The disruptive effects of pain on n-back task performance

in a large general population sample

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Number of pages: 29

Introduction: 492

Discussion: 1474

Figures: 1

Tables: 4

Abstract

Pain captures attention, displaces current concerns, and prioritizes escape and repair. This attentional capture can be measured by its effects on general cognition. Studies on induced pain, naturally occurring acute pain and chronic pain all demonstrate a detrimental effect on specific tasks of attention, especially those that involve working memory. However, studies to date have relied on relatively small samples, and/or one type of pain, thus restricting our ability to generalize to wider populations. We investigated the effect of pain on an n-back task in a large heterogeneous sample of 1318 adults. Participants were recruited from the general population and tested via the internet. Despite the heterogeneity of pain conditions, participant characteristics and testing environments, we found a performance decrement on the n-back task for those with pain, compared to those without: there were significantly more false alarms on non-target trials. Furthermore we also found an effect of pain intensity: performance was poorer in participants with higher intensity compared with lower intensity pain. We suggest that the effects of pain on attention found in the laboratory occur in more naturalistic settings. Pain is common in the general population and such interruption may have important, as yet uninvestigated, consequences for tasks of everyday cognition that involve working memory, such as concentration, reasoning, motor planning, and prospective memory.

Keywords: cognition; attention, working memory; updating; internet study

Summary: A large general population sample completed an n-back task online. Those who were in pain made more false alarms than those who were pain free.

1. Introduction

Beyond debate is the function of pain to alter behaviour by imposing an alarming motivational priority of escape, avoidance, or succour [16]. What is debateable is the 'cost' of attentional capture by pain. Pain is a quotidian experience [25,26]. Perhaps equally common is the natural repair of attention in the maintenance of coherent behaviour. Pain is part of a general danger detection system. To be interrupted by pain is normal. Therefore, perhaps also normal is the fast recovery from interruption. Maybe we are so good at recovery that such aversive interruption does not affect performance, except in the laboratory. Equally possible, however, is that pain has a cost so common that it goes largely unrecognized.

The effects of pain on cognition have been documented with laboratory induced pain, naturally occurring acute pain, and chronic pain [1,6,9,10,11,12,15,18,20,21,22,24,28]. For example, Moore, Keogh and Eccleston [21] compared healthy participants' performance on seven different aspects of attention when participants were pain free and during heat pain induction. They found that pain disrupted working memory updating, attention switching, and divided attention. Similar effects have been found with naturally occurring menstrual pain [18] and headache pain [22]. A meta-analysis revealed that chronic pain results in less accurate responses on tests of complex executive function and set shifting, and slower responses on inhibition, complex executive function and set shifting tasks [4].

Although there have been many small-sample observations, missing are data from large, heterogeneous, and naturalistic samples of the general population. Most studies on pain-related interference have homogenous samples and tightly-controlled laboratory conditions. While these characteristics are essential in establishing effects, it is now necessary to investigate whether the effects of pain on cognition are stable across different groups and in more naturalistic settings, sacrificing control over pain induction for scale,

heterogeneity, and self-reported pain experience. Our aim was to investigate the effect of pain on working memory in a large, heterogeneous, general population sample, recruited and tested on the internet, with participants experiencing a variety of pain states (e.g. transient, acute, chronic, no pain) (see [5] for a similar method). If the effects of pain on working memory are reliable and significant in day-to-day life, we would expect to see them even in less controlled environments such as this.

We predicted that participants who were in pain at the time of the study would have lower accuracy and slower reaction times on a working memory task than pain free individuals. We included sex and age in this analysis to investigate the generalizability of the effects across the sample. Given that women report a greater impact of pain on their lives than do men[17], women may also show larger effects of pain on attention. Furthermore, we predicted that within the pain group, high intensity pain would be associated with lower accuracy and slower reaction times than low intensity pain. We also examined the effect of the type of pain that participants experienced and whether it was acute or chronic.

