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Original experimental

The disruptive effects of pain on multitasking in a virtual errands task

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HIGHLIGHTS

- The Edinburgh Virtual Errands Test was completed with concurrent thermal pain.
- Pain affected multitasking for those reporting greater daily cognitive pain intrusion.
- More errors were made in pain on a virtual errands task e.g. entering incorrect rooms.
- Other aspects, including number of completed errands were unaffected by pain.

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ABSTRACT

Background and aims: Pain is known to have a disruptive effect on cognitive performance, but prior studies have used highly constrained laboratory tasks that lack ecological validity. In everyday life people are required to complete more complex sets of tasks, prioritising task completion and recalling lists of tasks which need to be completed, and these tasks continue to be attempted during episodes or states of pain. The present study therefore examined the impact of thermal induced pain on a simulated errand task.
Methods: Fifty-five healthy adults (36 female) performed the Edinburgh Virtual Errands Task (EVET) either during a painful thermal sensation or with no concurrent pain. Participants also completed the Experience of Cognitive Intrusion of Pain (ECIP) questionnaire to measure their self-reported cognitive impact of pain in general life.
Results: Participants who completed the EVET task in pain and who self-reported high intrusion of pain made significantly more errors than those who reported lower intrusion on the ECIP.
Conclusions: Findings here support the growing literature that suggests that pain has a significant impact on cognitive performance. Furthermore, these findings support the developing literature suggesting that this relationship is complex when considering real world cognition, and that self-report on the ECIP relates well to performance on a task designed to reflect the complexities of everyday living.
Implications: If extrapolated to chronic pain populations, these data suggest that pain during complex multitasking performance may have a significant impact on the number of errors made. For people highly vulnerable to cognitive intrusion by pain, this may result in errors such as selecting the wrong location or item to perform tasks, or forgetting to perform these tasks at the correct time. If these findings are shown to extend to chronic pain populations then occupational support to manage complex task performance, using for example diaries/electronic reminders, may help to improve everyday abilities.

1. Introduction

Pain functions to promote behavioural analgesia by interrupting current concerns and warn of potential danger [1]. This interruption can become disabling and chronic pain patients report cognitive problems, adding to the difficulties they face with the activities of daily living. Research has explored the nature of pain-related cognitive deficits in both chronic pain [2], and using experimentally-induced pain with healthy participants [3–6]. Meta-analyses have shown that the effects of chronic pain are greatest for complex memory, attention, and executive function tasks [7–9] which is supported by findings using experimental pain models on tasks ranging from sustained attention to complex dual-task performance [10–12]. However, most of the tasks

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used so far are artificial and designed to test specific cognitive functions in isolation. In everyday life, patients navigate complex sets of challenges facing multiple competing goals within a limited time (i.e., multitasking) [13]. A range of cognitive functions acting together are required for successful task performance (i.e., cooking or shopping). Therefore, further research is needed with tasks that more closely mimic these demands. A good example is the 'Multiple Errands' methodology [14], where participants are asked to complete a series of errands in either a real or virtual environment. This type of task has been shown to be sensitive to cognitive impairments stemming from acquired brain injury [14–17]. At present a single study has examined the effect of laboratory induced pain on more complex cognitions using the same pain induction technique employed in the present study [18]. Participants performed two tasks; the first involved the preparation of a simulated breakfast where items took different times to 'cook', at the same time as setting the table as many times as possible. In the second, participants tried to generate as many words as they could from two different lists of 7 letters (switching between the lists as often as they liked), participants were then asked to recall how they performed. Findings here were that pain resulted in poorer recall of performance and reduced focus on secondary task demands.

The disruptive effects of pain on performance may be mediated by individual differences in cognitive response to pain. For some, the experience of pain may result in pain-related ruminations, consuming attentional resources, while for others, pain may occupy less cognitive focus [19,20]. A self-report measure, the Experience of Cognitive Intrusion of Pain (ECIP), has been developed to index the extent to which individuals are susceptible to cognitive interruptions by pain [20]. In the present study a virtual version of the multiple errands methodology (the Edinburgh Virtual Errands Test, EVET [21]) was utilised to determine whether experimentally-induced thermal pain would have disruptive effects on performance. It was hypothesised that participants who experienced pain during the task would perform more poorly than those experiencing no pain. Further the sample was segmented into 'low' or 'high' groups on the ECIP measure, leading to the prediction that those in the 'high' group would be particularly strongly affected by pain.

