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Attentional control moderates the relationship between pain catastrophizing and selective attention to pain faces on the antisaccade task

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1 **Abstract**

2 Cognitive models of chronic pain emphasize the critical role of pain catastrophizing in

3 attentional bias to pain-related stimuli. The aim of this study was (a) to investigate the

4 relationship between pain catastrophizing and the ability to inhibit selective attention to pain-

5 related faces (attentional bias); and (b) to determine whether attentional control moderated

6 this relationship. One hundred and ten pain-free participants completed the anti-saccade task

7 with dynamic facial expressions, specifically painful, angry, happy, and neutral facial

8 expressions and questionnaires including a measure of pain catastrophizing. As predicted,

9 participants with high pain catastrophizing had significantly higher error rates for antisaccade

10 trials with pain faces relative to other facial expressions, indicating a difficulty disinhibiting

11 attention towards painful faces. In moderation analyses, data showed that attentional control

12 moderated the relationship between attentional bias to pain faces and pain catastrophizing.

13 Post-hoc analyses demonstrated that it was shifting attention (not focusing) that accounted for

14 this effect. Only for those with high self-reported ability to shift attention was there a

15 significant relationship between catastrophizing and attentional bias to pain. These findings

16 confirm that attentional control is necessary for an association between attentional bias and

17 catastrophizing to be observed, which may explain the lack of relationships between

18 attentional bias and individual characteristics, such as catastrophizing, in prior research.

19

20 **Keywords:** antisaccade task; attentional bias; emotional facial expressions; pain

21 catastrophizing

1. Introduction

Cognitive models of chronic pain propose pain catastrophizing as a risk factor that give rise to pain-related concerns and fuels attentional bias to pain-related information [1–6]. However, meta-analyses have failed to find relationships between theoretically important constructs, such as pain catastrophizing and attentional biases [7,8]. The absence of a relationship is problematic for these theories that suggest attentional biases are associated with pain catastrophizing [2–6].

There are explanations for this lack of relationship. Todd et al. [1] argued that attentional biases have a curvilinear relationship with threat and therefore relationships are obscured when assessed by simple correlations. Van Ryckegham et al. [9] have argued that the context of attentional biases is important to whether biases towards or away from pain are helpful. Another possibility was raised by Dear et al.[10], who found that the reliability of the dot-probe is poor, and reliability remains questionable for some indices using eye-tracking [11]. Another frequently raised issue is the lack of ecological validity of the stimuli (typically words). Numerous authors have argued that pain-related images[12], facial expressions[13] or somatosensory stimuli[5] are more suitable to assess attentional biases in pain. Although research has used facial expression (e.g. [35]), all studies have used static faces, whereas Ceccarini and Caudek [14], found that individuals were faster and more accurate in detecting an angry face in a crowd when the face images were dynamic.

It is also possible that the failure to observe predicted effects is due to the failure to identity

3

moderators of the relationship between catastrophizing and attentional bias. One potential

moderator is attentional control. Attentional control is defined as the effortful allocation of

attention toward goal-relevant information in the face of conflicting prepotent attentional

demands [15]. Heathcote et al.[16] found that attentional control moderated the relationship

between pain catastrophizing and attentional bias on a dot-probe task. They found a

significant positive relationship between attentional control and vigilance towards pain faces

only among healthy adolescents with high pain catastrophizing. In their second study [17], they

recorded eye movements of healthy children (aged 8-17) while looking at painful and neutral

faces. They found a moderation effect of attentional control on the relationships between

anxiety and attention to pain faces. Specifically, for children with low attentional control,

higher anxiety was associated with a decreased dwell time on pain faces, whereas for those

high in attentional control, the relationship was reversed. Lau et al.[18] further investigated

attentional control in adolescents by manipulating perceptual load and found that attentional

biases for pain-related stimuli were observed in children with pain resulting in impairment

compared with children without pain or those with low levels of impairment, but only under

low perceptual loads where attentional control resources are available. Finally, Mazidi et al [19]

found that attentional control moderated the relationship between pain catastrophizing and

attention to happy faces in pain patients. Those with high attentional control and high pain

catastrophizing focused more on happy faces (consistent with the vigilance-avoidance pattern

identified).

To address limitations of previous research, we chose ecologically valid stimuli (dynamic

painful facial expressions) and the anti-saccade task. The antisaccade task is a well-

established assessment approach to examine individual differences in volitional control of attention [20]. The task starts with a central fixation cross followed by a single peripheral visual stimulus presented either on the left or the right side of the fixation cross. Participants are instructed to look either towards the stimulus (prosaccade trial) or away from the stimulus at the opposite side of the screen (antisaccade trial). Saccades in the prosaccade trials are considered a stimulus-driven, reflexive response. In contrast, antisaccades are more challenging than prosaccades. Antisaccade trials involves the processes of (a) inhibiting a prosaccade to the stimulus and (b) shifting attention to the opposite direction of the stimulus [21]. Participants' error rates and reaction times are generally higher in antisaccade trials than prosaccade trials and the degree of slowing of responses in antisaccade trials compared with prosaccade trials is known as the antisaccade cost.

