks. After receiving threatening instructions, participants in the PEM group were asked to assess how worried and fearful they felt about the possible failure in tasks on a 100-point VAS. The scores on worry and fear were used to assess the effectiveness of the motivational manipulation. No one in PEM group would actually be stimulated regardless of their performance.

Participants were seated on a height-adjustable chair, and placed their chin on a chin rest to maintain their eye level to the centre of the screen and avoid their head moving during eye tracking. The distance from participants' eyes to the screen was 64 cm. Before the visual-probe task, participants finished a 9-point calibration procedure. The calibration would be accepted if the average calibration error was less than 0.5° of visual angle and all points had an error smaller than 1°. Each trial began with a drift check (i.e. a central dot). After ensuring the participants gazed on the central dot, the experimenter initiated the visual-probe task. The experimental procedure is illustrated in Fig. 1B.

Before the formal experiment, all participants completed a short practice session consisting of 10 trials. After completing the pictorial and verbal tasks, participants were instructed to fill out four questionnaires in an order of STAI, PASS, PCS and PFQ.

2.6 Eye movement indices

Each picture or word in a trial was defined as an area of interest (AOI) within which eye movements would be monitored (see Fig. 1A). Fixations out of AOIs were excluded from the analysis. Gaze with more than 100-ms durations and over 1° distance from neighbouring gazes was classified as fixation, the duration of which was recorded. Four parameters were calculated for each stimulus (Gao et al., 2011; Holas et al., 2014): (1) First fixation duration (FFD), the duration of time that a participant first fixate on an AOI; (2) First-run dwell time (FRD), the summation of the duration across all initial fixations when a participant first glances at an AOI, until he or she shifts gaze away from the AOI; (3) Dwell time (DT), the total duration of time that a participant

remains fixated on an AOI; (4) First fixation latency (FFL), the time that a participant takes before first fixating on an AOI following the onset of it.

The FFD measures the duration of a single fixation on a visual stimulus, whereas the FRD contains all fixations within the AOI before subjects switch their gaze away from it. Both indices reflect the maintenance of visual attention. The DT is calculated by summarizing the total fixation time on a stimulus for a single trial regardless of attention switching, and reflects overall attentional allocation. The FFL measures the latency of first fixation forming on a stimulus, and reflects attentional orientation.

2.7 Data analysis

Eye movement data were visualized and preprocessed via SR-Research DataViewer. All analyses were conducted using SPSS 22.0 (IBM Corporation, Armonk, NY, USA). Five participants were removed from the analysis due to that their saccades were out of the AOIs in more than 10% of trials, thus leaving a total of 60 participants (for each group, $n = 20$) for final analysis.

2.7.1 Analysis for eye movement data

Attentional bias scores for photo or word stimuli were obtained by subtracting the eye movement indices of neutral stimulus from those of the corresponding pain- or threat-related stimulus in each trial. The bias scores were calculated separately for pictorial task and verbal task.

Data of the pictorial task were analysed using one-way ANOVA, with group (NP, PE and PEM) as the between-subject variable. Dunnett's one-tailed t-test was performed to test if the means of NP group and PEM group was significantly smaller than that of the PE group. It should be noted that *post hoc* test would be conducted even if the p value for an ANOVA approaches but not reaches significance, because *post hoc* were regarded valid in such cases (Hsu, 1996; Liossi et al., 2014).

For the verbal task, analysis of covariance (ANCOVA), with bias score to catastrophe words entered as covariate, was conducted for each dependent variable of eye movement indices (FFD, FRD, DT and FFL bias scores). Then, a 2 (word type: sensory pain vs. health catastrophe) $\times$ 3 (group: NP, PE and PEM)) ANOVA was conducted on bias scores, with group as between-subject variable and word type as within-subject variable. Pairwise comparisons using Fisher's least significant difference method were used to clarify significant interactions.