2. Methods

2.1. Participants

Sixty-four adult participants were recruited from the staff and student population of Liverpool John Moores University. Of the 64 participants recruited, data is unavailable for 9 participants. Four participants were unable to successfully remember the errand list before completing the EVET and for a further five participants data is available due to a technical failure of either the cognitive task or the software running the pain paradigm. Of these participants 4 were in the non-pain group and 5 in the pain group. This left a total of 55 participants with data available for the EVET task (36 female), with a mean age of 20.27 years (SD = 4.54). Of these, 28 participants were randomly assigned to a pain condition (18 female) and 27 to a no pain control group (18 female). All participants reported that they were not in pain upon arrival on the day of testing, had no existing chronic pain condition, were not taking analgesic medication, had no skin complaints, heart conditions or skin sensitivity were not currently depressed and had no history of psychiatric conditions. First year undergraduate psychology students participated in exchange for course credit with all other participants receiving a small financial remuneration.

2.2. Pain manipulation

Pain induction was achieved through the use of a Medoc PATHWAY – Advanced Thermal Stimulator (ATS). This equipment is designed for use in clinical and research settings, and induces pain through a metal plate placed on the skin. The temperature is delivered and controlled through specialist hardware and software, designed for experimental purposes. First individual pain thresholds were identified for all participants using a search protocol. The 30 mm × 30 mm thermode was attached to the participant's right ankle. The baseline temperature of the thermode was set at 32 °C and participants altered the temperature using two buttons, one to increase the temperature and one to decrease the temperature. Participants were asked to increase the temperature to a level which was 'just painful'. This was then monitored for 15 s and participants were asked again if this was 'just painful', if the participant reported that this level was still 'just painful' then this was taken to be the participant's threshold, if not then participants were asked to adjust the temperature to be 'just painful' and this check was performed again. Participants in the non-pain condition completed the EVET without any painful stimulation.

During cognitive task performance participants in the pain condition completed the EVET task under pain stimulation. This pain stimulation was present only during the 8 min of the main task and all participants completed the learning and training phases pain free. Once an individual thermal pain threshold was identified this was used to personalise a protocol for use during the experimental tasks. Starting from a baseline of 32 °C the temperature increased at a rate of 8 °C/s to 1 °C above each participant's set pain threshold, the temperature then oscillated between 1 °C above and 1 °C below the participant's pain threshold at 8 °C/s for 10 oscillations before returning to the baseline temperature (32 °C) at a rate of 8 °C/s. The duration of each period of pain stimulation varied depending on participants pain threshold however each period of maximal stimulation was approximately 15 s and the break between periods of pain (for the return to baseline and start of another period of 10 oscillations) at the mean pain threshold was approximately 3 s. These various durations to reach threshold also meant participants received different number of total pain episodes (typically approximately 24 episodes during the task). All participants did however spend the majority of the task experiencing a sensation which was subjectively painful to them. This procedure was repeated on a continuous cycle throughout each task. This procedure was used to ensure that participants did not habituate to the painful stimulus.

2.2.1. Edinburgh Virtual Errands Task (EVET)

The EVET was built using Hammer environment editor, part of the software development kit associated with the computer game Half-Life 2, available on the Source games platform (for full description see Logie, Trawley, & Law, 2011).[1] The test takes place within a simulated shopping and office building presented using a standard PC and monitor. Participants navigate through a 4-floor building, taking a first-person perspective, in order to complete a series of errands that they have memorised before beginning the test. Participants control their direction of travel using the mouse and keyboard. There are 8 errands to be executed in 8 min, 3 of which have two steps to them (e.g., pick up a newspaper in G3 and take to desk in S4), two of which have a timed element (e.g., turn on cinema S7 at 5.30 min), and one of which is open-ended rather than discrete (sorting red and blue binders into different piles). A number of dependent measures were yielded:

[1] The EVET and accompanying data extraction utilities are available as a free download from http://www.psy.ed.ac.uk/resgroup/MT/index4.html.

Table 1
Bonuses and penalties applied to raw EVET score, following the procedure of Logie, Trawley and Law (2011). Note that data on stairwell rules breaks were unavailable in the current study.

