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7   People in pain make poorer decisions

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1   **People in pain make poorer decisions**

2

3   **Abstract**

4   Chronic pain affects 1 in 5 people and has been shown to disrupt attention. Here, we

5   investigated whether pain disrupts everyday decision making. In Study 1, 1322 participants

6   completed two tasks online: a shopping decisions task and a measure of decision outcomes

7   over the previous 10 years. Participants who were in pain during the study made more

8   errors on the shopping task than those who were pain-free. Participants with a recurrent

9   pain condition reported more negative outcomes from their past decisions than those

10   without recurrent pain. In Study 2, 44 healthy participants completed the shopping

11   decisions task with and without experimentally-induced pain. Participants made more

12   errors while in pain than while pain-free. We suggest that the disruptive effect of pain on

13   attending translates into poorer decisions in more complex and ecologically valid contexts,

14   that the effect is causal, and that the consequences are not only attentional, but financial.

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16   Keywords: Pain, cognitive disruption, decision making, finances, numeracy

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21   **Summary:**

22   Pain had a disruptive effect on decision making in ecologically valid contexts. The effect is

23   causal, and the consequences are not only cognitive, but financial.

24

1   **Introduction**

2   The disruptive effect of pain on attending has been demonstrated with

3   experimentally-induced pain[30,40], chronic pain[9,15] and transient pain such as

4   headache[4,24,31]. This field has predominantly focused on simple cognitive processes

5   (although sometimes using complex tasks combining multiple executive functions[25]). Few

6   studies have examined the effects of pain on higher-level cognition. One which did, found

7   that clinical pain was associated with less-abstract thinking[20], while another found no

8   evidence that experimentally-induced pain affected abstract thinking[2]. Here, we focus on

9   the potential impact of pain on higher-level real-world cognitive tasks requiring attention,

10   namely numerical reasoning and decision making, which have serious consequences if one

11   gets them wrong.

12   Reasoning and decision making are required in many areas of life and are influenced

13   by various cognitive and emotional factors. Here, we focus on numeracy as a domain that is

14   important in many areas of life, including budgeting, choosing a mortgage and choosing

15   insurance plans. Despite its importance, numeracy in adults is poor. In the quantitative

16   domain of the USA's 2003 National Assessment of Adult Literacy, 55% of adults performed

17   at a basic or below basic level (at best being able to locate easily-identifiable quantitative

18   information and solve one-step arithmetic problems when the operation was specified or

19   easily-inferred)[26]. These findings were echoed in a 2016 UK Money Advice Service

20   study[29] into the public's ability to choose the best supermarket deals for four products.

21   While 74% of participants chose the best deal for at least one product, only 2% chose

22   optimally for all four.

23   Attention is important for learning and performing numerical operations in both

24   children and adults[13,36]. Attention is also important in decision making, where we need

1   to consider various options, estimate their likely outcomes, then hold these in mind while

2   choosing among them. Given that pain impairs attention, it may also influence numerical

3   decision making. Indeed, there is some initial evidence that this is the case. Placing a hand

4   into ice-cold water changed participants' risk-taking on a financial decision-making task[35].

5   We investigated the effect of pain on everyday decision making. In Study 1, a large

6   general population sample recruited online reported whether they were currently in pain

7   and whether they had any recurrent pain conditions. They completed two tasks: the

8   shopping decision task used by the Money Advice Service[29] and the Decision Outcomes

9   Inventory (DOI[10]), which measures real-world outcomes of everyday decisions made over

10   the previous 10 years. We hypothesized that participants who were in pain would find the

11   best shopping deal on fewer items than participants who were pain-free. If the effect of

12   pain on attention does translate into poorer decision making, the outcomes of these poor

13   decisions may accumulate in people with chronic pain. We therefore hypothesized that

14   participants with pain that had lasted for three months or longer would report more

15   negative decision outcomes on the DOI than other participants. In Study 2 we took an

16   experimental approach to determine a causal relationship: participants completed an

17   extended shopping-decisions task with their hand in warm or painfully-cold water.