The degree to which errors and reaction times are greater in antisaccade trials is attributed to inhibitory attentional control [22,23]. This volitional control to inhibit a reflexive saccade to a stimulus in antisaccade trials has been shown to be modulated by the valence of emotional stimulus such as emotional facial expressions (e.g., see [24,25]). As such, the antisaccade task is capable of providing an index of attentional bias to emotional stimuli [26,27,28]. An index of attentional bias to emotional faces can be computed by subtracting the antisaccade cost (difference in reaction times for antisaccade versus prosaccade trials) of neutral stimuli from the antisaccade cost of emotional stimuli. The attention bias indicates the degree to which ability to engage in inhibitory attention is impaired by the presence of threatening stimuli [27,28]. There are other methods for measuring attention bias, such as the dot-probe paradigm [29]. Theoretically, attentional biases on the antisaccade task should be related to those on other

measures, but on the antisaccade task the components of attention specifically affected are inhibition and attention switching [20]. One of the problems with the dot-probe task, based on reaction times, is that it cannot determine which aspects of attention are affected [30].

In the present study, we hypothesized that participants with high pain catastrophizing would make more errors and take longer to attend away from painful (but not other) facial expressions than participants with low pain catastrophizing. We further hypothesized that attentional control would moderate the relationship between pain catastrophizing and attentional bias to pain faces.

2. Material and methods:

2.1 Participants

Participants were volunteer undergraduate students recruited by advertisement from Shahid Beheshti University. They received either course credits or vouchers in exchange for their participation. The inclusion criteria were being at least 18 years old and having normal or corrected to normal vision. The exclusion criteria were a history of pain for at least three months or current pain, history of head or spinal trauma, neurological and psychiatric history or being under the influence of alcohol or other substances. One hundred and seventy-one individuals contacted the researcher to participate in the study. Of those, 18 participants were excluded due to current or previous pain problems, 19 were excluded due to frequent or current migraine or tension-type headaches and one individual reported a history of head injury. Five other individuals were excluded as they reported a history of mental health

difficulties. The remaining 128 individuals were invited to take part in the experiment. There

was a difficulty in calibration for 8 participants, and another participant left the session before

completing all tasks. Nine participants were removed due to a technical problem in the

recording of data during antisaccade trials. The final sample consisted of 110 participants (93

females). Participants were categorised into either high (n = 51) or low pain catastrophizing

(n = 59) groups based on a median split of their scores on the Pain Catastrophizing Scale

(PCS) (median score = 25). The Research was carried out according to the Helsinki

declaration. The study was approved by the human research ethics committee of Shahid

Beheshti University and all participants gave informed consent at the beginning of the

session.

2.2 Measures:

2.2.1. Pain Catastrophizing Scale (PCS) [31]

The PCS is a 13-item self-report measure developed to assess individuals' frequency of

catastrophic thoughts relevant to painful experiences on 5-point Likert scale (0= not at all to

4= always). Higher scores indicate greater pain catastrophizing. The PCS has demonstrated

adequate psychometric properties for both clinical and non-clinical Iranian samples [32,33].

Internal consistency (Cronbach's alpha) in the present sample for the total score was 0.88.

2.2.2. Attentional Control Scale (ACS) [34]

The ACS is a self-report questionnaire that has been developed to measure individual

differences in attentional control capacity. The scale contains 20 items that rated on a 4-point

Likert scale ranging from (1= almost never; 4= always) with 11 items that are reverse-scored. Higher scores indicate greater self-reported ability to focusing and attentional shifting. The ACS has shown good adequate psychometric properties in an Iranian population [35]. In the current study, internal consistency (Cronbach's alpha) was 0.8 for the total score and 0.79 and 0.86 for focusing and shifting subscales, respectively.

2.2.3. Fear of Pain Questionnaire-III (FPQ-III) [36]

The fear of pain questionnaire is a 30-item questionnaire that evaluates an individual's fear of 30 painful incidents on a 5-point Likert scale ranging from (1= not at all; 5 = extreme) with higher scores indicating greater fear of pain. The FPQ-III has shown good psychometric properties in both clinical and non-clinical populations [37]. The Persian version of the questionnaire has reported good psychometric properties in previous research [38]. In the current study, the Cronbach's alpha was 0.92.

2.2.4. State-Trait Anxiety Inventory (STAI) [39]

This inventory contains 40 items which measure the presence and severity of current symptoms of anxiety (state) and a generalized propensity to be anxious (trait). The participants are asked to complete the 20 items allocated to each of the state and trait subscales on a 4-point Likert scale. For the state items, the categories range from (1= not at all) to (4 = very much), while for the trait items the range is from "1 = almost never" to "4 = almost always." Higher scores indicate greater anxiety. In the current study, internal consistency (Cronbach's alpha) was 0.93 and 0.91 for state and trait anxiety respectively.