Bonus points added	+4	+3	+2	+1	0
Number of folders sorted	30+	23–29	15–22	8–14	1–7
Cinema (absolute time discrepancy in seconds from 5:30 min)	0–2	3–5	6–7	8–10	11+
Meeting (time discrepancy in seconds over 3:00 min)	<=3 min	1–12	13–25	26–37	38+
Penalty points deducted	−4	−3	−2	−1	0
Number of objects picked up that were not on the errand list	4+	3	2	1	0
Number of rooms entered that were not on the errand list	4+	3	2	1	0

Learn: This was a measure of the participants' initial ability to recall the errand list following a fixed period of study. Following Logie, Trawley and Law (2011), participants were given an initial 2 min to read the errand list and then were asked to freely recall the information. They were then given a further 5 min of study and were given a test of cued recall, where they were given partial information about the errand and had to recall the rest. The free and cued recall scores were combined to form an overall 'Learn' variable (maximum of 37 points).

Recount: At the end of the test, participants were asked 3 questions that probed their ability to recount what had happened during the previous 8 min. They were asked 'what did you attempt?', 'what was unfinished?' and 'did you break any task rules?.' They were awarded a point for each piece of information they recounted (maximum of 26). If they broke a rule (such as entering the wrong room) on more than one occasion this was only scored once.

Remember: Participants were asked to freely recall all the information from the errand list at the end of the test, and then were given the series of cued recall prompts that they received during the procedure for 'Learn' (maximum score of 37).

Plan following: Participants made a written plan of the order in which they would attempt the errands before the test. This order was then compared with the order in which they actually attempted the errands to give a measure of plan following. They were awarded a point for every errand completed in the same sequential position as in their plan, and also a point for every pair of errands in the same sequential order even if the pairing occurred earlier or later in their plan. Thus, if participants deviated from their plan by missing out only one errand they were not heavily penalised. The score was divided by the number of errands-parts actually completed, thus avoiding a penalty for partial completion.

EVET score, bonuses and penalties: A weighted score was calculated based on Logie, Trawley and Law (2011). Participants were awarded a point for every errand or part of an errand they completed (max 11), but then the score was adjusted. They were penalised for entering rooms or picking up objects other than those on the errand list. They were also given bonuses for completing the timed errands on time, and according to the number of folders that they managed to sort. The allocation of bonus and penalty points is shown in Table 1, and is based on normative data from Logie, Trawley and Law (2011). These two aspects of performance were also examined separately from EVET score, because they may provide revealing information about differences in strategy between the groups. Participants with a high penalty score may have adopted an unplanned and disinhibited, 'click on everything' approach to the task. Conversely, participants who achieved high bonuses may have organised their time effectively, in order to prioritise the two errands that had to be completed at particular times.

2.3. Questionnaire measures

The ECIP was selected to further investigate the link between self-report and objectively measured cognitive interruption by pain. Other measures of general mood and pain specific emotion and cognition were also used to ensure no differences between the pain and non-pain groups on these measures. These measures were selected to assess aspects of cognitive intrusion by pain, fear of pain from injury/insult & general distress and give a wide range of potential explanation for the impact of pain [22,23].

2.3.1. Experience of Cognitive Intrusion of Pain (ECIP) [20]

The ECIP is a 10 item self-report measure designed to assess interruption by pain, rumination in pain and control by pain. Participants are asked to think about when they have been in pain and indicate on a 7 point Likert scale how a number of items apply to them (i.e. "Pain interrupts my thinking"). This measure has high internal consistency, Chronbach's alpha = .96–.97 [20], and .96 in the present study.

2.3.2. Pain Anxiety Symptoms Scale (PASS) [24]

The PASS is a 40 item self-report measure of pain related fear and anxiety. Participants are asked how frequently they engage in a range of behaviours when in pain e.g., avoiding activities when hurt. The internal consistency of the total and the subscales is adequate to excellent, Chronbach's alpha = .67–.92 [25,26] and .93 in the present study.

2.3.3. Anxiety Sensitivity Index-3 (ASI-3) [27]

The ASI-3 is an 18 item scale which measures fear associated with experiencing anxiety-related symptoms. Participants are asked how strongly they agree with a range of statements pertaining to the amount of fear experienced when they experience a particular sensation e.g., they would be scared if they experienced a rapidly beating heart. The ASI-3 subscales have high internal reliability in both healthy and clinical samples with Chronbach's alphas of between .73 and .91 [27] and .87 in the present study.