2. Method

2.1. Participants

A general population sample was recruited to complete a letter n-back task and a series of questionnaires online. The inclusion criteria were that participants had to be aged 18 or over and with access to an internet-enabled laptop or desktop computer. We did not restrict or control recruitment in any other way. One thousand and five hundred participants were accessed through Amazon Mechanical Turk (MTurk; www.MTurk.com). MTurk is an open online marketplace for recruiting individuals to complete tasks for a small fee, and can be used to obtain high-quality reliable research data quickly and

inexpensively[7,23]. Participants recruited via MTurk were paid $1 for their participation.

Previous research suggests that participants recruited via MTurk are often internally

motivated[7]. An additional 199 participants were accessed via forums, websites and pain-

related discussion groups that hosted a link to the web experiment. Participants recruited

outside of MTurk did not receive $1 for their participation. At the end of the study,

participants were provided with links to other websites where they could complete similar

tasks in the form of games, in order to discourage repeat submissions.

Of the 1699 participant entries, 20 participants were identified as having two

submissions each. In these cases, only the first submission was included, and the 20

duplicate submissions were excluded. This left 1679 unique data submissions. Of these 1679

submissions, 15 were from individuals who did not give consent to take part, and did not

progress past the information and consent page. One further participant reported their age

as under 18 (17). Participants who indicated that they did not want to seriously participate

(N = 18), and those who did not report whether or not they were currently in pain (an

additional 8 participants) were also excluded, leaving a total of 1637 participants. Socio-

demographic and pain-related information of this sample is presented in Tables 1 and 2.

2.2.   Measures

2.2.1. Seriousness check

The use of seriousness checks in online research is recommended to improve data

validity by identifying non-serious submissions[3]. Therefore, before completing the

experiment participants were asked to indicate whether they were seriously participating or

just browsing the study pages. In order to further confirm whether participants had taken

participation seriously, participants were also asked to report whether they had answered

the questions honestly (yes (N = 1462), mostly yes (N = 56), mostly no (N = 4), no (N = 1),

missing data (N = 111)) at the end of the experiment.

2.2.2. Demographics

Participants were asked to provide demographic information including age, sex, native

language, country of residence, ethnicity, and level of education.

2.2.3. Pain status

In order to ascertain current pain, participants were asked to indicate whether or not

they were currently in any pain as well as the intensity of this pain on a 21-point scale

labelled 0 'no pain at all' to 10 'pain could not be worse' (with non-numbered midpoints

available between each number). Participants were asked to indicate the type(s) of pain

they were experiencing by selecting any applicable items from a list or entering any other

conditions in a free text box. They were also asked to report the duration of their current

pain using a free text box, and responses were coded as acute (< 3 months) or chronic (> 3

months). These data are summarised in Table 2. Some details about pain diagnosis,

analgesic treatment, and coping mechanisms were also requested. However, due to the

study being conducted online we aimed to keep it as short as possible, and we did not

assess non-pain-related health factors.

2.2.4. N-back task

The n-back task is a measure of working memory updating which has been shown to

be sensitive to the effects of experimental pain[6,21] and naturally occurring pain[18,22]. The

current experiment utilised a 2-back version of the n-back task. During this task,

participants were presented with a stream of 90 letters (all of the consonants were included

except 'Y'), which appeared one at a time in the centre of their computer monitor. The

letters were capitalised and appeared in black Arial font on a white background. The size of

the letters was 20% of the monitor height. Each letter was presented for 500ms, followed by a 1500ms blank screen. Participants were instructed to report whether the letter currently on screen matched the letter presented two letters back; they indicated their response using two separate keys (0 and 1) on their computer keyboard. The task included 30 target stimuli and 60 non-target stimuli presented in a random order.

2.2.5.   Cognitive intrusion and pain dominance

Participants completed the Cognitive Intrusion of Pain (CIP) scale[2] to measure their experience of cognitive intrusion from pain. These data are not relevant to our current research questions and are reported elsewhere[2].

2.2.6.   Environment

Participants were not instructed to complete the study under any specific conditions, but they were asked a series of questions regarding the environment in which they completed it. They were asked to indicate where they completed the study (home (N = 1376), work (N = 112), internet café (N = 8), library (N = 17), public transport (N = 1), outdoors (N = 3), other (N = 4)), whether they were interrupted during the study (no (N = 1404), once (N = 106), a few times (N = 24), repeatedly (N = 4)) and the amount of noise in their environment on a scale of 0 (silent) to 10 (very noisy, M = 1.36, SD = 1.89).