2.7.2 Analysis for reaction time

Reaction time was calculated separately for congruent trails and incongruent trails. Analyses were performed on reaction time for picture task and word task separately. Mixed ANOVAs were conducted with congruence as a variable. In addition, the mean reaction time (mRT) was calculated by averaging the reaction times in all trails, which represents the average speed in which participants detected the probe. One-way ANOVA and Dunnett t-test were used to examine the differences among groups. Significant difference in mRT between PEM vs. PE would indicate successful manipulation of motivation.

Chi-square tests and one-way ANOVAs were used to explore differences in demographic characteristics and questionnaire data between groups. Partial eta-squared η^2 and Cohen's d were used to quantify effect sizes in ANOVAs and *post hoc* tests, respectively. Significance level was set at $p < 0.05$.

3. Results

3.1 Participant characteristics

The three groups were comparable for sex ratio, years of age, and questionnaire scores (i.e. scores on STAI, PASS-20, PCS, and FPQ III) (all Ps > 0.05), as shown in Table 1. In addition, no difference was found between PE group and PEM group in the pain tolerance levels (see Table 1), suggesting that they had experienced the same degree of pain.

3.2 Analysis of eye movement behaviours

The eye movement data of the visual-probe tasks are presented in Table 2. The attentional bias scores (subtracting the eye movement indices of neutral stimulus from those of the corresponding pain- or threat-related stimulus) of each participant were used in the statistical analysis.

3.2.1 Pictorial visual-probe task

In the picture task, when the bias score indices for FFD, FRD, DT were examined separately, we found similar patterns across groups in terms of the difference between NP versus PE and PE versus PEM (see Fig. 2A, B and C).

3.2.1.1 FRD

One-way ANOVA revealed a significant main effect of group only for the FRD bias score ($F(2, 59) = 3.67$, $p = 0.032$, $\eta^2 = 0.11$). *Post hoc* analysis showed significant difference between NP versus PE (mean difference (MD) = 98.98, $p = 0.011$, $d = 0.80$) as well as between PE versus PEM (MD = 74.72, $p = 0.049$, $d = 0.63$) (Fig. 2B). The higher score of PE than NP indicates that people with acute pain experience have increased attentional bias towards pain-related information as compared to those without pain experience; the lower score of PEM than PE indicates that the pain-related attentional bias is suppressed by motivation.

3.2.1.2 FFD, DT and FFL

Although no significant main effect was found for the FFD bias score ($F(2, 59) = 1.95$, $p = 0.15$, $\eta^2 = 0.064$), pairwise comparisons showed that there was a trend towards stronger bias of PE group than NP group (MD = 26.08, $p = 0.077$, $d = 0.48$), and a trend towards significant difference between PE versus PEM (MD = 25.21, $p = 0.086$, $d = 0.52$)

Table 1 Means (SD) for self-reported characteristics of three groups.

Measure	Group			F/t value	p value
	NP (n = 20)	PE (n = 20)	PEM (n = 20)		
Sex	10 men	10 men	10 men		1
Age in years	22.40 (2.19)	22.35 (2.16)	21.58 (2.12)	0.67	0.52
TAI	46.65 (5.39)	43.2 (5.19)	46.75 (5.67)	2.78	0.07
SAI	42.65 (6.68)	41.15 (4.27)	45.45 (4.63)	2.99	0.06
PASS-20	53.55 (17.86)	47.6 (13.05)	46.35 (15.10)	1.24	0.30
PCS	28.20 (11.85)	23.55 (8.03)	26.45 (8.06)	1.23	0.20
FPQ III	97.45 (16.47)	101.72 (9.80)	94.5 (14.65)	1.52	0.23
Pain tolerance threshold (°C)	–	44.75 (2.99)	45.81 (2.16)	1.29	0.20
Fear			41.92 (21.87)		
Worry			32.71 (20.21)		

NP, no-pain group; PE, pain-experience group; PEM, pain-experience-with-motivation-group; TAI, Trait Anxiety Index; SAI, Strait Anxiety Index; PASS, Pain Anxiety Symptoms Scales; PCS, Pain Catastrophizing Scale; PFQ, Fear of Pain Questionnaire.