18

19   **Study 1 Method**

20   Design and procedure

21   Participants (N = 1322) took part online and were recruited via Amazon's Mechanical

22   Turk (N = 658) and Prolific.ac (N = 664). Research has shown data collected online for

23   psychology studies is reliable[11,33] and that samples tend to be more diverse than

24   traditional university-based samples[27]. The large sample size was decided based on

1   previous online pain studies[3,5,7], taking into account the likelihood of substantial non-

2   completion, the noise associated with online data collection, and likely percentages of

3   participants who would report current pain (estimated at 30%) or recurrent pain (estimated

4   at 40%), to ensure sufficient numbers of participants in each cell (a minimum of 20) of the

5   current pain x recurrent pain x sex interaction. We achieved this aim, with the smallest cell

6   size in our primary analyses (after exclusions, see the "Data Cleaning" section) being 22

7   participants who were male with both current and recurrent pain.

8   Participants were directed to the study pages in Qualtrics via the recruitment

9   systems. After giving informed consent, participants then answered demographic questions,

10   reported whether they had current and/or recurrent pain, completed the Decision

11   Outcomes Inventory and completed a shopping decisions task (see below for question and

12   task details). A 'debrief' page appeared at the end which gave information on the purpose

13   of the study, how to contact the researchers with any questions, and how to receive

14   payment on MTurk or Prolific ($2 or £2 respectively, based on the recommended per-hour

15   rates for each recruitment site).

16

17   Participants and demographics

18   Participants (N = 1322) were 699 males, 619 females, 3 trans females and 1 trans

19   male. Ages ranged from 18 to 74 (M = 33.98, SD = 10.80). English was the first language for

20   1201 participants, with 16 reporting Hindi, 11 reporting Portuguese, and the remaining 94

21   reporting a wide variety of other languages. The majority of participants were based in the

22   USA (N = 799), followed by the UK (N = 341), and India (N = 44), with the remaining 138

23   reporting a variety of other countries. Participants reported their highest educational

24   qualification, and 54% reported a university degree or above.

1

2   Pain characteristics

3   Participants were asked whether they were in pain at the time of the study ("Are you

4   in pain at this very moment, from any cause?" Yes: N = 337, 25%, No: N = 985, 75%). Those

5   who reported a current pain condition answered follow-up questions about the type,

6   intensity, and duration of their pain. Participants were then asked whether they had any

7   recurrent pain conditions that were not causing them pain at the time ("Do you have a

8   recurrent pain condition that is not causing you pain at this moment in time?" Yes = 407,

9   31%, No = 915, 69%). Those who reported a recurrent pain condition answered follow-up

10   questions about the type, intensity, and duration of the pain. The type of pain was selected

11   from a list of options, separately for current and recurrent pain (see Table 1; participants

12   were able to select multiple types of pain). Pain intensity was indicated on a numerical

13   rating scale from 0 "No pain at all" to 10 "Worst pain imaginable" separately for current and

14   recurrent pain (current M = 3.47, SD = 1.79, 95% CI [3.28, 3.66]; recurrent M = 5.42, SD =

15   1.83, 95% CI [5.24, 5.60], participants were instructed to give an average pain rating if they

16   had more than one recurrent painful condition). Participants were asked to indicate when

17   their pain had started from a list of options (see Table 2), separately for current and

18   recurrent pain. They were instructed to answer based on their longest standing painful

19   condition if they had more than one type of current pain or more than one type of recurrent

20   pain.

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23   Insert Table 1 here

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6   Measures

7   *Shopping-Decisions Task*

8   The shopping-decision task was adapted from that used by the UK Money Advice

9   Service[29] (see https://figshare.com/s/17f3800d66375b92fb71 for the questions used

10   here). We used the original four questions, based on actual deals available in supermarkets,

11   and created two new ones to increase the potential variance in the data. Each question

12   asked participants which of 4 or 5 options represented the best deal for buying a particular

13   product. For example:

14   Of the following options for milk, which represents the best deal?:

15   a) Six pints of milk for £1.80

16   b) Four pints of milk for £1.40

17   c) Two six-pint cartons of milk on offer for £3.50

18   d) Two four-pint cartons of milk on offer for £2

19   We included a "don't know" option for each question. This was intended to serve two

20   purposes: first, to reduce the risk of participants getting correct answers simply by guessing,

21   and second, to reduce the risk of any participants with mathematics anxiety[21] feeling

22   anxious about being asked to perform arithmetic, by making it clear that they could avoid it

23   if they wished.