2.3.   Procedure

The study was approved by the Departments of Psychology and Health ethics boards at the University of Bath. Participants were directed to the study webpages via MTurk, pain discussion forums, or other online advertisements. The study was presented to participants using Inquisit 4 Web[14], which provides millisecond accuracy for stimulus presentation and response timing[13]. Minimum system requirements are needed to be able to run the programme, including: Windows XP or Mac OSX 10.6; Pentium 166 MHz processor; 10 MB

of available hard-disk space; DirectX compatible SuperVGA graphics system. The study

began with an information and consent page. Participants were required to check a box and

click next if they consented to take part, or to exit the programme if they did not consent.

Participants who gave consent then completed the following sections in order:

demographics questions, pain questions, CIP scale, n-back task and environment questions.

Finally, participants saw a debrief page and received a completion code for the MTurk

payment system. The experiment took approximately 10 – 15 minutes to complete and

responses were anonymous. Participants were able to withdraw at any time.

2.1.   Analysis

Sex differences in the prevalence of pain were investigated using a Chi-Square test.

The relationship between age and pain prevalence was investigated using a logistic

regression analysis. The relationship between pain and n-back task performance (measured

by number of hits, number of correct rejections, hit RTs and correct rejection RTs) was

investigated with 3 analyses: 1) an examination of the main and interactive effects of pain,

sex and age on n-back performance using a 2 (Pain: present, absent) × 2 (Sex: female, male)

ANCOVA with age as a covariate, 2) a correlation between pain intensity and n-back

accuracies and RTs within the pain group, 3) an investigation of the effects of pain type and

duration on n-back performance using a 6 (Pain Group: arthritis only, backache only,

headache and migraine only, musculoskeletal pain only, multiple pain conditions, and

'other' pain conditions) x 2 (Pain Duration: acute, chronic) ANOVA (age and sex are not

included here due to small cell sizes).

3.   Results

3.1. Environmental effects and data cleaning

Of the 1637 participants who started the study, 94 did not complete the n-back task. For the remaining 1543 participants who did complete the n-back, the relationship between task performance and the participants' environments was investigated using two regression models with five independent variables: noise, interruptions, location (e.g. home, work), honesty and effort, one model to predict number of hits and one to predict number of correct rejections. Number of hits was significantly predicted by the model, $R^2 = .044$, $F(5,1503) = 13.70$, $p < .001$, and three predictors were significant: interruptions, $β = -.093$, $p = .001$, honesty, $β = -.100$, $p < .001$, and effort, $β = .124$, $p < .001$. Number of hits was not predicted by noise, $β = .049$, $p = .095$, or location, $β = -.017$, $p = .515$. Number of correct rejections was also significantly predicted by the model, $R^2 = .037$, $F(5,1503) = 11.41$, $p < .001$, and the same three predictors were significant: interruptions, $β = -.073$, $p = .010$, honesty, $β = -.108$, $p < .001$, and effort, $β = .096$, $p = .001$. Again, correct rejections were not predicted by noise, $β = .018$, $p = .528$, or location $β = .042$, $p = .097$.

Based on these findings, participants were excluded if they reported that they were interrupted from their environment during the study a few times or constantly ($N = 28$), if they reported that they did not answer the study questions honestly ($N = 5$), if they rated their effort on the n-back task as lower than 5 out of 10 ($N = 14$), if they did not provide answers to these questions ($N = 12$), or if their performance on the n-back task was not significantly above chance level on both target and non-target trials, suggesting that they did not understand the task, were guessing, were responding randomly, or were simply unable to perform the task ($N = 166$). To test for bias in which participants performed above chance level we examined the demographic characteristics of participants who were significantly above chance level on the n-back task and those who were not using Chi-