2.3.4. Fear of Pain Questionnaire (FPQ-III) [28]

The FPQ-III is a 30 item self-report questionnaire to assess fear of different causes of pain. Participants are asked how much they fear the pain associated with a range of injuries, such as breaking one's arm. The FPQ-III has an excellent Chronbach's alpha ($\alpha = .92$) indicating high internal reliability [25] and .91 in the present study.

2.3.5. Pain Catastrophizing Scale (PCS) [29]

The PCS is a 13 item self-report scale to measure rumination and magnification of pain related thoughts and one's perceived helplessness in relation to pain. Participants are asked how strongly they agree with a range of statements e.g., when in pain I can't get it out of my mind. The PCS has good reliability (Cronbach's alpha $\alpha = .87$) and .89 in the present study.

2.3.6. Depression Anxiety Stress Questionnaire-21 (DASS-21) [30]

The DASS-21 consists of 21 items that measure depression, anxiety and stress experiences over the past week. Participants are asked how often a range of statements applied to them in the past week, e.g., whether they found it hard to wind down. The DASS-21 has high internal reliability (Cronbach's alpha = .82–.94) in both clinical and non-clinical samples [31,32] and .95 in the present study.

2.4. Procedure

Following ethical committee approval (Liverpool John Moores University Ethics Committee Ref: 15/NSP/001) each participant consented to take part. Each participant first completed the search protocol to identify their pain thresholds. Following this participants were introduced to the EVET task and were given as long as necessary to complete the training task which involved completing a number of errands which were primed on screen. These training errands are designed to introduce the participant to the environment and give them practice of using the controls. Following this participants were given the errand list to memorise and free and cued recall was assessed (see 'Learn' above). Once participants had completed the assessed recall of errands they were given a planning sheet with a diagram of the building and a numbered list with empty slots, and instructed to indicate the order in which they intended to complete the tasks. Once participants had completed this they were asked to recall all the errands, if they successfully did this they moved on to the test phase. If they could not recall all the errands then they were asked to study the list again until accuracy was 100%. Participants were given as long as they wished to learn the list at this stage and could not begin the test until they had done so. Participants were then told if they had been allocated to the pain or the control condition. All instruction and errand sheets were taken away from the desk and the participant was given 8 min to perform as many errands as they could. They were told that they were allowed to deviate from the plan they had made previously if they wished, but that they must not go into rooms that were not on the list or pick up objects other than those specified. After completing the task participants completed three 10 cm Visual Analogue Scales (VAS) to measure pain intensity, pain distress and pain awareness during the task. Participants were the asked to recount all the tasks that they had attempted, any they had left unfinished, and all rules they recalled breaking. Finally participants were asked to perform the free and cued recall of all tasks. Lastly, participants completed a range of questionnaire measures including the ECIP.

2.5. Analysis

All data were assessed for normal distribution, with acceptable skewness values between −2.56 and 2.56 [33], where data did not meet normal distribution then a Log 10 transformation was applied. If this did not correct the skew then raw data was analysed and non-parametric tests run where these were available. Data were examined for outliers (mean scores greater than three standard deviations above/below the group mean) [34]. Two outliers were found for penalties however these were only one greater than the next highest score and removal of outlying participants did not change the overall pattern of findings and therefore full data are reported.

The first stage of the analysis was to examine if the two groups were well matched on all baseline variables. To achieve this we used independent samples *t*-tests to compare the pain group to the non-pain group on all questionnaire measures as well as for baseline pain thresholds and participants' learning of the task before pain administration. Finally group differences were assessed between the pain and no pain groups for pain intensity, pain distress and pain awareness to ensure that the pain group experienced more pain and more pain related distress during the task.

Following this a median split was conducted on the ECIP scores to allow us to examine for the effects of self-reported cognitive intrusion by pain on the size of the deficit in multitasking performance as a result of the experimentally induced pain stimulus. To investigate the effects of pain and ECIP group on each element of the EVET score, data were entered into a series of between groups ANOVAs. Each of these included pain and EVET score as between subject factors. Outcome variables here were overall EVET score, closeness of plan following, the number of elements successfully completed, bonuses (for completing tasks at the correct time/sorting folders), penalties (for tasks violations), as well as post task assessments of participants' recounting and recalling of the task requirements and their own performance. Where significant interactions were observed these were broken down using *t*-tests or Mann–Whitney *U* tests where appropriate. Throughout the research alpha was held at .05.