Table 2 Means (SD) of eye movement indices for pictorial and verbal visual-probe tasks in three groups.

Stimulus type	Groups		
	NP	PE	PEM
First fixation duration (FFD) (ms)			
Photo pair			
Painful	289.52 (86.53)	264.09 (66.72)	264.86 (50.58)
Neutral	271.68 (60.88)	242.68 (35.97)	258.59 (54.61)
Word pair			
Sensory pain	341.53 (103.21)	337.98 (96.67)	306.27 (69.86)
Neutral	332.28 (112.12)	332.41 (126.81)	283.61 (55.53)
Word pair			
Health catastrophe	352.87 (100.45)	331.39 (95.24)	295.14 (90.27)
Neutral	332.50 (94.90)	320.19 (144.27)	305.29 (94.12)
First-run fixations dwell time (FRD) (ms)			
Photo pair			
Painful	846.40 (237.32)	830.93 (226.42)	761.94 (261.15)
Neutral	711.33 (218.94)	672.38 (209.86)	687.89 (240.42)
Word pair			
Sensory pain	571.31 (142.53)	586.88 (136.46)	549.72 (121.18)
Neutral	543.66 (182.74)	542.89 (166.32)	471.96 (130.14)
Word pair			
Health catastrophe	589.51 (187.42)	551.75 (146.95)	492.11 (119.30)
Neutral	534.94 (136.61)	558.12 (178.87)	493.52 (132.38)
Dwell time (DT) (ms)			
Photo pair			
Painful	1539.34 (213.91)	1614.32 (214.02)	1482.57 (190.00)
Neutral	1413.95 (185.08)	1369.73 (162.43)	1376.02 (211.60)
Word pair			
Sensory pain	623.12 (135.44)	644.41 (107.58)	652.08 (94.78)
Neutral	618.27 (144.79	592.69 (129.69	591.50 (129.22)
Word pair			
Health catastrophe	646.62 (154.81)	617.35 (105.28)	598.42 (85.06)
Neutral	588.96 (111.00)	619.00 (133.68)	612.25 (101.98)
First fixation latency (FFL) (ms)			
Photo pair			
Painful	671.33 (121.22)	641.74 (104.59)	670.40 (114.31)
Neutral	711.25 (154.65)	625.81 (122.19)	664.80 (125.04)
Word pair			
Sensory pain	558.31 (102.59)	552.12 (95.97)	537.99 (88.07)
Neutral	550.61 (108.33)	564.48 (94.64)	558.10 (121.47)
Word pair			
Health catastrophe	530.99 (81.84)	556.85 (99.50)	549.00 (119.74)
Neutral	577.03 (121.61)	553.27 (87.52)	525.06 (91.01)

NP, no-pain group; PE, pain-experience group; PEM, pain-experience-with-motivation group.

(Fig. 2A). There was no difference for the DT bias score index among three groups ($F(2, 59) = 1.53$, $p = 0.23$, $\eta^2 = 0.051$) (Fig. 2C). Similarly, no group difference was found in the FFL bias score ($F(2, 59) = 1.25$, $p = 0.29$, $\eta^2 = 0.04$), suggesting that acute pain experience does not affect attention orientation response.

3.2.2 Verbal visual-probe task

The univariate ANCOVA on bias scores to sensory pain words, controlling the influence of general threat (catastrophe words), did not reveal any effect for group (FFD: $F(2, 57) = 0.025$, $p = 0.98$; FRD: $F(2, 57) = 0.73$, $p = 0.49$; DT: $F(2, 57) = 0.88$, $p = 0.42$; FFL: $F(2, 57) = 0.48$, $p = 0.62$). This suggests that the experimental manipulations do not have an effect on the attentional bias towards pain words (see Fig. 3A and B).