1   2.2.5. The Beck Depression Inventory-II (BDI-II) [40]

2   The BDI-II is a self-report questionnaire evaluating depressive symptoms over the past two

3   weeks. It contains 21 items on a 4-point scale ranging from (0 = symptom absent) to (3 =

4   severe). Higher scores indicate higher levels of depression. The Persian version of the BDI-II

5   has shown robust psychometric properties [41]. The Cronbach's alpha for the present study was

6   0.90.

7

8   **2.3 Apparatus and stimulus material:**

9   Eye movements were recorded using SensoMotoric Instruments (SMI) remote eye-tracker

10   with 120 Hz sampling rate that uses the corneal reflection of an infrared light source. Stimuli

11   were set and presented by Experiment Center software, and eye-movements were extracted

12   using Begaze program. The stimuli were displayed on a 21inch LCD monitor.

13

14   The facial expression stimuli were taken from the STOIC database [42], which recruited actors

15   to create the stimuli. These dynamic facial expressions were used in previous studies [43,44].

16   The dynamic faces used in the present study consisted of six adult faces (3 female) depicting

17   pain, angry, happy, or neutral facial expressions. The original videos consisted of 15 frames

18   and the rate of 30 HZ displaying. We increased the duration of each video to 800 ms and

19   faces were resized to 60 mm × 74 mm in dimension (approximately 5.7 × 7.0 visual degree)

20   using the Adobe Premiere Pro (Adobe Systems, 2015). Stimuli were grey scaled and their

21   luminance and contrast were calibrated. All non-facial features (hair, ears, and neck) were

1   removed using a mid-gray elliptical mask, and they were presented against a uniform black

2   background (See Fig. 1).

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8   Fig. 1. Process of change during the presentation of dynamic faces

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10   **2.4 The Antisaccade and Prosaccade tasks** [45]

11   The task was adapted by the antisaccade task, which is widely used in the anxiety literature

12   [20]. Each trial began with a fixation cross (1.15° × 1.15°) that remained on the screen for 1600

13   ms in the centre of the monitor. Participants were instructed to fixate on the cross until it

14   disappeared. Then a single face appeared at 12.3 visual degree to the side of the fixation

15   cross. In half the trials, the face appeared to the left and in the other half it appeared to the

16   right. In the antisaccade task, participants were asked to look at the opposite side of the

17   screen (i.e., the mirror position of the image), as quickly as possible without looking at the

18   presented image. For the prosaccade trials, they were asked to look at the image as quickly as

19   possible. The next trial was presented following an inter-trial interval, which was randomly

20   scheduled to be between 700 ms and 1300 to reduce the monotonous nature of the task [46,47].

21

1   A total of 192 trials were presented over two blocks, with one antisaccade block and one

2   prosaccade block which were counterbalanced in order of presentation. Each block consisted

3   of 96 trials, including 24 pain, 24 angry, 24 happy, and 24 neutral faces. Trials were counter-

4   balanced both for gender and left-right presentation on the screen. The order of blocks was

5   counterbalanced with half of the participants assigned to the antisaccade set first and the other

6   half to prosaccade set first. The experimental paradigm is illustrated in fig. 2.

7

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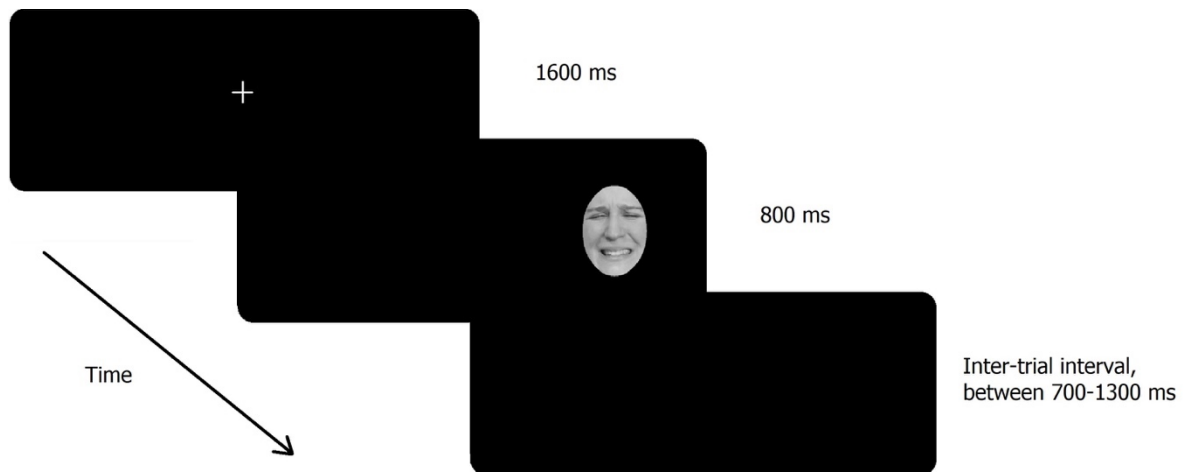
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10   Fig. 2. Example of a trial with a pain face

11

12   **2.5 Procedure**

13   At the beginning of the session, participants read the information sheet and gave informed

14   consent. Participants were told that the aim of the study was to examine visual perception and

15   accuracy of eye movements. Participants were then seated at a distance of 60 cm in front of a

16   monitor in a sound-proofed room where they were assessed individually. Their chin was

placed on a vertically adjustable chin rest to reduce head movements and increase the accuracy of eye tracking. Participants were informed that they would complete a computer task where they would see an image on the computer and that there would be two blocks of trials, with a short break in between each block.

