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The disruptive effects of pain on the early allocation of attentional resources: An attentional blink study

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Abstract

Background: Recent evidence suggests that pain dampens attentional processes. However, much of this work has been based on higher-order attentional tasks that involve only spatial attention. Other aspects of the process through which pain engages and holds attention are relatively understudied, in particular, temporal attention. The present set of studies explored how naturally occurring pain (i.e. acute headache) and pain-valenced stimuli affect the ability to recall the second of two targets presented in rapid succession.

Methods: Across both experiments participants were required to indicate the presence of a predefined probe (T2) and, in the dual task, identify a target (T1). The probe (T2) was placed in three different temporal proximities (ranging from 70 to 1000 ms) following presentation of the target (T1). In Experiment 1, 36 participants completed a task that comprised a rapid stream of letters. Experiment 2 manipulated the threat value, and the complexity, of the stimuli by replacing letters with words. In the dual task condition, T1 was a word from one of four valence categories (neutral, positive, negative, pain).

Results: Being in acute pain reduced the accuracy of identification. This reduction in performance occurred regardless of the temporal positioning of the probe, consistent with previous work that suggests pain has an overall dampening effect. Furthermore, when the valence category of the word was pain-related, T2 accuracy performance was negatively affected.

Conclusion: These findings add to the previous evidence that pain has a general dampening effect on attention and that pain-related stimuli are difficult to disengage from.

Significance: Pain captures attention to allow cognate resources to be directed appropriately in response. However, the temporal effects of this attentional capture are poorly understood. Findings indicate that acute headache pain has a negative impact on participants' performance when identifying the second of two targets presented in close temporal proximity, and that pain-valenced stimuli exacerbate this effect. These findings demonstrate how pain affects early attention and highlights the potential role of disengagement, rather than orientation, of attention in the pain experience.

1 | BACKGROUND

Consistent evidence has shown that pain is typically afforded high priority in attentional processing (Crombez et al., 2005; Van Damme et al., 2007). This hypervigilance is an evolutionarily adaptive system which allows us to efficiently respond to potential somatic threats (Crombez et al., 2005), and has been considered from both the resource-model perspective (Eccleston, 1994), whereby pain depletes available attentional resource, and more recently from the motivational perspective, whereby attention to pain serves, or interferes with, a goal-related purpose (Van Damme et al., 2010).

Hypervigilance to pain has two core behavioural effects; firstly, pain has a negative influence on performance in tasks that require attention processes, including threat cues previously associated with pain but presented in the absence of pain (Moore et al., 2013). Secondly, individuals show an attentional bias towards stimuli which are associated with painful experiences, such as pain-related words (Roelofs et al., 2002), facial expressions (Keogh et al., 2018) or body postures (Walsh et al., 2020). These two effects can be termed attentional disruption and attentional bias.

To date, attentional disruption has largely been investigated through the examination of spatial attention, that is, the extent to which pain-related stimuli draw attention to specific points of the visual field, potentially to the detriment of target recognition in other areas (Eccleston, 1994; Moore et al., 2013; Van Damme et al., 2004), or has more generally considered the extent to which pain disrupts other areas of executive functioning (Moore et al., 2012). However, we do not have an as-developed understanding of the timeline of attentional disruption by pain. This is largely because tasks which are attuned to temporal aspects of attention are underused in pain research, with some limited exceptions (Harker et al., 2011).

The attentional blink (AB) is an effect that is considered to reflect the temporal limits of selective attentional resources (Raymond et al., 1992). This robust finding, demonstrated using a rapid visual stream presentation (RSVP), highlights a deficit in the reporting of the second of two stimuli (i.e. the probe, known as T2) when the probe is presented within close temporal proximity (i.e. 200–500 ms) to the first - known as T1 (Dux & Marois, 2009). The task relevance of T1 ensures that attention is directed to the processing of this stimulus among the stream of distractors. The close temporal proximity between T1 and T2 disrupts attentional engagement because processing of T1 leaves little resource capacity for processing of T2. That is, the more attentional resources directed towards engaging and encoding T1 means that there are less available resources for processing subsequent items, such as T2 (for reviews see, Dux & Marois, 2009; Martens & Wyble, 2010; Zivony & Lamy, 2020).

The effect is also exacerbated by attentional bias, such that presenting emotionally salient stimuli further negatively impacts task performance (Mathewson et al., 2008). Importantly, the AB has been demonstrated in patients with chronic pain (Harker et al., 2011). However, this finding may be conflated with the high propensity of depression among this sample, which in turn may affect attentional allocation (Rokke et al., 2002). As such, the present study investigates how pain can affect early attentional allocation in otherwise healthy individuals experiencing acute headache pain.