3.2.2.1 FRD and DT

Interestingly, the ANOVA revealed a significant word type × group interaction for the DT bias
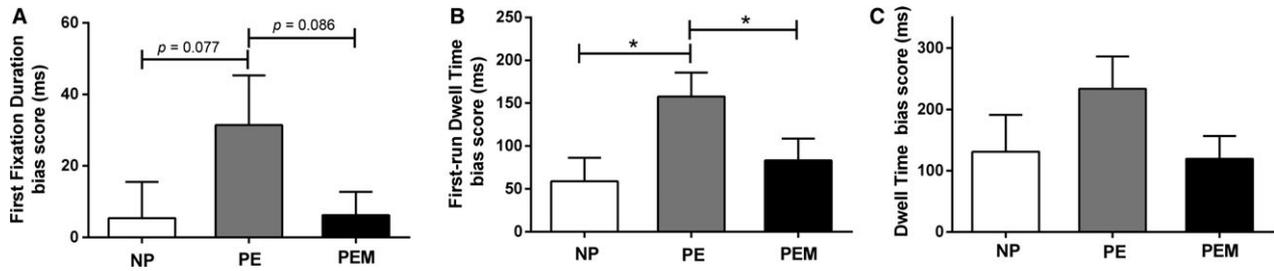
Figure 2 Eye movement indices of attentional bias in the pictorial dot-probe task. (A) Comparison of first fixation duration (FFD) bias towards painful photos among groups. A marginally significant difference was found between PE versus NP ($p = 0.077$) and between PE versus PEM ($p = 0.086$). (B) Comparison of first-run dwell time (FRD) bias towards painful photos among groups. There was significant difference between PE versus NP as well as between PE versus PEM. (C) Comparison of dwell time (DT) bias towards painful photos. No difference was found among groups. NP, no-pain; PE, pain-experience; PEM, pain-experience-with-motivation. Data are means ± SEM. *$p < 0.05$.
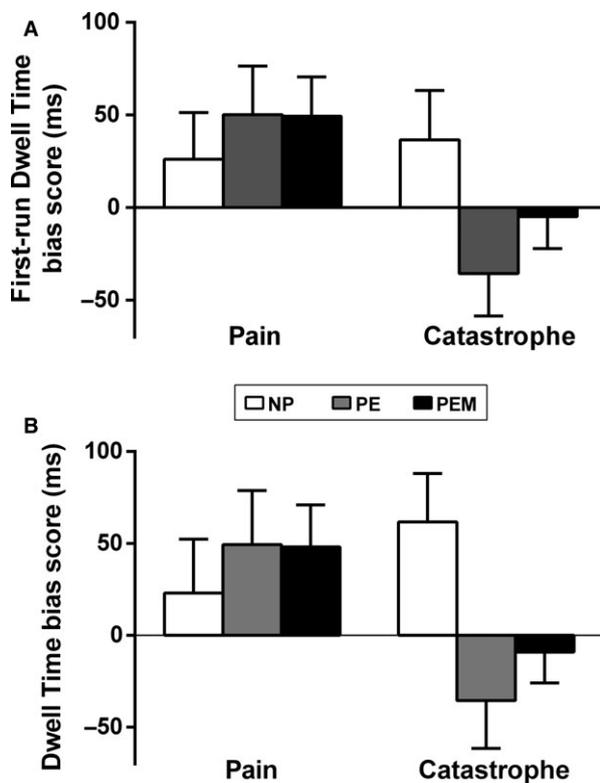
Figure 3 Eye movement indices of attentional bias in the verbal dot-probe task. The two-way ANOVA revealed marginally significant word type × group interaction for the FRD bias score (A) and significant word type × group interaction for the FRD and DT bias score (B). In particular, FRD and DT bias scores in PE groups were significantly lower towards catastrophe words than towards pain words, but no such difference was found in NP group. NP, no-pain; PE, pain-experience; PEM, pain-experience-with-motivation. Data are means ± SEM.