A nine-point calibration procedure preceded ten practice trials prior to the commencement of the first block. At the beginning of each block, the instructions were presented on the screen and explained by the experimenter. Participants were asked to respond as quickly and accurately as possible. The main experimental task began after successful calibration (error less than 1 VA). After finishing the task, participants completed the questionnaires, were debriefed and thanked.

2.6 Data preparation and analysis plan

Data were extracted using the BeGaze software (SensoMotoric Instruments GmbH., Teltow, Germany). To be defined as a saccade, eye movements needed to be made during the presentation of stimuli. In order to exclude anticipatory saccades, only saccades that occurred 83 ms or more after stimulus presentation were included in the analyses [48,49]. Similarly, only saccades that commenced from the centre of the screen (i.e. the fixation point) were included. The first saccade needed to be more than 3 degrees in amplitude and have a velocity threshold exceeding 30º/sec [46,50]. Ninety-two percent of all trials recorded saccades that met these criteria and were included in the analysis (the remaining 8% of trials were excluded). To assess task performance, we calculated two indices: 1) *response accuracy* that was calculated as the percentage of trials on which the participant made an error by dividing the

1 number of trials with incorrect saccade responses by the number of trials for which a reliable

2 saccade was recorded [49], and 2) ***latency of first correct saccade*** that we indexed as the time

3 between the onset of the stimuli and the initiation of the saccade in the correct direction.

4 Furthermore, we calculated saccade latency bias scores, which we refer to as *attentional bias*,

5 by subtracting the mean latency of prosaccade trials from antisaccade trials (the antisaccade

6 cost) for each emotion and then subtracting the antisaccade cost for neutral faces from other

7 emotions (pain, angry, happy) [27]. Larger saccade latency bias scores (attentional bias) show

8 more difficulty in shifting attention away from emotional faces compared with neutral faces.

9

10 All statistical analyses were performed using SPSS (IBM Cop. V. 22). To examine the

11 differences between groups, based on pain catastrophizing, in demographic characteristics

12 and questionnaires data, X^2 and t-tests were used for categorical and continuous variables

13 respectively. To examine differences in saccade error rate and latency, a series of repeated

14 measures Analyses of Variance (ANOVA) with trial type (antisaccade versus prosaccade)

15 and valence (pain vs. angry vs. happy vs. neutral) as the within group factors and group (high

16 versus low levels of pain catastrophizing) as the between group variable were performed.

17 Where significant differences were found in ANOVAs, t-tests were used to further explain

18 the effect(s). To control the false discovery rate in multiple testing, the Benjamini-Hochberg

19 correction was used [51]. To quantify effect sizes of observed results, partial eta-squared η_p^2 and

20 Cohen's *d* were calculated (with 95% confidence intervals (CIs)). One problem that has

21 plagued the attentional bias literature is the unreliability of the tasks used to assess attentional

22 bias, such as the dot-probe [12]. Therefore, we conducted split half reliability for error rates and

23 latency scores for each stimulus valence.

24

Moderator analyses were conducted using the Hayes and Preacher method [52], and the PROCESS syntax [53]. PROCESS model 1 was applied which estimates a moderation model with a single moderator of the effect of an independent variable (pain catastrophizing) on a dependent variable (attentional bias to pain faces) by virtue of different levels of a moderating variable (attentional control scale scores). Interpretation of moderator effects was facilitated through a simple slopes analysis. Finally, we re-ran exploratory analyses using the two subscales of the ACS (i.e. focusing or shifting) to determine whether one or other aspect of attentional control might best account for the findings.

3. Results:

3.1. Preliminary Analyses

Participants with higher levels of PCS ($M = 31.9$, $SD = 5.37$) showed significantly greater trait anxiety, fear of pain, depression and lower ACS scores compared with those with lower PCS ($M = 18.29$, $SD = 5.52$) (See Table 1). The PCS scores were associated with a number of baseline characteristics including age ($r = -0.25$, $p = 0.008$), depression ($r = 0.23$, $p = 0.01$), attentional control ($r = -0.24$, $p = 0.011$). Women had higher catastrophizing scores than men ($t = 2.16$, $p = 0.033$). People who had higher levels of catastrophizing, also had higher levels of depression, as expected [54]. Similarly, differences in attention control were expected to be related to anxiety-related constructs (see Shi et al., [55]). Therefore, we did not see the need to control for these variables. We did, however, repeat our analyses controlling for depression, gender and age in the analyses, but since the pattern of results from the Analysis of Covariance (ANCOVA) was identical to those of the ANOVA, only the latter are reported here.