To date little is known about how pain affects early attentional allocation of cognate resources and how disruption of this attentional allocation can affect later stage processing. Experiment 1 will examine these using the original RSVP paradigm (Raymond et al., 1992). Experiment 2 will examine bias in temporal attention allocation using affective word stimuli. If pain depletes available attentional resources then it is expected that there will be a greater deficit in accuracy for the identification of the second target in the RSVP task when in pain, relative to the no-pain condition for both experiments. It is predicted that this disruption might be more prominent when the second target is presented within close temporal proximity to the first, and that pain-valenced stimuli will reduce accuracy of T2 given our hypervilliance to these cues.

2 | EXPERIMENT 1: ATTENTIONAL BLINK

2.1 | Method

2.1.1 | Participants

In order to determine an adequate sample size to detect the attentional blink, an a-priori power analysis was conducted. Based on the data from Experiment 2 of Raymond, Shapiro & Arnell (1992) ($N = 10$), the effect size (ES) for the interaction between task (single vs. dual) and probe serial position was used. This effect size was $d = 1.5$, considered to be large using Cohen's criteria (Cohen, 2013). Setting an alpha of .05 and power at 0.90, the projected sample size was calculated using G*power. According to these calculations to detect an effect of this magnitude the required sample size is approximately $N = 3$. However, the proposed sample size of 48 was more than adequate for the main objective of the study and allowed for appropriately powered subgroup analysis and possible mediating effect of subjective rating of pain.

A total of 47 participants, aged between 18–32, were recruited from Bath Spa University in return for course credit. However, 11 failed to return for the second session. As such, 36 participants (30 female) completed the study - once while experiencing a naturally occurring non-tension headache and once without. The time between testing sessions ranged from 6 to 36 days, with an average of 16.53 days. Participants reported no other diagnosis of chronic pain, other non-headache related acute pain, and reported as never having suffered migraines. Participants were instructed not to take any analgesics before completing the task.

2.1.2 | Current headache questionnaire (CHQ)

The current headache questionnaire, developed by Moore et al (Moore et al., 2012), was used to assess participants' current and typical headache characteristics, including pain intensity and duration. Items relating to visual distortion were also used to screen out participants suffering from migraine-headache and aura-headache, as the sensory distortion associated with these subtypes can affect performance in visual tasks.

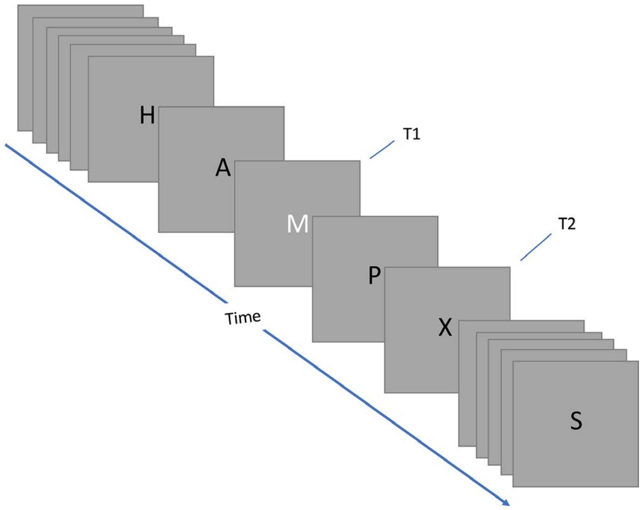

FIGURE 1 Illustrates the rapid visual stream presentation on a single trial for Experiment 1. The target (T1), which is embedded in the stream, comprises a white letter that participants were asked to identify in the dual task. The probe (T2) was a black X presented at a variable serial position after the target

2.1.3 | Attentional blink paradigm

The attentional blink paradigm requires participants to view a RSVP of letters in two tasks (dual-task and single-task). In the dual task condition the participant is asked to identify the white letter (known as T1), and a probe, which in the present experiment is an ‘X’ (referred to as T2). In the single-task condition the participant is only required to identify if T2 is present. The attentional blink is defined as a difference in T2 detection accuracy in each task, such that task performance is significantly poorer in the dual-task condition if T2 is presented within a window referred to as stimulus onset asynchrony (SOA) of between 200 ms and 500 ms after the presentation of T1.