Square tests. There was no evidence of dependency between above chance performance and presence/absence of pain, χ^2 (1) = .04, p = .851, or between above chance performance and type of pain, χ^2 (6) = 11.00, p = .089. However, above chance performance did differ by sex, χ^2 (1) = 6.48, p = .011, with more males (90.8%) than females (86.6%) scoring above chance level. Participants who did not perform significantly above chance rated their effort on the n-back task as 9.20 out of 10 and those who scored above chance level rated their effort as 9.33 out of 10, which were not significantly different, t(1482) = 1.51, p = .132, d = .11. Of note, participants who were in pain and those who were not were similar in the amount of effort they reported dedicating to the n-back task, t(1316) = 1.26, p = .207, d = .07, background noise, t(1316) = .09, p = .929, d = .01, interruptions, t(1316) = .89, p = .374, d = .08, and honesty, t(1316) = 1.39, p = .165, d = .12.

These exclusion criteria left 1318 participants for the analysis, 534 of whom were in pain and 784 of whom were not in pain. For analyses including Sex, we limited the sample to participants reporting that they were male or female and excluded those reporting that they were intersex or transgender due to small cell counts. For these analyses, the sample size was 1308, with 530 participants in pain and 778 not in pain.

The RT data were screened for extreme values. There were no anticipation RTs (shorter than 300ms). Because response times had an upper limit of 2500ms, none were removed from the upper end. For trials where a participant failed to respond (8.55% of all trials), their RT was removed and their accuracy coded as incorrect. Mean RTs for each participant were also examined for outliers. This led to nine participants being excluded from the analyses of hit RTs and 13 being excluded from the analyses of correct rejection RTs. However, these participants' accuracy data was retained. As such, the sample size for reaction time analyses was slightly smaller than for accuracy analyses.

3.2.   Demographics and pain prevalence

Demographics for the final sample are presented in Table 1, and pain characteristics of the sample are presented in Table 2. Sex differences in the prevalence of pain were investigated using a Chi-Square test, which revealed that, as expected[17], more women (49%) than men (33%) reported that they were in pain, $\chi^2(1) = 33.94$, $p < .001$. Within the group of participants who were in pain, there was no sex difference for the intensity of pain reported, $t(528) = 1.37$, $p = .171$ (males: M = 7.47, SD = 4.60, females: M = 8.02, SD = 4.51).

A logistic regression also showed that pain was more common in older participants than in younger participants, Wald = 30.45, Exp(B) = 1.03, $p < .001$. For every one year increase in age, participants were 1.03 times more likely to report pain.

3.3.   N-back task performance

Table 3 shows the mean accuracy and reaction times (RTs) for each type of trial (target and non-target) and each type of response (target hits, target misses, non-target correct rejections and non-target false alarms) in the pain and no pain groups. Table 4 shows the correlations between the four outcome measures used below. The number of hits and correct rejections that participants scored were not correlated. Next we present the analyses of the relationship between pain and performance on the n-back task.

3.3.1.   Effects of pain, sex and age on number of hits

For number of hits, there were no significant main effects or interactions (all $ps > .084$).

3.3.2.   Effects of pain, sex and age on number of correct rejections

For number of correct rejections, there was a main effect of Pain, $F(1,1299) = 5.99$, $p = .015$, $\eta^2_p = .005$, with participants who reported pain scoring lower ($M = 85.12\%$, $SD = 17.83\%$) than those who reported no pain ($M = 88.50\%$, $SD = 14.62\%$, see Figure 1). There was a significant interaction between Sex and Age, $F(1,1299) = 4.98$, $p = .026$, $\eta^2_p = .004$. In women, there was a significant negative correlation between age and number of correct rejections, $r(635) = .120$, $p = .003$, while in men there was no correlation between age and number of correct rejections, $r(672) < .001$, $p = 1.00$, and these correlations were significantly different, $z = -2.17$, $p = .030$. All other effects were non-significant: pain did not interact with sex or age.