1   Answers were scored as either correct or incorrect and participants were given a

2   total score ranging from 0 to 6.

3

4   *Decision Outcomes Inventory (DOI)*

5   The DOI asks participants to report whether or not they have experienced each of 41

6   negative decision outcomes, such as missing a flight, receiving parking tickets, or going

7   bankrupt[10]. Thirty-five of these outcomes are preceded by filter questions asking whether

8   participants had had the opportunity to experience the outcome. For example, the question

9   "Have you had your electricity, cable, gas or water shut off because you didn't pay on

10   time?" was preceded by "Have you been responsible for electricity, cable, gas or water

11   payments?".

12   Scores on the DOI are weighted by the proportion of the sample who reported

13   experiencing each outcome, with less common outcomes being weighted more heavily than

14   more common ones on the assumption that frequency reflects severity (e.g. many more

15   people have been lost while driving than have spent a night in jail). For example, if 500

16   participants have bought their own food, and 470 of these have thrown away food that

17   went bad, the score for experiencing this negative outcome would be 1 - 470/500 = .06.

18   Participants received a positive weighted score if they had avoided a negative

19   outcome (e.g. +0.06 if they had bought their own food and never had to throw any away

20   because it had gone bad), a negative weighting if they had experienced the negative

21   outcome (e.g. -0.06 if they had bought their own food and had to throw some away because

22   it went bad), and no weighting if they had not had the opportunity to make the bad decision

23   (e.g. 0 if they had never bought their own food). Therefore, lower scores indicated more

24   and/or more severe negative outcomes from decisions.

1

2   Ethics

3   The study was approved by the Loughborough University Ethical Approvals (Human

4   Participants) Sub-Committee.

5

6   Hypotheses

7   We hypothesized that participants who were in pain at the time of the study would

8   find the best shopping deal on fewer items than participants who were pain free. We did

9   not expect participants with recurrent pain conditions that were not causing pain at the

10   time to be affected on the shopping task: only current pain was hypothesized to have an

11   effect. If the effect of pain on attention does translate into poorer decision making, the

12   outcomes of these poor decisions may accumulate in people with recurrent or chronic pain.

13   We therefore hypothesized that participants with chronic pain would report more negative

14   outcomes from their decisions on the DOI than participants without chronic pain. This was

15   because we expected pain to have disrupted the decision-making process at the time that

16   some of the decisions were made. We did not expect current pain to affect to DOI scores.

17

18   **Study 1 Results**

19   All analyses were two-tailed.

20

21   Data access

22   Data files and analysis scripts are openly available at

23   https://figshare.com/s/17f3800d66375b92fb71

24

1   Data cleaning

2   A total of 1559 participants accessed the study pages. Of these, 1360 gave consent

3   and proceeded, and 1322 completed the study. Eight participants missed one or two items

4   on the DOI, but a score was calculated excluding the missing items and their data were

5   included.

6   Our analyses included participants' sex, given that females tend to report more pain

7   than males and at a higher intensity[18, 32], and they also tend to have higher self-reported

8   levels of cognitive intrusion from pain than males[3]. We therefore limited the analyses to

9   participants reporting their sex as male or female (N = 1318, excluding the four participants

10 who reported other sexes).

11   In the shopping-decision analysis, all available data (N = 1318) were included. In the

12 DOI analysis, however, only participants from the USA were included. This was because the

13 frequency and acceptability of the outcomes on the DOI may vary between countries, and

14 scores are weighted based on the relative frequency within the sample (see Method).

15 Therefore, including multiple countries may inappropriately skew the weightings given to

16 different decision outcomes (e.g. if alcohol-related outcomes are substantially more

17 common in Country A than in Country B, calculating weightings across the two countries

18 combined would overstate the severity in Country A by making drinking appear less

19 common that it is in that country, and understate the severity in Country B by making

20 drinking appear more common than it is in that country). The largest subgroup of

21 participants was from the USA (N = 795), so the scoring and analysis was limited to this

22 group. Eight negative outliers (more than 3 standard deviations below the group mean)

23 were removed from the DOI scores, bringing the sample size to 787.