The importance of routinely reporting the reliability of behavioural measures has been emphasized recently [56]. The odd-even split half reliability was used to gain the internal consistency of the antisaccade errors and antisaccade/prosaccade latency scores across all participants for each facial type in the study. Split-half correlations were computed between odd and even items and the Spearman-Brown prophecy formula used to correct for test length. The split-half reliability of antisaccade errors was .85 for each emotion type and .96 across all trials. With respect to latency scores, the reliability scores were excellent for both antisaccade and prosaccade trials (.95 to .98).

Table 1 Comparison between characteristics of two groups with high and low levels of Pain Catastrophizing

	High PCS	Low PCS	t(108)	*p-value*
Age	18.80 (0.89)	19.24 (1.98)	-1.44	0.15
Years of education	13.25 (0.74)	13.27 (0.71)	-0.12	0.91
State anxiety	39.92 (13.19)	37.66 (9.56)	1.01	0.31
Trait anxiety	43.84 (10.06)	39.66 (9.47)	2.24	0.03
Depression	15.86 (9.80)	10.49 (9.22)	2.96	0.004
Attentional Control	48.78 (6.94)	52.25 (8.19)	-2.37	0.019
Fear of Pain	88.65 (18.18)	81.59 (18.03)	2.04	0.044
PCS = Pain Catastrophizing Scale				

3.2 Saccade Error Rates

Means and standard deviations of pro- and antisaccade error rates and latency for participants with high and low pain catastrophizing are shown in table 2. For error rates, a series of repeated measure ANOVAs with trial type (antisaccade vs. prosaccade), and face emotions

1   (pain vs. angry vs. happy vs. neutral) as the within subject variables and group (High PCS vs.

2   Low PCS) as the between subject variable were conducted. The ANOVAs revealed a main

3   effect of trial type [$F(1, 108) = 118.27$, p< 0.001; $\eta_p^2 = 0.52$; 95% CI: (0.41 to 0.6)],

4   indicating higher error rates for antisaccade trials compared with prosaccade trials, as

5   expected. The main effect of face emotions was significant as well [$F(1, 108) = 4.41$,

6   p=0.005; $\eta_p^2 = 0.039$; 95% CI: (0.001 to 0.11)], indicating higher error rates for pain faces

7   compared with angry [$t(109) = 2.88$, $p = 0.005$, Cohen's $d = 0.27$; 95% CI: (0.08 to 0.46)]

8   and happy faces [$t(109) = 2.77$, $p = 0.007$, Cohen's $d = 0.26$; 95% CI: (0.07 to 0.45)]. This

9   main effect was qualified by a two-way interaction between trial type and face emotion [$F(1,$

10   $108) = 4.74$, p< 0.003; $\eta_p^2 = 0.042$; 95% CI: (0.002 to 0.12)], and the three-way interaction

11   between group, trial type and face emotion interaction [$F(1, 108) = 2.82$, p= 0.039; $\eta_p^2 =$

12   0.025; 95% CI: (0.001 to 0.09)]. No other main or interaction effect was found (all Fs ≤ 1.92,

13   ps > 0.13; $\eta_p^2 ≤ 0.017$).

14

15   To understand the results more clearly, we conducted paired t-tests for face type (pain, angry,

16   happy, and neutral) separately for prosaccade and antisaccade trials and for each PCS group.

17   For prosaccade trials, the only significant difference observed was that amongst those low in

18   PCS, there were more errors for happy than neutral faces: $t(58) = -2.09$, $p = 0.041$, Cohen's d

19   = 0.27; 95% CI: (0.01 to 0.53). No significant difference was found for those with higher PCS

20   scores [all $t(50) ≤ 1.5$, ps > 0.14]. For antisaccade trials, there was no significant difference

21   between faces for participants with low PCS, but those with high PCS showed higher error

22   rates for pain faces than angry faces [$t(50) = 4.05$, $p < 0.001$, Cohen's $d = 0.57$; 95% CI: (0.27

23   to 0.86)] and happy faces [$t(50) = 2.46$, $p = 0.017$, Cohen's $d = 0.34$; 95% CI: (0.06 to 0.62)]

1   but not neutral faces [$t(50) = 1.99, p = 0.052$]. There were also significant differences between

2   angry and neutral faces [t(50) = -2.32, p = 0.024, Cohen's d = 0.32; 95% CI: (0.04 to 0.6)]

3

3.3 Saccade Latency

5   For saccade latency, a 2 (group: high vs low PCS) x 2 (trial type: antisaccade vs. prosaccade)

6   x 4 (face emotions: pain vs. angry vs. happy vs. neutral) ANOVA was performed. Consistent

7   with the results for error rates, the results revealed a significant main effect for trial type [$F(1,$

8    $108) = 501.67$, p< 0.001; η_p^2 = 0.82; 95% CI: (0.77 to 0.85)], indicating that prosaccades were

9   faster compared with antisaccades. The main effect of face emotions was significant too [$F(1,$

10   $108) = 4.18$, p= 0.006; η_p^2 = 0.037; 95% CI: (0.001 to 0.11)], indicating longer latency scores

11   for pain faces compared with neutral [$t(109) = 2.82, p = 0.006$, Cohen's d = 0.27; 95% CI:

12   (0.08 to 0.46)] and angry faces [$t(109) = 2.37, p = 0.02$, Cohen's d = 0.22; 95% CI: (0.04 to

13   0.41)], and longer latency score for happy faces compared with neutral faces [$t(109) =$

14   2.76, $p = 0.007$, Cohen's d = 0.26; 95% CI: (0.07 to 0.45)]. No other significant main or

15   interaction effects were observed [all Fs ≤ 1.51, ps > 0.21; $\eta_p^2 \leq 0.014$].