Insert Figure 1 about here

Overall, participants in pain were more likely to mistake non-targets for targets (i.e. have more false alarms). This could be because they genuinely believed they were targets, or it could be that participants in pain were more likely to select the 'target' option when unsure. To discriminate between these hypotheses we compared RTs for false alarms on non-target trials with RTs for hits on target trials using a 2 (Trial Type) × 2 (Pain) ANOVA. To support the first hypothesis we would expect the RTs to be similar across trial types in participants with pain. To support the second hypothesis we would expect RTs for false alarms to be longer than RTs for hits in participants with pain. Our analysis revealed a main effect of Trial Type on RTs, $F(1,1200) = 6.66$, $p = .010$, $\eta^2_p = .006$, with false alarms ($M = 1222$, $SD = 217$) taking longer than hits ($M = 1210$, $SD = 180$) (note that the sample size here is slightly smaller than in the other RTs analyses because some participants did not make any false alarms, meaning they did not have a false alarm RT score). There was no main

effect of pain, $F(1,1200) = 2.43$, $p = .120$. There was a marginally significant interaction between Trial Type and Pain, $F(1,1200) = 2.94$, $p = .087$, $\eta^2_p = .002$, which was due to longer RTs for false alarms ($M = 1216$, $SD = 219$) than for hits ($M = 1199$, $SD = 175$) in the participants without pain, $t(706) = 3.17$, $p = .002$, $d = .09$, and no difference in RTs for false alarms ($M = 1226$, $SD = 207$) and for hits ($M = 1223$, $SD = 180$) in participants with pain, $t(494) = .62$, $p = .537$, $d = .02$. This suggests that in the absence of pain participants hesitate before making false alarms, but in the presence of pain they do not. In other words, participants in pain may be more likely to genuinely mistake non-targets for targets than those without pain, although the two-way interaction did not quite reach significance.

3.3.3. Effects of pain, sex and age on hit RTs

For hit RTs, there was a significant main effect of Age, $F(2,1284) = 48.32$, $p < .001$, $\eta^2_p = .036$, with RTs increasing as age increased, $r(1292) = .225$, $p < .001$. There was a significant main effect of sex, with women's RTs ($M = 1215.76$, $SD = 179$) being longer than men's ($M = 1202.29$, $SD = 186$). Finally there was an interaction between Sex and Age, $F(1,1284) = 6.43$, $p = .011$, $\eta^2_p = .005$, which was due to a stronger positive correlation between age and hit RTs in women, $r(631) = .309$, $p < .001$, then in men, $r(661) = .127$, $p = .001$, $z = 3.44$, $p < .001$. All other effects were non-significant.

3.3.4. Effects of pain, sex and age on correct rejection RTs

For correct rejection RTs, there was a significant main effect of Age, $F(2,1274) = 47.79$, $p < .001$, $\eta^2_p = .036$, with RTs increasing as age increased, $r(1282) = .220$, $p < .001$. There was a significant main effect of sex, with women's RTs ($M = 1161$, $SD = 167$) being longer than men's ($M = 1154$, $SD = 173$). Finally there was an interaction between Sex and Age, $F(1,1274) = 5.39$, $p = .020$, $\eta^2_p = .004$, which was due to a stronger positive correlation

between age and hit RTs in women, r(622) = .302, p < .001, then in men, r(660) = .127, p = .001, z = 3.43, p < .001. All other effects were non-significant.

3.3.5. Pain intensity and n-back scores

To examine the influence of pain intensity on n-back performance, we ran a series of correlations between pain intensity and n-back scores within the pain group. There was no relationship between pain intensity and number of hits, r(534) = -.07, p = .132, but there was a significant relationship between pain intensity and number of correct rejections, r(534) = -.16, p < .001. The more intense participants reported their pain to be, the fewer correct rejections (and more false alarms) they made. There was no relationship between pain intensity and hit RTs, r(534) = .003, p = .949, or correct rejection RTs, r(534) = .025, p = .558.

3.3.6. N-back performance in different pain conditions and pain durations

Pain reduced the number of correct rejections that participants made, and this effect was correlated with pain intensity. Next, we investigated the effects of the type and duration of pain that participants reported on their n-back performance, using a 6 (Pain Group: arthritis only, backache only, headache and migraine only, musculoskeletal pain only, multiple pain conditions, and 'other' pain conditions) x 2 (Pain Duration: acute, chronic) ANOVA, within those reporting pain. There were no main effects and no interactions for Pain Type or Duration for number of hits, number of correct rejections, hit RTs or correct rejection RTs, all ps > .143.