3. Results

Initially a manipulation check was conducted to ensure that the pain thresholds and scores on the questionnaires of the pain and non-pain groups were not different and that the pain group reported greater pain during the task compared to the non-pain group (see Table 2). Pain thresholds were not recorded from 5 participants in the non-pain group due to computer error. Data were entered into a series of independent t-tests, these suggested that there were no significant differences between the pain thresholds for the pain and the non-pain groups thresholds, $t(48) = .08$, $p = .93$, suggesting both groups are drawn from the same population. Further there were no significant differences between the groups for Fear of Pain (FPQ), $t(53) = 1.59$, $p = .12$, Pain Catastrophizing (PCS) $t(53) = .53$, $p = .60$, Anxiety Sensitivity (ASI) $t(53) = .85$, $p = .34$, Cognitive Intrusion by Pain (ECIP) $t(53) = .24$, $p = .81$, or Pain Anxiety (PASS) $t(53) = 1.56$, $p = .12$. Analysis of the General Distress (DASS) scores however suggested that individuals in the no pain group had significantly higher general distress than the pain group, $t(53) = 2.07$, $p = .046$. This suggests that the groups were generally well matched and that the only difference between the groups relates to general non pain related distress. When considering the differences between the pain and non-pain groups in response to the visual analogue scales it was found that the pain group experience significantly more pain, $t(53) = 11.58$, $p < .001$, more pain distress, $t(53) = 6.61$, $p < .001$, and more pain awareness, $t(53) = 8.78$, $p < .001$. It is also important to note that the groups did not differ on the 'Learn' variable, $t(53) = .75$, $p = .45$, demonstrating that there was no difference in their ability to encode the errand list before executing the EVET.

A number of outcome variables were generated from the EVET task, each of these is highlighted in the methods section, and means and standard deviations are shown in Table 3.

To analyse the role of pain and self-reported cognitive intrusion of pain data were initially entered into a series of 2 (pain group Vs non-pain group) × 2 (low ECIP vs high ECIP) AVOVAs. Where these suggested a significant interaction, it was broken down using simple main effect analysis where the data met

Table 2
To show means and standard deviations for pain thresholds and subjective rating of pain during EVET task.

	Pain	Non-pain
Threshold	42.19 (2.69)	42.25 (2.82)
Pain rating[a]	44.32 (18.53)	2.63 (2.53)
Pain distress[b]	35.96 (24.99)	3.44 (5.42)
Pain awareness[c]	61.61 (26.53)	6.74 (3.67)
ECIP	20.10 (10.71)	21.00 (16.29)
FPQ	72.71 (22.39)	81.15 (16.25)
PCS	21.21 (6.27)	20.00 (10.45)
ASI	13.75 (00.56)	17.89 (11.63)
DASS	17.96 (13.11)	27.41 (20.08)
PASS	26.29 (13.97)	33.78 (21.02)

[a] No pain at all – worst pain imaginable.
[b] No distress at all – most distress imaginable.
[c] Not aware at all – extremely aware.

Table 3
To show means and standard deviations for pain and non-pain groups performance on the EVET task.

	Non-pain		Pain	
	Low ECIP	High ECIP	Low ECIP	High ECIP
EVET score	10.63 (5.88)	10.54 (6.05)	11.27 (4.17)	7.77 (3.77)
Plan following	.65 (.17)	.54 (.28)	.44 (.30)	.47 (.27)
Elements completed	7.12 (2.42)	8.08 (2.69)	7.64 (1.96)	6.62 (2.02)
Bonuses	4.13 (3.09)	2.77 (3.61)	4.00 (3.22)	2.38 (2.57)
Penalties	.63 (1.41)	.31 (.63)	.18 (.40)	1.23 (1.36)
Learning	21.50 (4.07)	22.69 (5.50)	20.18 (4.98)	22.00 (5.63)
Recount	14.38 (3.62)	14.46 (5.87)	12.64 (4.70)	14.92 (4.89)
Remember	27.13 (5.69)	30.85 (4.81)	31.55 (4.55)	29.31 (5.71)

parametric assumptions and where they violated these assumptions, data were analysed with Mann–Whitney *U* tests. The between subjects ANOVA for penalties data revealed no significant main effect of pain group, $F(1,51) = .42$, $p = .52$, $\eta^2 = .01$, and no significant main effect of ECIP group, $F(1,51) = 1.63$, $p = .21$, $\eta^2 = .03$. There was however a significant interaction between pain group and ECIP group, $F(1,51) = 6.59$, $p = .01$, $\eta^2 = .11$. This interaction was broken down using a number of Mann–Whitney *U* tests this revealed no significant differences between participants in pain and not in pain in either the low ECIP group, $U = 75$, $p = .16$, or the high ECIP group, $U = 60$, $p = .08$. When participants were not in pain there was no significant difference between the low and high ECIP group, $U = 78.5$, $p = .45$, however, when participants were in pain more penalties were made in the high ECIP group compared to the low ECIP group, $U = 57$, $p = .02$.