score ($F(2, 57) = 4.09$, $p = 0.022$, $\eta^2 = 0.13$). The bias scores in PE and PEM groups were significant lower towards catastrophe words than towards pain words (PE group: MD = 84.88, SD = 32.07, $p = 0.010$, $d = 0.35$; PEM group: MD = 57.31,

SD = 32.07, $p = 0.079$, $d = 2.25$); by contrast, no difference was found in NP group. This suggests that, under the condition of a prior pain experience, the bias towards threat-related information may be inhibited when pain-related information is presented concurrently (Fig. 3B). The analysis of FRD bias scores found a similar result except that the word type × group interaction was marginally significant ($F(2, 57) = 2.77$, $p = 0.071$, $\eta^2 = 0.089$) (Fig. 3A).

3.3 Analysis of reaction time

For the pictorial task, there were neither main effects nor an interaction involving the reaction time. For the verbal task, the mixed ANOVA, with congruence and word type as within-subject variables, group as between-subject variable, revealed significant group effect ($F(1, 57) = 3.23$, $p = 0.047$, $\eta^2 = 0.10$) and word type × congruence interaction ($F(2, 57) = 5.21$, $p = 0.026$, $\eta^2 = 0.084$). No other significance was found.

The mRT for both tasks are shown in Fig. 4A and B. One-way ANOVA revealed significant main effects of group for the pictorial task: $F(2, 58) = 3.36$, $p = 0.037$, $\eta^2 = 0.037$) and the verbal task ($F(2, 58) = 14.77$, $p < 0.0001$, $\eta^2 = 0.090$). Post hoc comparison showed a faster response of PEM group than PE group (pictorial task: MD = 51.88, $p = 0.021$, $d = 0.45$; verbal task: MD = 69.46, $p < 0.0001$, $d = 0.68$). The better performance of PEM group suggests that the motivational manipulation was successful.

4. Discussion

This is the first study investigating the effect of experimental pain and motivational manipulation on
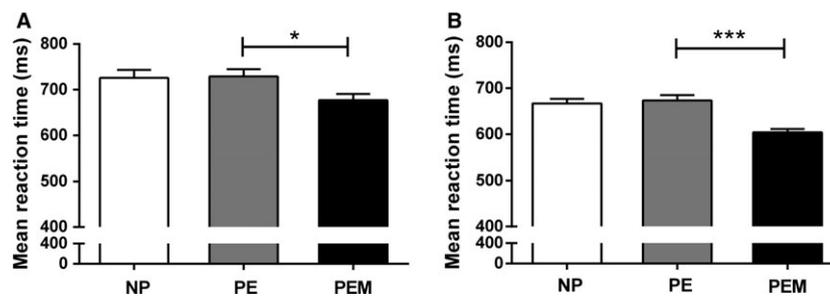
Figure 4 A: Mean reaction time in the pictorial task (A) and verbal task (B). For both tasks, a faster response was observed for PEM than PE, indicating the effectiveness of motivational manipulation. NP, no-pain; PE, pain-experience; PEM, pain-experience-with-motivation. Data are mean ± SEM. $*p < 0.05$; $***p < 0.001$.

pain-related attentional bias via eye movement behaviours. We found that participants with prior acute pain experience exhibited a stronger bias towards pain pictures, and such bias was inhibited by enhanced motivation. The results partially corroborated our initial hypothesis.

4.1 Facilitory effect of experimental pain on pain-related attentional bias

Attentional bias towards pain-related information is a subtle phenomenon, and results from previous research have been inconsistent (Schoth et al., 2012). Compared to chronic pain that has relatively robust effects on attention bias, little evidence can be found to support the effects of acute pain (Crombez et al., 2013). Using eye tracking technique, our study demonstrated that the experience of acute experimental pain effectively increased the bias to pain-related information in healthy subjects.