4. Discussion

Pain reduces working memory performance. Participants in pain at the time of the study made more errors, more often falsely identifying letters as seen when they had not

been presented. This effect of accuracy was consistent across sex and age but sensitive to the intensity of pain experienced: the more intense the pain, the more false alarms participants made. Performance did not significantly differ depending on the type of pain, classified largely by location, or the chronicity of pain.

Of interest here is the specificity of the effects. Pain disrupted working memory by increasing the chance of wrongly identifying non-targets as targets, an effect exacerbated by intensity. A similar pattern of results was found in Keogh et al's[18] study of menstrual pain using the same n-back task, and in Kuhajda, Thorn, Klinger and Rubin's[20] study of headache and migraine using a word recognition test at 1-7 days post encoding. If pain-related increases in false alarms occur consistently for both working memory and longer-term memory, its impact on day-to-day life is potentially extensive. However, Moore, Keogh and Eccleston[22] found a different effect on n-back performance in their study of headache pain: accuracy for targets but not non-targets was reduced when participants were in pain. This inconsistency is difficult to reconcile. It cannot be explained simply by the type of pain studied (which was the same in Moore et al and Kuhadja et al) or the type of task used (which was the same in Moore et al and Keogh et al). However, it could be the specific combination of headache and n-back task that produces a reduction in the number of hits. To investigate this possibility we ran an additional analysis to compare the number of hits in participants with headache pain (N = 45) versus menstrual pain (N = 9). This analysis was hindered by a small number of participants with menstrual pain and no other pain conditions, and although the comparison was not significant, $t(52)$ = 1.75, p = .086, participants with headache had 11% fewer hits than participants with menstrual pain. Taken together these findings suggest that headache specifically impairs working memory for

targets, while pain in general increases false alarms in working and longer-term memory. Further investigation is needed to confirm this.

We tested between two hypotheses of the higher number of false alarms in participants with pain: either participants believed that the non-targets were targets, in which case their RTs should be similar for false alarms and hits, or participants were more likely to select 'target' when they were unsure, in which case we expected RTs for false alarms to be longer than RTs for hits, due to hesitation. The latter seemed to be the case in participants without pain, but we found no difference in RTs for hits and false alarms for participants with pain. This suggests that participants who are in pain may be genuinely mistaking non-targets for targets. However, the interaction between trial type and pain did not achieve significance, and these hypotheses should be investigated further in future research.

Multiple executive processes are involved in performing the n-back task: actively maintaining the previous n items; updating working memory with new items; rapidly binding items to their serial position; and inhibiting any interference from items that appeared not-n items back[8]. It is unclear which of these processes could be responsible for the increase in false alarms in participants with pain. False alarms may result from incorrect updating of new items (i.e. updating the working memory record with new letters which were not presented), incorrect binding of items to their serial position so that letters seen 1- or 3-back are incorrectly coded as being 2-back, or failure to inhibit interference from recently seen items which were not exactly n-items back. The latter explanation seems most likely, since the former two would likely reduce the number of hits in addition to increasing the number of false alarms.

A major strength of this study is the size and diversity of our sample, which allowed us to examine the effects of types of pain and duration of pain on n-back performance. Neither type nor duration of pain had a significant effect on number of hits, number of correct rejections, hit RTs or correct rejection RTs, which suggests that the effect of pain on working memory is general rather than specific to certain conditions.

We also investigated the role of sex and age in working memory disruption from pain. While 47% of women reported pain compared to 33% of men, there was no difference in pain intensity between the sexes and there were no interactions between pain and sex on task performance. This suggests that although females may be more susceptible to pain or more willing to report it, they do not differ broadly from men in terms of working memory disruption from pain. Our sample reported a wide range of ages (18 to 71), in contrast to the majority of pain and cognition research which tends to recruit samples with narrower age ranges, such as students[e.g. 18,19,21,22,28]. Sex and age interacted to affect number of correct rejections and RTs to both hits and correct rejections. In women, age was more strongly associated with a decline in accuracy and an increase in RTs than in men. Importantly, however, there were no interactions between age and pain on task performance, which suggests that the effects of pain on working memory are generalisable across the age range we examined, and provides some reassurance that samples with limited age ranges in this field should not be a substantial cause for concern.