For EVET score there was no significant main effect of pain group, $F(1,51) = .31$, $p = .58$, $\eta^2 = .01$, or ECIP group, $F(1,51) = .89$, $p = .35$, $\eta^2 = .02$, and no significant interaction, $F(1,51) = 1.15$, $p = .29$, $\eta^2 = .02$. For bonuses there was no significant main effect of pain group, $F(1,51) = .01$, $p = .92$, $\eta^2 < .01$, or ECIP group, $F(1,51) = 1.51$, $p = .23$, $\eta^2 = .29$ and no significant interaction, $F(1,51) = .18$, $p = .67$, $\eta^2 < .01$. For plan following there was no significant main effect of pain group, $F(1,51) = 1.20$, $p = .28$, $\eta^2 = .023$, or ECIP group, $F(1,51) = .05$, $p = .83$, $\eta^2 = .001$, and no significant interaction, $F(1,51) = .01$, $p = .01$, $\eta^2 < .001$. For recounting there was no significant main effect of pain group, $F(1,51) = .002$, $p = .96$, $\eta^2 < .01$, or ECIP group, $F(1,51) = 2.48$, $p = .12$, $\eta^2 = .05$, and no significant interaction, $F(1,51) = .51$, $p = .48$, $\eta^2 = .01$. For remembering there was no significant main effect of pain group, $F(1,51) = .17$, $p = .68$, $\eta^2 < .01$, or ECIP group, $F(1,51) = .83$, $p = .37$, $\eta^2 = .02$, and no significant interaction, $F(1,51) = 1.35$, $p = .25$, $\eta^2 = .03$

4. Discussion

The purpose of the current study was to examine the effect of experimental thermal pain on multitasking performance using the EVET, hypothesising that participants who completed the EVET in pain would show significant impairment in performance and recall compared to participants not in pain. Further we hypothesised that participants who report greater pain based cognitive interruption in their daily lives (ECIP) would show a greater interruptive effect of pain compared to those who report less pain related interference. The findings suggested no significant overall effect of pain on performance on the EVET. In relation to our second hypothesis, however, there was a significant effect of self-reported cognitive intrusion on performance in pain on the EVET task, i.e., individuals who self-reported greater effects of pain on performance generally, were more affected by experimental pain on aspects of EVET performance. Specifically, they more often violated the rules of the task by entering rooms and picking up objects that were not related to their goals. This could not be explained by forgetting of the errands, as there were no group differences on the 'remember' measure. These types of error can arise from a lack of inhibitory control – participants are not sure a particular room/object is correct but click on it any case.

The most similar previous study, Keogh, Moore, Duggan, Payne and Eccleston [18], examined participant's performance while experiencing the same pain stimulus used in the current study while performing measures of multitasking during a simulated breakfast preparation task, and a task of volitional switching during a word generation task. Keogh, Moore, Duggan, Payne and Eccleston's [18] findings were that the effect of pain was indirect and represented effects on peripheral measures, in a similar vein to the present study. Other previous research also suggests that the interruptive effect of pain is greatest during tasks which involve switching between tasks or managing multiple simultaneous demands [10] and indeed there are some suggestions that secondary tasks in dual task paradigms are maximally effected by pain [10,18]. In the current study, although a number of errands must be completed for successful performance these have to be performed in a serial rather than a parallel manner, and it is up to the participant to decide which of these tasks is 'primary' at any given time. Once a participant elects to complete a particular errand their primary task becomes one of navigation to the correct location, and secondary demands may come from online plan adjustments and retrievals from long-term memory (for the errand list). However, these may not represent a continuous demand in the same way as a secondary task in a traditional dual-task paradigm, where the participant must respond to a stream of incoming stimuli. Because of the self-directed nature of the EVET, participants may have been able to time their bursts of online planning activity for moments when the oscillations of the heat stimulus were relatively less painful. Therefore, they may have been able to protect performance in a way that the participants would not able to when keeping up a fast and accurate stream of responses to secondary task stimuli. This account is of course speculative, but could be tested in future research using different types of dual-task situations and pain induction protocols.