In the pictorial task, we found that the subjects with prior experimental pain showed a stronger bias towards pain pictures than those without pain experience (significant in FRD; marginal in FFD; not significant in DT and FFL). The marginal significance on FFD index might be due to that it measures the duration of a single fixation and is not as stable as FRD that contains more fixations thus allowing for sufficient elaboration upon stimuli. The DT, reflecting the overall attention allocation, did not exhibit any differences between PE and NP. This might be explained by the long exposure duration of picture stimuli (4000 ms) that may lead to equivalent attention allocation at the later processing stage (>1250 ms). The findings of no FFL bias were also not surprising. The failure to find a difference on FFL may be due to the high similarity in the background scenes of a pair of picture stimuli. As a result, the difference (i.e. painful vs.

normal situations) did not stand out and participants may spend more time detecting the difference, making the initial orienting of attention almost random.

Although previous studies have found evidence of attentional bias in chronic pain patients, they yielded inconsistent results (Schoth et al., 2012). The current study demonstrated that the attentional bias for pain-related information can even occur in experimental pain situations, making it possible that the intermittent attacks of pain experienced by patients would be sufficient to engender hypervigilance to pain and pain-related cues in daily life. The increased and continued attentional engagement by pain-related information would interfere with other processes that demand attention, and as a result, lead to detectable decline in cognitive functions over years.

We did not find any significant effects in the word task. Some possible explanations are as follows. Firstly, the sensory pain words used in the verbal task were selected from McGill Pain Questionnaire that is designed to measure clinical pain. Healthy people may be unfamiliar with these descriptive words (e.g. transfixing, throbbing) and thereby generate relatively weak brain responses. Secondly, the design of the verbal task might be responsible, where pain words were presented concurrently with threat words. Processing of the threat words may interfere with adequate responding to pain words.

4.2 Suppression of attentional bias by motivational manipulation

The current study demonstrated a modulatory effect of motivation on pain-related bias, which was only observed in the pictorial task. Under the condition that can enhance motivation, the bias index of FRD displayed a significant reduction (PEM vs. PE),

suggesting that motivation may modulate the stage of attention maintenance. Again, the other three indices did not show any significant variation (marginal in FFD; not significant in DT and FFL).

In this experiment, attentional bias was measured with eye movements during an extended visual-probe task. Participants were asked to respond to a letter probe following one of two simultaneously presented pictures, with a relatively long asynchrony (4000 ms) between picture onset and probe onset. In such a task, both bottom-up processing for picture stimuli and top-down processing for letter probe were involved and shared the limited attentional resources. Under the motivation condition, subjects were motivated to perform better in order to successfully escape impending pain. In other words, participants in the PEM group had to maximize their speed and accuracy in response to the probe. Thus, the attentioanl resources may be allocated more to the probe detection instead of maintaining on the picture stimuli. As a result, the attention resources engaged by pain-related picture stimuli were reduced and thereby attentional bias inhibited, accompanied by shortened reaction time.

Experimental approaches for manipulating motivations involve two main types: the pursuit of rewards or avoidance of unwanted outcomes, both used for boosting participants' performance on a given task (Robinson et al., 2010). Although the behavioural effects are always similar between reward and punishment motivation, they are mediated by different neural mechanisms (Knutson et al., 2001; Fernando et al., 2013). Successful obtaining a reward (e.g. money) activates the 'reward circuits' in the brain, including the anterior cingulate cortex, the orbital prefrontal cortex, the ventral striatum, the ventral pallidum, and the midbrain dopamine neurons (Haber and Knutson, 2010). By contrast, success in escaping negative outcomes (e.g. monetary loss, aversive stimulation) leads to activations predominately in the inferior frontal gyrus and the insula (Wächter et al., 2009), and is related to the serotonergic system rather than the dopamine system. In the current study, threat of punishment was used to motivate participants to perform better. Effective modulation by this type of approach was observed, as represented by reduced attentional bias, faster key press response and the emotion of fear and anxiety the motivation group. Future study could investigate the modulatory effect of reward motivation, thus to clarify the relationship between different motives and attentional bias.