A limitation to this study is that a proportion of participants (11%) failed to perform above chance level on the n-back task. The online nature of the study meant that participants were not able to ask the researchers for clarifications if they were unsure how to perform the task. Importantly, we found no evidence that above chance performance was dependent on presence/absence of pain or type of pain. The online nature of the study

also meant that we were limited in how many measures we could administer, and so we did not assess psychological traits such as catastrophizing. Individual difference measures such as this have been studied extensively in the laboratory and they were not relevant to our main aim here.

Of note is that the effect sizes we found were small: false alarms were 3.4% higher in participants with pain than in those without. For comparison, cocaine has been found to reduce hits on a 2-back task by 8%[27]. However, the effect size we found here was comparable to those found in other pain studies. Keogh et al[18] found 2.5% more false alarms on a 2-back task in participants with menstrual pain, while Buhle and Wager[6] found an approximately 4% decrease in hits on a 3-back task when participants experienced high heat pain induction compared to low heat. The small magnitude of the effect of pain on n-back performance is reassuring in a sense, but we should be careful not to dismiss the relevance of small effects on processes as important as working memory. In a complex situation such as driving, where multiple processes are reliant on working memory and multiple decisions are made every minute, 3% more errors could have very important consequences.

We have taken pain and attention research out of the laboratory and replicated previous findings, but future research should go further by examining the effect of everyday pain on tasks that more closely resemble the use of working memory in the real world, such as driving, cooking or shopping. Our research has already begun to move in this direction. Keogh, Moore, Duggan, Payne and Eccleston[19] investigated the effects of thermal pain induction on a complex computerised breakfast making task and found impaired ability to multitask in participants experiencing pain. Further research in this direction should

establish the extent of attentional disruption from pain in day-to-day life and investigate strategies people use to deal with this disruption.

In summary, we have conducted a novel large-scale internet study recruiting participants with a variety of painful conditions and shown that working memory is impaired in people with naturally occurring pain in the general population. This is the first study of pain and cognition to recruit such a large and diverse sample, and to use the internet for recruitment and testing. Our findings represent further evidence that pain has a disruptive effect on working memory, and they suggest that the effect is reliable enough to be seen across a variety of pain conditions, intensities and durations, and in participants from multiple countries with a wide range of ages and testing environments. This not only provides convincing evidence that the effects of pain on working memory are robust, but it also demonstrates that it is feasible and worthwhile to conduct pain cognition research online.