In both conditions the target stimuli comprised uppercase letters that were drawn randomly from the alphabet (with the exception of ‘X’, which was always used as the probe). Each letter is presented singularly at the centre of a 15-inch retina display 60 Hz monitor with a standard pixel height and width of 1,280 × 800. The area surrounding each letter presentation was grey. All letters were black with the exception of the designated target that was white. All letters were presented at the size of 24 pt using the mono font style, with some variation in width based on the characteristics of each letter (see Figure 1 for examples). Each RSVP trial began with a 200 ms fixation display followed by a 200 ms blank screen before the stream of letters was presented. Each frame appeared for 16.67 ms and was followed by a 83.35 ms blank screen. The positioning of the probe (T2) in this experiment was always presented in one of three lag positions following the presentation of T1 (e.g. lag 1, lag 3 or lag 8). That is, T1 appeared either one, three or eight frames prior to T2. The duration of each trial was variable such that the number of letters that preceded T1 was randomly selected between 7 and 15, but the number of letters that followed T1 was always fixed at 8 (for an example of a trial sequence see, Figure 1). At the end of each trial participants were required to respond either ‘y’ or ‘n’ as to the presence of T2 and, in the dual task condition, report the identity of T1. At the end of each block a participant was given feedback on the accuracy of T2 detection. Trials were presented in blocks, with five blocks of 36 trials within each condition. Before the experiment began participants were given a single block of practice trials with nine trials in each condition. The order of presentation for the experimental blocks was counterbalanced such that, across participants, half were given the dual-task condition first and the other half the single-task condition first. Presentation of these stimuli was controlled using OpenSesame v3.2 (Mathôt et al., 2012).

2.1.4 | Procedure

Each participant took part in two experimental sessions whereby they completed the experiment, once in pain and once free of pain. The order in which participants completed the task was also counterbalanced such that half the participants completed the task in pain followed by reporting no pain and the other half of participants completed the task free of pain, before doing the task again with reported pain, to control for practice effects. In every session participants completed the questionnaire before the task began.

2.1.5 | Data treatment

Analysis of the data focused on participants' response accuracy to T1 and T2 (a measure of stimulus detection). That is, the dual task responses for T2 were assessed only in instances where T1 was correctly identified - a measure of the AB.

2.2 | Results

To ensure that there were differences in the subjective rating of pain between the two conditions a *t*-test was conducted. Participants reported significantly more subjective pain in the pain condition (average = 44.8) than the no pain condition (average = 0, $t(35) = 13.1$, $p < .001$). The analysis of T1 accuracy indicated no significant differences in performance between pain conditions ($t(35) = -0.60$, $p = .55$). Overall, T1 was correctly reported in 78% of trials (*SEM* = 0.34).

The data for conditional T2 accuracy are summarised in Figure 2. Inspection of this figure suggests that completing the task in pain reduces overall performance for correct detection of T2, but does not alter the pattern of results compared to completing the task without reported pain. A 2 (Pain condition; pain, no pain) × 2 (task; single, dual) × 3 (T2 lag position; 1, 3, 8) within subjects' factorial ANOVA was conducted with T2 detection accuracy as the dependent variable.

This analysis showed a significant main effect of pain condition ($F(1,35) = 26.76$, $p < .001$, $\eta_p^2 = 0.43$), showing an overall dampening effect of pain with T2 detection accuracy being better in the no pain condition (mean accuracy [M: 75.5%]) than the pain condition (M: 67.70%). A significant main effect of task was also observed ($F(1,35) = 131.51$, $p < .001$, $\eta_p^2 = 0.79$), showing greater T2 detection accuracy

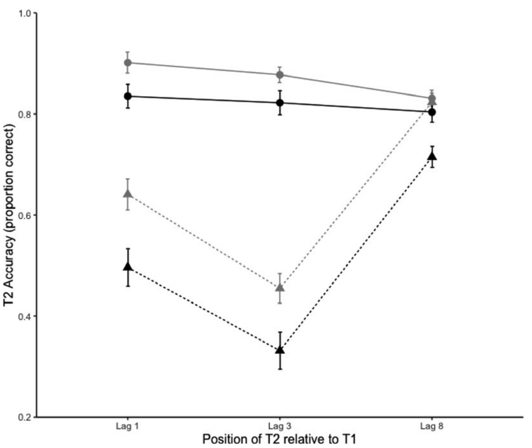

FIGURE 2 Displays data from Experiment 1 as a function of SOA (ms) and T2 accuracy across tasks (single and dual). Solid lines represent the single task condition, the dashed line represents the dual task condition. The data presented in this figure are displayed as proportion correct and error bars represent standard error of the mean (*SEM*)

in the single task condition (M: 84.5%) compared to the dual task condition (M: 57.7%). A final significant main effect of lag position was also observed ($F(2,70) = 39.91$, $p < .001$, $\eta_p^2 = 0.53$), with post-hoc Bonferroni corrected *t*-test analysis (corrected alpha value: .016) showing that T2 detection accuracy was significantly greater at lag position 8 (M: 79.3%) than lag position 1 (M: 71.85%, $t(70) = 3.88$, $p < .001$) and lag position 3 (M: 62.15%, $t(70) = 8.91$, $p < .001$), and that T2 detection accuracy was significantly greater at lag position 1 than lag position 3 ($t(70) = 5.03$, $p < .001$).