4.3 Suppression of bias to threat words following brief pain experience

Beyond our hypothesis, we found that the attentional bias towards catastrophe words was significantly suppressed (deviation into the opposite direction) after participants experienced experimental pain. As demonstrated in our results, in the pain-experience group, individuals exhibited much weaker DT bias towards catastrophe words than pain words, while in the no-pain group there was no such difference. This inhibitory effect on threat-related bias might be because the individuals' attention became liable to be captured and overoccupied by pain-related information when they had just experienced pain. Thereafter, any other kinds of information, even those of great salience, could not effectively attract attention. Thus, it can be inferred that experience of pain would selectively facilitate attentional processing for pain-related information while inhibiting attention towards pain-irrelevant stimuli. In such a case, normal functions would be impaired (Van Ryckeghem et al., 2013; Higgins et al., 2015).

4.4 The relationship between attentional bias and hypervigilance

Although attentional bias is closely related to hypervigilance, they are separable processes. Attentional bias refers to the preferential allocation of attention towards salient stimuli such as danger or threat (Van Damme et al., 2010); hypervigilance might be defined as the alertness of cognitive system or a state of readiness of detecting high priority signals that are threatening or potentially dangerous (Richards et al., 2014). Attentional bias is driven by both exogenous and endogenous factors and is mainly associated with the orienting network (frontal and parietal cortex), while hypervigilance is primarily internally driven and is more linked to the alerting network (locus coeruleus and the right frontal and parietal cortex) (Posner, 2012; Richards et al., 2014). For healthy subjects, pain-related information may capture their attention in a stimulus-driven mode (i.e. attentional bias towards pain-related information), as demonstrated in the present study. By contrast, for patients with chronic pain, pain may become the focus of attention, and they tend to display a hypervigilance to pain and pain-related information, thus causing the exacerbation or maintenance of pain (Crombez et al., 2005).

4.5 Limitations

Some limitations of this study should be addressed.

First, the design was different between tasks. In the verbal task, pain-neutral, health catastrophe-neutral and neutral-neutral word pairs were employed, whereas in the pictorial task, only pain-neutral and neutral-neutral picture pairs were used. This was due to the difficulty in matching background features between painful pictures and catastrophe pictures. The asymmetry in the task design might hinder the effective, direct comparison of effects between stimulus types and thus weaken the conclusions.

Second, the pain experience was produced via pain tolerance measurement instead of applying a painful stimulus of known intensity and duration. We did not adopt the common method on the consideration that participants may guess the purpose of the experiment, including the link between successive sessions. Baseline test of pain sensitivity may not allow them to infer the causality between pain experience and subsequent attentional bias measurement. Although the stimulus intensity used here seems insufficient and may not ensure consistency across participants, significant effects on attentional bias reflected by eye movement indices were found in the subsequent visual-probe task.

Third, we used a relatively long presentation time (i.e. 4000 ms) for pictorial stimuli in the frame of a dot-probe task. Long exposure time allowed participants to freely view, and discriminate two similar pictures with sufficient time; also, we need an active task to determine the effect of motivational manipulation. Thus, we used a modified visual-probe task that combined a free-viewing task and a reaction time task in the present study.

Taken together, the current study, using eye tracking method, explored the effects of brief pain experience on pain-related attentional bias. The results of the pictorial task showed that prior pain exposure caused stronger pain-related attentional bias, and the somatic pain-induced attentional bias could be suppressed in the condition of enhanced motivation for a goal. This study provided new evidence for pain-related attentional bias in healthy subjects, and shed light on understanding of how past pain experience affects selective attention as well as on effective coping strategies.

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