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Table 2

Means and standard deviations of antisaccade and prosaccade error rates and latency for participants with high and low Pain Catastrophizing

Variable		High PCS		Low PCS	
Type	**Valence**	**M**	**SD**	**M**	**SD**
Antisaccade					
Error Rate (%)	Pain	14.83	13.43	13.09	14.46
	Angry	9.72	9.95	12.46	13.71
	Happy	11.66	13.19	11.08	11.64
	Neutral	12.54	12.48	12.72	13.36
Latency (ms)	Pain	243.66	45.04	236.38	53.05
	Angry	242.07	44.84	236.46	51.57
	Happy	240.67	42.58	242.42	57.25
	Neutral	238.23	45.13	235.83	43.60
Prosaccade					
Error Rate (%)	Pain	0.09	0.63	0.15	0.83
	Angry	0.48	1.78	0.14	0.76
	Happy	0.08	0.58	0.07	0.54
	Neutral	0.45	1.67	0.38	1.27
Latency (ms)	Pain	152.04	24.30	150.21	22.29
	Angry	145.81	23.48	146.77	22.25
	Happy	149.69	21.73	149.34	23.01
	Neutral	145.71	21.74	147.39	22.56

1

3.4. Moderation analyses

To test the hypothesis that attentional control moderates the association between pain

catastrophizing and attentional bias for pain faces, a moderation model was tested with all

18

participants. The dependent variable in this model was attentional bias to pain faces and the

independent variable was PCS and the moderator variable was ACS scores. The moderation

effect was significant (B = 0.075, 95% CI [0.011, 0.14], t = 2.31, p = 0.022).

Exploration of the conditional effect of PCS on attentional bias at values of the attentional

control revealed the following:

1. When attentional control is low (one SD below the mean) there was no significant relationship between PCS and attentional bias to pain faces [B = -0.305, 95% CI [-1.03, 0.42], t = -0.84, p = 0.40].

2. At the mean value of attentional control (within one SD of the mean), there was no relationship between PCS and attentional bias to pain faces [B = 0.224, 95% CI [-0.35, 0.79], t = 0.77, p = 0.44].

3. At a high level of attentional control (one SD above the mean), there was a significant positive relationship between PCS and attentional bias to pain faces [B = 0.828, 95% CI [0.043, 1.61], t = 2.09, p = 0.039].

Figure 3 demonstrates the conditional effects described above, confirming that there is a

positive relationship between pain catastrophizing and attentional bias to pain faces, only at

high levels of attentional control.
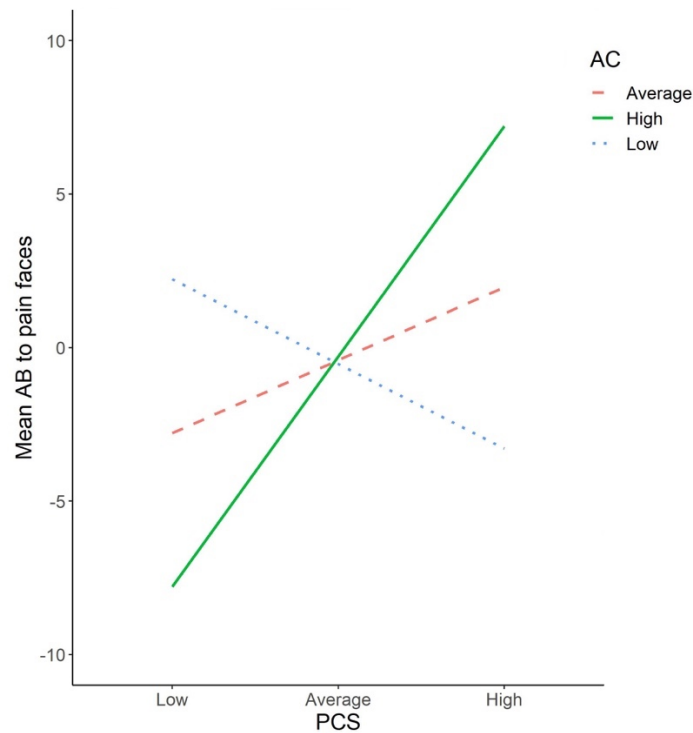
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3 Fig. 3. Simple slopes equations of Attentional Control (AC) moderation effect on