In addition to these individual main effects, a significant interaction was also observed between pain condition × task ($F(1,35) = 10.13$, $p = .003$, $\eta_p^2 = 0.22$). Further analysis of this interaction, conducted using Bonferroni corrected *t*-tests, demonstrated that while no significant difference was found in T2 detection accuracy scores between the pain- single task (M: 82%) and no pain-single task (M: 87%) conditions ($t(62.80) = 2.40$, $p = .12$), a significant difference in T2 accuracy was found between pain-dual task (M: 51%) and no pain-dual task (M: 64%, $t(62.80) = 6.06$, $p < .001$). All other comparisons were significant to $p < .001$, and full results are available in the accompanying supplementary materials.

A final significant interaction was observed between task × lag position ($F(2,70) = 62.28$, $p < .001$, $\eta_p^2 = 0.64$). This interaction effectively demonstrates the previously observed blink effect, with no significant differences in T2 detection accuracy in the single-task condition at any lag position (all $p > .05$), and no significant difference in detection accuracy between the single and dual task conditions at lag position 8 ($t(87.2) = 1.53$, $p = 1.00$), demonstrating attentional recovery at lag position 8. In the dual-task condition, a significant difference in T2 detection accuracy was observed between lag position 1 and lag position 3 ($t(139.7) = 6.57$, $p < .001$), lag position 1 and lag position 8 ($t(139.7) = 7.51$, $p < .001$), and between lag position 3 and lag position 8 ($t(139.7) = 14.09$, $p < .001$). T2 detection accuracy was significantly poorer in the dual-task condition than the control condition at lag position 1 ($t(87.2) = 9.47$, $p < .001$) and lag position 3 ($t(87.2) = 14.31$, $p < .001$), demonstrating the attentional blink effect.

The three-way interaction between pain condition × task × lag position was not significant ($F(2,70) = 0.04$, $p = .97$). However, a theoretically motivated exploration of these differences was conducted in order to explore the possibility that the dampening effect of pain was driven by a reduction of attentional resources at specific lag positions. As such, a paired *t*-test analysis was conducted comparing T2 detection accuracy at each lag position in the pain and no-pain conditions in the dual-task only. This showed that T2 detection accuracy was significantly diminished in the pain condition compared to the no-pain condition at lag position 1 ($t(174) = 4.93$, $p < .001$), lag position 3 ($t(174) = 4.21$, $p = .003$) and lag position 8 ($t(174) = 3.70$, $p = .02$), demonstrating that the dampening effect of pain on attentional performance was not specific to any lag position, but rather a more general performance inhibition effect.

3 | EXPERIMENT 2: AFFECTIVE WORD BLINK

Experiment 1 provided evidence that the AB effect is exacerbated by headache pain, such that the T2 detection was negatively affected at each lag position while participants were in pain. These data indicate that there is evidence of cognitive intrusion on attention as a result of pain. A further consideration with regards to the intrusive effect of pain on attention is stimulus characteristic; there is a broad evidence base showing that pain-related stimuli can have a greater cognitive intrusion effect on attentional task performance than neutral stimuli (Todd et al., 2018), and that this in part due to differential attentional processes for pain-valenced stimuli (Keogh et al., 2018). This is particularly relevant during both acute and chronic painful experiences (Khatibi et al., 2009). Previous evidence demonstrates a bottom-up, stimulus-driven influence on how attention is allocated to, and influenced by, pain, as well as the broader attentional modulation effect of pain (Eccleston & Crombez, 1999). Experiment 2 was designed to further investigate these effects by considering how stimulus characteristics influence temporal engagement of attention, in so doing contributing to and expanding this literature base.

For Experiment 2, the same task design was used. However, the neutral letter stimuli were replaced with affective word stimuli in order to investigate the influence of stimulus valence on AB performance; where appropriate these are detailed in the method section below. Unless specified all other details remained the same.

3.1 | Method

3.1.1 | Participants

A total of 36 participants, between the ages of 18–34, were recruited for Experiment 2. However, due to a combination of drop-out and a computer error 15 participants' data were retained for the analysis (10 female, 5 male). These participants were naive to the study and had not completed Experiment 1. This set of participants fulfilled the same criteria as the previous experiment and completed the same psychometric assessment, as described in the previous experiment. The time between testing sessions in Experiment 2 ranged from 9 to 33 days, with an average of 18.26 days between testing sessions. These individuals completed the study in return for course credit.

3.1.2 | Stimuli

The stimuli for Experiment 2 comprised 48 words taken from a list previously used by Keogh et al. (2021). Words were categorised as positive (e.g. "smile"), negative (e.g. "reject"), neutral (e.g. "table") or pain-related (e.g. "aching"), with 12 words in each category. The probe was a predefined neutral word, but in the dual-task condition the target word belonged to one of the four predefined categories. All other presentation details (e.g. size, colours) were consistent with the description of the previous experiment.