Another possible explanation for the limited impact of pain in the current study could be that the EVET is more engaging than previous tasks used to examine attentional interruption by pain. Past studies have typically used neutral and repetitive controlled cognitive tasks [10–12], whereas the EVET is based on a commercially available computer game system. Previous research suggests that when a task is manipulated to an optimal level of immersion then it has the maximal ability to produce attention based analgesia in children undergoing burns treatment [35]. It is possible that making the task longer (therefore asking participants to tolerate the pain for longer) or making the pain more threatening [11] (therefore prioritising pain) might increase the interruptive effect of pain on cognition and increase the attentional interruption seen. This however seems unlikely as the intensity of the pain is not continuously high, and shorter tasks have shown sensitivity to pain in previous studies [10,18].

Participants reporting greater pain related cognitive interference in their daily lives accrued more penalties on the EVET compared to those with lower self-reported cognitive intrusion by pain. This extends previous findings which have suggested individual differences in pain related cognitive interference. In previous studies either pain-affect variables related to the Fear of Pain [36], or factors conceptually related to cognitions about pain (including catastrophic thought [37]), have been the primary variables of interest. These variables are relevant to models of pain development, particularly the progression from acute to chronic pain states [38], however they indirectly examine the important issue of the role of cognition. Before pain can be ruminated upon or catastrophized about, it must first interrupt our current thinking [20]. The present study shows that individuals who perceive this

interruption to be a greater problem also demonstrate disruptive effects under laboratory conditions.

One consideration is that the significant effect of pain in the current task was limited to an increase in the number of penalties committed by those in the high ECIP group. It is therefore important that considerations of the finding here should be cautious, as no effect of pain or ECIP group was identified for the remaining measures on the EVET. It is possible that effects of pain on real world tasks are most easily identified for a measure of errors in performance and not the ability to complete the target task. This is at odds with recent studies which suggest that acute pain (i.e. headache and menstrual pain) result in people slowing down their performance in an attempt to maintain accuracy and avoid errors/penalties [12,39]. This either suggests that acute pain and experimental models affect performance differently, or that the consequences of pain for more ecologically valid tasks differs to those for more controlled tasks in the lab. There is also a risk that the reported effect could be a result of the number of comparisons, although it was in the predicted direction. It would certainly be beneficial for this effect to be replicated to confirm the phenomena.

One limitation of the current study is that a number of participants had to be removed. This was largely driven by technical failures and therefore occurred at random and should not have a systematic effect. However, four participants were removed due to a failure to understand the task or to be able to memorise the errand list. Therefore it is possible that individuals who have underlying reduced memory are not represented in this sample and that these individuals might be those most vulnerable to the interruptive effects of pain on cognitive function. In future studies a simplified version of the EVET with participants either retaining the list of errands on paper, or with a reduced number of errands, might allow a wider range of participants to complete the task.

A further consideration is that, although the present study adopted a demanding and multifaceted task compared to previous reports, the practice of using pain in controlled experimental contexts fails to represent the complexity of experience of pain in the real world. Everyday pain has qualities which make it fundamentally different to those found in the laboratory [40]. It may therefore be valuable to adopt protocols for examining naturally occurring pain in studies of attentional interference [41]. It is also important to consider that from these data, we cannot demonstrate that the interruptive effect on performance here is specific to pain. Indeed, other threatening stimuli (i.e. loud noises) may also disrupt performance and indeed mild, non-painful, thermal stimuli may also interrupt performance, however in previous research the effect of non-painful heat on cognitive performance has been limited relative to pain [10].

In conclusion, the findings of the present study suggest that, during thermal experimental pain, individuals who self-report greater cognitive interference by pain in everyday life made more errors on a simulated errand completion task than those who reported less pain related interference. The findings of this study support the growing literature suggesting an effect of pain on attentional performance and in particular the emerging literature which is identifying the translation of these effects into more ecologically valid task parameters. However, it is important to consider that the impact of pain in this study is limited to a single aspect of performance and that further replication and consideration of this effect is needed to more fully understand the impact of pain on multitasking performance.

Ethical issues

All participants gave full informed consent to participate in this research and this research received ethical approval from the Liverpool John Moores University Research Ethics Committee (REF: 15/NSP/001).

Conflict of interest

The authors have no conflict of interest in producing this manuscript.

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