4 pain catastrophizing and attentional bias to pain faces. Green=High AC, Dashed

5 Red=Average AC, Dotted Blue=Low AC

6

7 **Post-Hoc Analyses**

8 In post-hoc analyses, we examined the two subscales of the ACS separately to determine

9 whether the moderating role of attentional control was better accounting for by processes

10 involved in focusing or shifting attention. Results showed that it was the shifting score that

11 moderated the relationship between pain catastrophizing and attentional bias to pain faces (B

12 $= 0.20$; 95% CI: (0.70, 0.33); $t = 3.53$; $p = 0.003$). The pattern of the moderation was identical

13 to that reported for the full scale. That is, at high levels of attentional control, the relationship

between PCS and attentional bias was strong and positive, indicating that those who

catastrophize more in relation to pain had more attentional bias towards pain. However, this

relationship was absent at lower levels of attentional control. For the focusing subscale, there

was no evidence of significant moderation.

4. Discussion

The aim of this study was to determine whether people high in pain catastrophizing

demonstrated attentional bias to pain-related faces in comparison to those low in pain

catastrophizing using dynamic pain faces and the antisaccade task. Further, we aimed to

determine whether these effects were moderated by the level of attentional control, such that

the relationships were stronger in people with high attentional control. Our results confirmed

that for error rates, participants high in pain catastrophizing were more likely to make errors

in relation to painful faces in comparison to angry or happy faces, although the difference

with neutral faces failed to reach significance. In contrast, the effect of pain catastrophizing

on response latency bias in the antisaccade task was not significant. The latter null findings,

however, were further clarified by the moderating role of attentional control. That is, the

relationship between pain catastrophizing and attentional bias to pain faces was only

significant in those people who reported a high level of attentional control.

These findings have important theoretical implications and may clarify why it has been so

difficult to establish relationships between pain catastrophizing and attentional biases to pain.

Fear-avoidance models of chronic pain suggest that the degree to which individuals pay

21

attention to pain-related stimuli contributes to the vicious cycle in which they avoid pain-provoking tasks, become more disabled and experience increased pain. Pain catastrophizing is theorized to be one proximal factor that gives rise to 'hypervigilance' [2,57] but to date, relationships between pain catastrophizing and attentional bias have not been consistently found [58]. Our findings contribute to a small, but growing number of studies that show that attentional control may be the missing variable.

The results of the present study are consistent with studies by Heathcote and colleagues [16,17]. In their first study, they found that poorer attentional control was related to increased vigilance to pain faces only in adolescents with high pain catastrophizing. In their second study they found that among children with low attentional control, the higher their anxiety, the more they avoided looking at pain faces. In contrast, for those high in attentional control, the relationship was reversed. Our results are also consistent with the results of Lau et al. [18]. Lau et al. found that among youth with interfering pain from a community sample, attentional bias was observed, but only under conditions of low perceptual load. This is because under conditions of high attentional load, attentional control resources are unavailable to participants, indicating that attentional control is necessary for the relationship between attentional bias and pain to be observed.

In our study, there were differences amongst all those with high pain catastrophizing in the ability to inhibit attention towards pain-related faces (error rates) compared with happy and angry faces, but the speed with which all participants were able to inhibit their attention was impacted by pain catastrophizing only when attentional control was high. Furthermore, post-hoc analyses showed that this was not related to self-reported ability to focus attention, but

rather the ability to shift attention. Only one recent study has investigated the moderating role

of attentional control in adults with chronic pain between attentional bias and pain

catastrophizing [19]. Mazidi et al.[19] used a dot-probe task with eye-tracking (with 1500msec

presentation). They found a general pattern of vigilance-avoidance amongst people with and

without chronic pain and a moderation effect of attentional control in the relationship

between pain catastrophizing and attention to happy faces. Specifically, for those patients

with higher attentional control, those who also had higher pain catastrophizing attended more

to happy faces. Furthermore, this study found, in contrast to the present results, that it was

focusing (and not shifting) that moderated this effect.

It seems likely that the differences in the nature of the tasks might account for the different

findings. Mazidi et al. [19] used a dot-probe task and the moderation effect was found for

sustained attention (i.e. overall dwell time) in people with chronic pain. Results suggested

that it was the ability to focus attention that moderated the relationship between attention bias

and pain catastrophizing. Results suggested that when people with chronic pain reported a

high level of attentional focus, those with high levels of pain catastrophizing were more

likely to focus overall on happy (not pain) faces compared with neutral faces, consistent with

the overall pattern of vigilance-avoidance. In contrast, in this study, we used the antisaccade

task, which assesses the ability to inhibit the initial attention towards pain faces. Only for

those with high levels of attentional control was there a relationship between pain

catastrophizing and a response latency (more difficulty inhibiting attention to the pain face).

Essentially in the antisaccade task, it is the ability to shift attention from the distractor

stimulus and inhibition of prepotent response, that is being assessed [25], whereas for overall

dwell time on the dot-probe it is arguably the ability to disengage or avoid the stimuli (see [59]).