3.1.3 | Design & procedure

Participants in Experiment 2 followed the same general procedure as Experiment 1. Briefly participants were exposed to a rapid visual presentation of the same type of stimuli, in this experiment these stimuli were words, which included a to-be-identified target presented in white and then a predefined probe in one of three lag positions. However, in Experiment 2 the target (T1) belonged to one of four categories indicating the affective valence of the word. Other notable changes included: presentation timings for the words were elongated to allow for processing of the affective components and additional complexity of the stimuli. That is, each frame displaying word stimuli was presented for 83.35 ms. Similar to Experiment 1, the positioning of the probe in this experiment was always presented in one of three lag positions following the presentation of T1. These positions were lag 1, lag 3 or lag 8 following the offset of T1. Furthermore, in the dual task condition, participants were asked to type the target word for T1 before being asked if they had seen a predefined probe word (floor). Participants responded in the same way as the previous experiment. That is, they were asked to respond at the end of the trial sequence. In this case, participants were asked to type their response to T1 and indicate if they had seen T2 (see Figure 3 for illustration of a trial within Experiment 2).

3.2 | Results

A t-test analysis was used to compare subjective pain scores in the pain and no pain conditions, showing that participants reported significantly more subjective pain in the pain condition (M: 47.7) than in the no pain condition (M: 0, $t(33) = 17.5$, $p < .001$).

The analysis of T1 accuracy indicated significant differences in performance between pain conditions ($t(14) = 2.72$, $p = .017$). That is, there was a higher proportion of correct responses to T1 in the no-pain condition (87%) compared with the pain condition (82.4%) Overall, T1 was correctly reported in 84.7% of trials ($SEM = 0.28$).

To investigate the role of word valence in addition to pain on AB performance, a 2 (Pain condition; pain, no pain) × 2 (Task; single, dual) × 3 (T2 lag position; 1, 3, 8) × 4 (Word valence; pain, negative, positive, neutral) repeated measures ANOVA was conducted. Results showed a significant main effect of task ($F(1,14) = 50.99$, $p < .001$, $\eta_p^2 = 0.79$), with T2 detection accuracy significantly higher overall in the single task condition (M: 91%) than the dual task condition (M: 70.40%), and a significant main effect of lag position ($F(2,28) = 27.80$, $p < .001$, $\eta_p^2 = 0.67$). Post-hoc analysis of this main effect, using Bonferroni corrected *t*-tests (corrected alpha = .017) showed that T2 recognition accuracy was significantly better when T2 was presented at lag position 8 than at lag position 1 ($t(28) = 7.45$, $p < .001$) and lag position 3 ($t(28) = 3.56$, $p = .004$). T2 detection accuracy was also significantly better at lag position 3 than at lag position 1 ($t(28) = 3.90$, $p = .002$). However, no main effects of either pain condition ($F(1,14) = 0.57$, $p = .46$) or word valence ($F(3,42) = 1.63$, $p = .10$) were observed.

In addition to the observed main effects, two significant interaction effects were also observed. The first of these was an interaction between task × lag position ($F(2,28) = 6.87$, $p = .004$, $\eta_p^2 = 0.33$). Further analysis using Bonferroni-corrected *t*-tests showed significant differences between single- and dual-task conditions at lag position 1 ($t(37.8) = 6.95$, $p < .001$), and lag position 3 ($t(37.8) = 5.74$, $p < .001$), but no significant difference in T2 detection accuracy between tasks at lag position 8 ($t(37.8) = 2.47$, $p = .27$). Significant differences in T2 detection accuracy were also observed within the experimental task condition between lag position 1 and lag positions 3 ($t(55.4) = 3.64$, $p = .009$), lag 1 and 8 ($t(55.4) = 7.96$, $p < .001$), as well as between lag position 3 and lag position 8 ($t(55.4) = 4.32$, $p < .001$). No other significant differences were observed between pairings (for full output, see supplementary materials). This interaction is illustrated in Figure 4.