Acknowledgements

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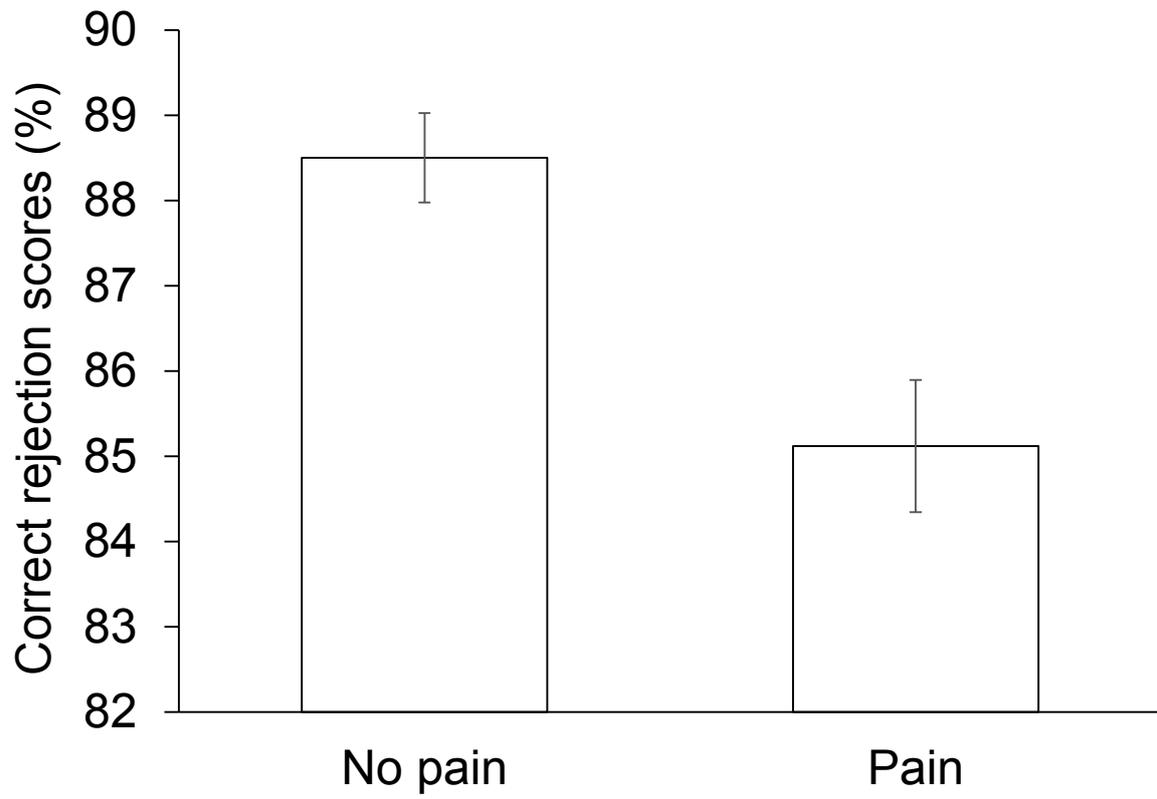
Figure 1. Correct rejection scores in the pain and no pain groups. Error bars reflect ±1 standard error of the mean.

Table 1. Socio-demographic characteristics of the sample.

Demographic	N, mean (SD), or %
Age	34.34 (11.25)
Sex	
Female	810
Male	814
Intersex/transgender	11
No response	2
Gender	
Woman	815
Man	815
Transgender	2
No response	5
Native Language English	87.5%
Country	
US	1378
India	213
Other	44
No response	2
Ethnicity	
White	1119
Asian	293
Black	102
Mixed	69
Other/unknown	52
No response	2
Education	
None	12
High school, A-level or equivalent	658
Degree or higher degree	964
No response	3

Table 2. Prevalence of pain in the sample.

Pain characteristics (n = 1637)	N	% of sample or mean (SD)
Current pain		
Yes	660	40.3%
No	977	59.7%
Pain intensity 0 – 10 (in pain group only)		4.10 (2.33)
Pain Type[a]		
Arthritis	110	6.7%
Backache	306	18.7%
Headache/migraine	200	12.2%
Menstrual	56	3.4%
Musculoskeletal	162	9.9%
Nerve-related	61	3.7%
Stomach pain	65	4.0%
Dental pain	77	4.7%
No pain	977	59.7%
Pain duration		
No pain	977	59.7%
Acute (less than 3 months)	285	17.4%
Chronic (more than 3 months)	295	18.0%
Pain with unspecified duration	79	4.8%

[a] Some participants reported multiple pain conditions so the total here is greater than 1637 or 100%

Table 3. Mean accuracy and RT scores on the N-back task in the pain and no pain groups. Standard deviations in parentheses.

		Targets		Non-targets	
		Hits	Misses	Correct rejections	False alarms
Acc (%)	Pain	74.02 (17.48)	25.98 (17.48)	85.12 (17.83)	14.88 (17.83)
	No pain	73.59 (17.65)	26.41 (17.65)	88.51 (14.62)	11.49 (14.62)
	Average	73.77 (17.58)	26.23 (17.58)	87.14 (16.08)	12.86 (16.08)
RT (ms)	Pain	1222 (179)	1223 (234)	1173 (168)	1227 (207)
	No pain	1203 (178)	1210 (237)	1149 (164)	1217 (223)
	Average	1211 (179)	1215 (236)	1159 (166)	1221 (217)

Table 4. Correlations between accuracy and RT measures. * *p* < .001.

	Correct rejections	Hit RTs	Correct rejection RTs
Hits	.049	.205*	.308*
Correct rejections	-	-.037	-.103*
Hit RTs	-	-	.866*