Therefore, it makes sense that shifting would be the aspect of attention important for the

antisaccade task, whereas focusing would be more relevant to the task used by Mazidi et al.[19].

While this interpretation seems intuitive, it is important to note that the analyses of shifting

versus focusing in both studies were post-hoc which is a limitation. Future research should

systematically investigate which aspects of attentional control are relevant for which aspects

of attentional bias.

Despite careful attention to methodology, there were limitations that should be borne in mind

in interpreting the results. Firstly, the sample used in this study were healthy pain-free

participants and therefore the degree to which the results would apply to people with chronic

pain is unclear. Secondly, the sample in this study consisted mainly of women. There is

evidence of the impact of gender on pain outcome [60,61]. Recruiting a more balanced sample

would allow future researchers to examine gender-related factors and improve the

generalizability of the results. Thirdly, the assessment of attentional control was made using

self-report and is subject to the limitations of the self-report assessment [62,63], however, the

ACS covers a broader formulation of attentional control compared with a single behavioural

task [63]. While the antisaccade task can be used to assess attentional control, it is the reaction

time to neutral trials which is indicative of attentional control. Since this same variable was

used to calculate the attentional bias scores, it would not have provided an independent

measure of attentional control. Finally, it should be noted that the faces used in the present

study were posed emotions by actors and do not represent spontaneous and authentic

expressions. Studies show differential neural activity when judging posed versus genuine

facial displays of emotions [64]. Future research can address how this might impact attentional

processes to pain facial expressions. These limitations notwithstanding, the current study is

1   the first to use the antisaccade task in relation to pain-related stimuli and used more

2   ecologically valid stimuli with the inclusion of dynamic faces. The results have important

3   implications.

4

5   Firstly, these results suggest that one reason why constructs such as pain catastrophizing have

6   not been reliably associated with attentional biases in pain (e.g. Crombez et al., [7]) is that they

7   are only associated amongst those with high levels of attentional control. The effect of pain

8   on attention itself has long been described (see[4]). Although attentional control has rarely been

9   studied in chronic pain samples, a recent meta-analysis has found that experimentally induced

10   pain reliably affects some aspects of attention, notably orientation [65]. Further, there is

11   evidence of small to moderate deficits in executive function (a construct related to attentional

12   control) in people with chronic pain compared with those without [66]. These results suggest

13   that further study of attentional control in chronic pain would be worthwhile, since in other

14   areas of literature, such as anxiety research, deficits in attentional control have proved crucial

15   in understanding of attention bias.

16

17   In the anxiety literature it is now established that deficits in attentional control are associated

18   with greater severity of anxiety [55], and a moderating role of attentional control has been found

19   between attentional bias to threat and anxiety severity [67]. Further, in anxiety, attentional

20   control has been found to moderate the efficacy for interventions that aim to modify biases,

21   specifically Attention Bias Modification (ABM) [68]. ABM uses attentional bias paradigms

22   (typically the dot-probe) to modify selective attention with a view to improving outcomes.

23   Despite mixed results, ABM has been found to be efficacious in the prevention and treatment

of anxiety (see [69] for a review of meta-analyses). In chronic pain, however, despite early trials

finding evidence that ABM improves pain-related outcomes (e.g. [70,71]), others have failed to

find an effect [72]. Importantly, none of the available trials have found the predicted change in

attention bias, even when positive clinical outcomes were evident.

Attentional control could explain the success of ABM in the absence of changes in attentional

bias. For example, if ABM proved to be effective only for those with high levels of

attentional control, this might explain why it is in some contexts effective (such as with

adults; [70,71]), but not with adolescents [72]. Alternatively, while ABM aims to change attentional

bias, ABM has also been shown to improve attentional control [73]. Heeren et al.[74] found that

ABM training (regardless of whether the training was biased towards threat, away from threat

or unbiased [i.e. the placebo condition]) resulted in improvements in attentional control. In

Post-Traumatic Stress Disorder (PTSD) clinical trials have also shown that the placebo

training is efficacious in reducing PTSD symptoms, leading the authors to rename the

placebo 'attention control training'[75]. While speculative, our results suggest that attentional

control and its role in attentional bias and ABM should be the focus of future research if we

are to better understand the role of attention bias in pain.

In summary, this study confirmed that high levels of pain catastrophizing were associated

with increased difficulty in inhibiting a response to pain faces compared with neutral faces.

When participants were able to inhibit the response towards painful faces, pain

catastrophizing did not affect how quickly participants were able to do so overall. However,

level of attentional control did moderate this relationship, such that the relationship between

response latency and pain catastrophizing was only significant amongst those with the highest

level of attentional control. These results underscore the importance of assessing attentional

control in the study of attentional biases in pain.

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Author Contributions

S.R. was involved in the design, data collection, preparation, analysis and writing the manuscript. M.M, M.D. and A.K. were involved in the design, preparation, analysis and writing the manuscript. L.S. was involved in the analysis and writing the manuscript.

Additional Information

Competing interests

The author(s) declare no competing interests.

Data Availability. The data of the current study are available from the corresponding author on reasonable request.