A final significant interaction was observed between task × word valence ($F(3,42) = 4.85$, $p = .006$, $\eta_p^2 = 0.26$). Post-hoc Bonferroni-corrected comparisons showed significant differences between single- and dual-task conditions for all four word valence categories (positive: $t(38.2) = 5.10$, $p < .001$); negative: $t(38.2) = 3.68$, $p = .002$); neutral: $t(38.2) = 4.61$, $p = .001$); and pain: $t(38.2) = 7.69$, $p < .001$), echoing the main effect of task condition and showing overall decreased performance in T2 detection in the dual-task condition, although it should be noted that this reduction in performance was greatest for pain-words (see Figure 5 below). To explore the effect of specific valence categories within tasks, two one way repeated measures ANOVAs were conducted, one for the dual task condition and one for the single task condition, each considering the four valence levels. For the dual task, this revealed a significant main effect of valence ($F(3,42) = 3.95$, $p = .01$, $\eta_p^2 = 0.22$), with post-hoc Bonferroni corrected *t*-test showing that T2 detection accuracy was significantly worse in the dual task condition for pain words compared to negative words ($t(14) = -3.16$, $p = .04$) and neutral words ($t(14) = -4.22$, $p = .005$), with no further significant differences. For the single task, there was no main effect of valence on T2 detection accuracy ($F(3,42) = 0.66$, $p = .58$). A full comparison within this interaction is available in the supplementary materials provided, and illustrated in Figure 5.

In order to further explore participant disengagement from stimuli with specific valence characteristics, a disengagement efficiency index was calculated per Olatunji et al., (2011). The purpose of a disengagement efficiency index score is to

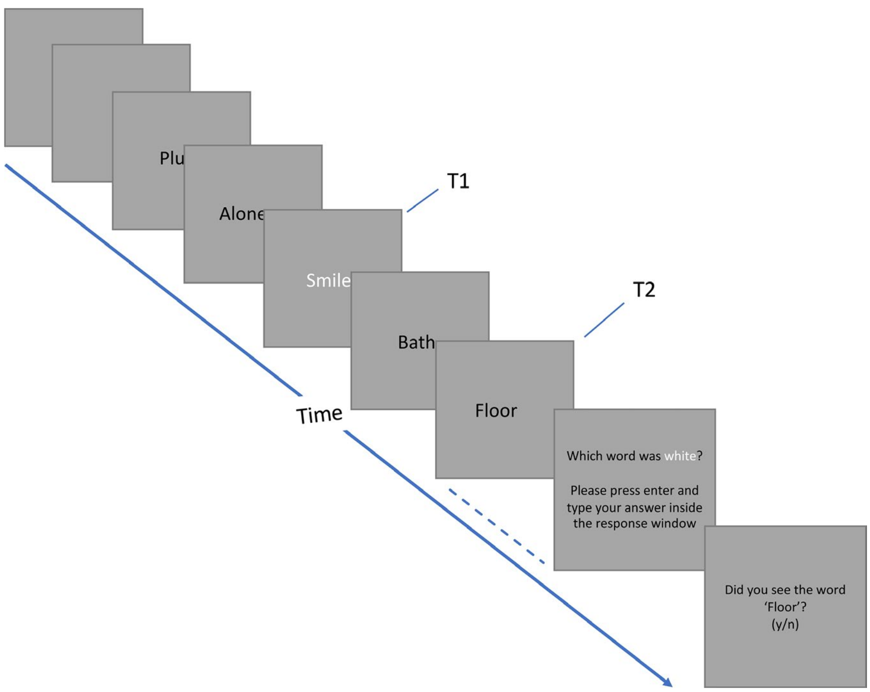

FIGURE 3 Illustrates the RSVP trial for Experiment 2. T1 is a white word taken from one of four affect categories. T2, in this instance presented at lag position 3, was presented in black text like the distractors words. The dashed line represents stimuli that were presented following T2 before the participant was required to respond

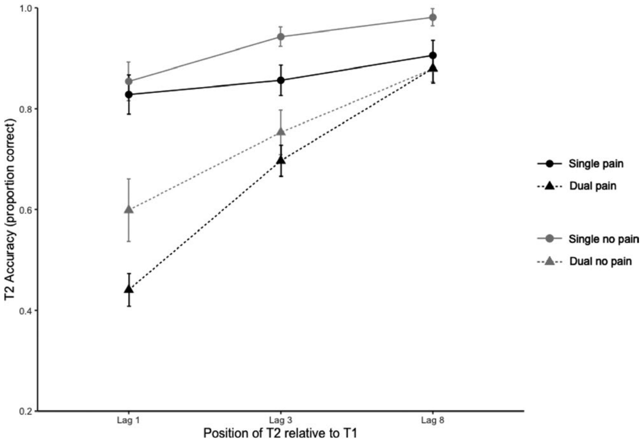

FIGURE 4 Displays data from Experiment 2 as a function of SOA (ms) and T2 accuracy across tasks (single and dual). Solid lines represent the single task condition, the dashed line represents the dual task condition. The data presented in this figure are displayed as proportion correct and error bars represent standard error of the mean (*SEM*)

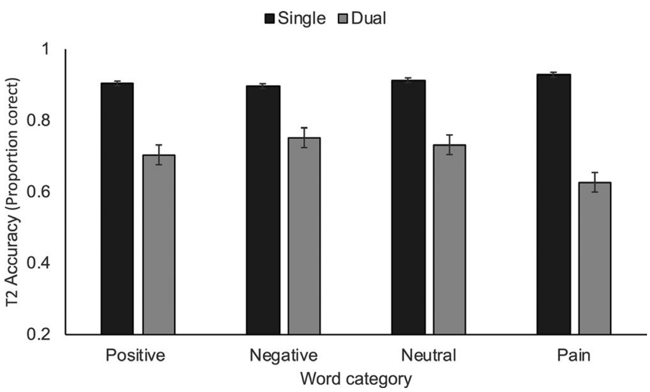

FIGURE 5 Displays data from Experiment 2 as a function of task type (single versus. dual) and affective word category of T1. Data is accuracy (proportion correct) of T2 and error bars represent *SEM*

TABLE 1 Presents descriptives from the disengagement efficiency index analysis in Experiment 2. The data are organized by pain conditions within each stimulus valence category

	Valence			
Condition	**Pain**	**Negative**	**Positive**	**Neutral**
Pain	0.10	0.26	0.16	0.20
No pain	0.19	0.24	0.01	0.16

examine the observed difference in T2 recognition accuracy between lag positions 3 and 8, smaller index scores indicate that attentional disengagement was less efficient as the deficit in T2 recognition had not recovered. A higher disengagement efficiency score indicates more efficient disengagement between lag positions 3 and 8. Table 1 (below) presents the disengagement efficiency indexes for each valence category in the pain and no pain conditions.

3.3 | Conclusions

The experiments reported here examine the effect that pain has on temporal allocation of attentional resources. Being in pain reduced performance in both the single task and dual tasks compared with completing the task in the absence of any reported pain. Comparison between these two tasks indicated the presence of the attentional deficits when reporting the second of two targets within the stream of presentation. This effect was observed in both pain conditions. However when the stimuli become more complex (i.e. comprising words rather than letters), and the timings of stimulus presentation elongated, the effect that pain has on temporal attention was mitigated. That said, pain-related stimuli at the target did affect accuracy of the probe. These results are consistent with previous findings indicating that pain, and pain related stimuli have a negative effect on attentional allocation (Eccleston & Crombez, 1999). What is novel about the current findings is they demonstrate that the dampening effect of pain extends to temporal attention allocation in healthy individuals experiencing acute naturally occurring pain.

Considered more broadly, the present findings add to the current literature relating to pain and attention. The modulating effect of pain has traditionally been studied using tasks that are generally considered to reflect different facets of attention, and more broadly executive function. Most notably, Moore et al. (2012) showed a general dampening effect of pain on attentional engagement and disengagement processes across a range of tasks, with particularly strong effects for tasks which required the deployment of attentional resources across multiple demands, and those most taxing on the attentional resource system, such as the *n*-back. This has been further replicated by the same group using non-experimental pain induction processes, including headache and menstrual pain (Keogh et al., 2014; Moore et al., 2013). The performance deficit observed in these tasks has been considered in the context of a more general cognitive intrusion effect, whereby performance deficits across a range of tasks examining cognitive skills, including executive function (Berryman et al., 2014), abstract thinking (Gunnarsson & Agerström, 2018) and financial decision making (Attridge et al., 2019); although these effects remain consistently task specific, and are not observed across all areas of attention and cognitive processing. Accordingly, it is important to use experimental tasks which specifically target aspects of attention, and more broadly cognition, in order to evaluate the specific influence of pain on these processes. The results presented here are among the first to consider the way pain affects the temporal limitations of our attentional capacity, with results showing a similar general dampening effect consistent to those observed previously. This effect was not specific to any lag position, but rather more generally influenced participants' ability to identify T2 at all target points.

The attentional blink deficit is thought to reflect the temporal limit of selective attention (Dux Asplund et al., 2008; Olivers & Nieuwenhuis, 2005). While there are many competing theories as to the exact mechanisms that underpin the AB deficit (e.g. Nieuwenstein et al., 2009; Olivers & Meeter, 2008; Shapiro & Raymond, 1994), one theoretical framework that can appeal to both the standard AB effect and the emotional attentional blink (EAB), observed across the present two experiments, is the two stage bottleneck theories (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998). Bottleneck theories posit that the AB occurs as a result of limited capacity of processing task relevant targets into working memory. These two-stage models suggest that during stage 1 all stimuli activate a stored conceptual representation. However, it is only T1 that enters a limited capacity stage 2, which consolidates the target into working memory. The second stage is initiated by task relevant features that are identified within stage 1 processing. The AB deficit in accurately reporting the second target (T2) is a result of the limited capacity at stage 2. As a consequence when T2 is presented in close temporal proximity to T1, it remains in stage 1 until consolidation of T1 is complete, making it susceptible to competition, decay and/or inhibition.

The current set of findings can be explained within the context of the bottleneck theories, but also suggest that selective attention can also be depleted from other internal states, namely the experience of acute pain. That is, being in pain further depletes attentional resources such that reduced capacity for consolidation of T2 is exacerbated. If, as suggested, negative states (including being in pain) affect this consolidation, then the current findings provide some evidence for this account given that acute naturally occurring headache pain reduced detection accuracy for T2 observed across both experiments.

In addition to these general findings demonstrating a typical dampening effect of pain on attention, this study further considered the role of stimulus valence on attentional engagement, showing that participants had poorer T2 accuracy when T1 was a pain-valenced word than when T1 was positive, negative or neutral, and that pain-valenced T1 stimuli also exacerbated the disparity in T2 accuracy between experimental conditions. Taken together, these findings suggest that pain-valenced stimuli at T1 slowed participants' disengagement from T1 and reorientation towards T2 during the blink task, although only in the dual-task condition. There was no additional effect of pain condition, demonstrating that the effect of pain stimulus valence at T1 is independent of pain condition. These findings are consistent with previous evidence that has shown that emotion eliciting stimuli (e.g. words, images), commandeer selective attention (see, Mathewson et al. (2008); Most et al. (2005)). Specifically, they are also consistent with the findings that emotional stimuli can impair visual perception of subsequently presented neutral stimuli (Arnell et al., 2007; Most et al., 2005, 2007; Smith et al., 2006). These findings have been explained in the context of the two stage model outline earlier. Specifically, presenting emotional stimuli results in enhanced processing at stage 1 and also at subsequent stage 2 processing (Bachmann & Hommuk, 2005; Chun & Potter, 1995; Potter Staub & O'Connor, 2002). The effect of this enhanced processing is a reduction in the ability to report neutral stimuli when presented further in the RSVP (for a more detailed analysis see, Bocanegra & Zeelenberg, 2009; McHugo et al., 2013). More generally, there is evidence of slower disengagement from pain-related visual stimuli, across different stimulus types and different experimental tasks (Keogh et al., 2018; Walsh et al., 2020), and these findings are consistent with the literature suggesting that motivationally relevant stimuli modulate temporal attention (Koster et al., 2006; van Ryckeghem & Crombez, 2018).

One potential limitation of the results reported here is in considering only one type of pain. Previous research has considered a range of real-world pain types when considering the influence of pain on attention, including menstrual pain and techniques which mimic chronicity (Keogh et al., 2014; Wiech et al., 2005). There is likely to be some variation in the impact of different pain subtypes on attention, which limits the extent to which the findings from these studies can be applied more broadly.

A further limitation of the present set of experiments relates to the effect of word valence in experiment 2. While experiment 2 found no overall effect of T1 valence at present the RSVP consists of multiple valenced words. As such, this may make it less clear how broader bottom-up stimulus characteristics, in particular arousal associated with different valence categories, may influence attentional processing of pain. That is, on a single trial, there will be competition for attentional resources from multiple valence sources - even foil stimuli present in the stream that are not crucial to task performance. Whilst this is in keeping with previous evidence, as presented earlier, future research should better control for the type of valenced words presented within the stream in order to directly compare the influence that different valence categories have at stage 1 processing. Eccleston and Crombez (1999) highlighted the complex role of affective and motivational environmental factors in the interruptive influence of pain on attention, and stimulus-valence driven effects have previously been observed in other attention tasks (Keogh et al., 2018; Walsh et al., 2020). Importantly, previous evidence (Godfrey et al., 2020) suggests that T2 valence may have a greater influence on attentional engagement in pain, and this effect needs to be considered in more detail. Similarly, alongside affective word stimuli, previous research has examined the role of a broader range of affective stimuli, including facial expressions (Keogh et al., 2018) and body postures (Aviezer et al., 2012; Walsh et al., 2017), and these have also been considered using the blink paradigm, although not in pain research (Bannerman et al., 2009; Jong et al., 2009). Facial expressions in particular have been included in existing research considering pain and attention using the dot-probe paradigm, and evidence suggests that facial expressions of pain, and other affective experiences, are processed in as little as 33 ms (Keogh et al., 2018), making this kind of stimulus ideally suited to the attentional blink paradigm.

To conclude, across two experiments we have demonstrated that pain negatively affects performance in the dual condition of the attentional blink task. This negative influence on performance does not appear to be time-point specific, but rather a more general dampening effect on attentional processing similar to those observed in previous studies. Stimulus valence does not appear to play a role in this effect, although the present findings are limited in terms of the relative position of the affective stimulus (at the T1 position only), as well as the nature of the stimulus (which was limited to affective word stimuli). Future research may wish to consider the role of other affective stimuli, in particular facial expressions and body postures, as well as the role of stimulus valence at different points in the blink paradigm.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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