1   We checked for repeated IP addresses within the dataset, and aside from cases of

2   participants opening the link twice but only completing the study once, we identified 15 IP

3   addresses which appeared with two complete submissions, and one which appeared with

4   three complete submissions. It is not possible to know whether these participants

5   completed the study multiple times or whether they were different individuals with the

6   same IP address (e.g. because they were in the same household, public library, university

7   student residence, or public or university computer room). We re-analysed the data

8   excluding these cases, and the pattern of results remained the same as reported below

9   where they are included.

10   We also checked for cases where participants completed the study very quickly,

11   which might indicate that they were not responding seriously. We chose six minutes as a

12   cut-off time based on a drop-off in the distribution of submission durations below this point.

13   There were 71 participants with a study duration of less than six minutes, and when these

14   participants were excluded the pattern of results remained the same as reported below

15   where they are included.

16

17   Effect of pain on shopping deal scores

18   Scores on the shopping task (number of correct answers out of 6) were entered into

19   a 2 (current pain: yes [N = 336], no [N = 982]) x 2 (recurrent pain: yes [N = 406], no [N =

20   912]) x 2 (sex: female [N = 619], male [N = 699]) ANCOVA with age as a covariate. Age was

21   used as a covariate because it correlated with shopping scores, r_s (1318) = .097, p < .001,

22   and differed by current (yes/no) and recurrent (yes/no) pain, both ps < .001. Highest

23   qualification was correlated with shopping scores, r_s (1310) = .109, p < .001, but did not

24   differ by current (yes/no) or recurrent (yes/no) pain, ps > .406. Our final sample of 1318

1   gave us 95.4% power to detect main effects and 2×2 interactions with a small effect size of

2   η_p^2 = 0.01.

3   The ANCOVA revealed a significant main effect of current pain, $F(1,1309)$ = 5.36, p =

4   .021, η_p^2 = .004, with participants who were in pain scoring lower (M = 2.86, SD = 1.69, 95%

5   CI [2.68, 3.04]) than those who were not in pain (M = 3.11, SD = 1.85, 95% CI [3.00, 3.23],

6   see Figure 1). There was no significant main effect of recurrent pain, $F(1,1309)$ = 1.19, p =

7   .275, η_p^2 = .001 (recurrent pain M = 2.93, SD = 1.75, 95% CI [2.76, 3.10]; no recurrent pain M

8   = 3.05, SD = 1.99, 95% CI [2.92, 3.18]). There was no significant main effect of sex, $F(1,1309)$

9   = 2.77, p = .096, η_p^2 = .002, (females M = 3.08, SD = 1.94, 95% CI [2.93, 3.23]; males M =

10   2.90, SD = 2.04, 95% CI [2.74, 3.05]). There were no significant interactions, all ps > .149.

11

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13   Insert Figure 1 here

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15

16   The data show that current but not recurrent pain was associated with more errors

17   in finding the best shopping deal, with a small effect size. To explore the extent of this effect

18   in terms of money spent, we calculated the average price per unit of the deals chosen by

19   participants in the current pain and no current pain groups. These data are presented in

20   Table 3 along with the best price available for each item. These data suggest that in general,

21   participants would have spent more than necessary on all items, and that those in pain

22   spent more than those not in pain on half of the items.

23

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2   Insert Table 3 here

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4

5 Effect of pain on DOI scores

6   For the DOI, we hypothesised that participants who had recurrent pain would score

7 lower than those without recurrent pain, but that current pain would not affect scores.

8 Therefore, participants who had current pain which had lasted for three months or longer

9 were included in the recurrent pain group. DOI scores were analysed using a 2 (current pain:

10 yes [N = 132], no [N = 655]) x 2 (recurrent pain: yes [N = 218], no [N = 569]) x 2 (sex: female

11 [N = 352], male [N = 435]) ANCOVA. Age and highest qualification were both related to DOI

12 scores, ps < .001, and age differed by recurrent pain, p = .001, so it was included as a

13 covariate. Our final sample of 787 gave us 80.4% power to detect main effects and 2×2

14 interactions with a small effect size of η_p^2 = 0.01.

15   There was a main effect of recurrent pain on DOI scores, F(1,778) = 4.73, p = .030,

16 η_p^2 = .006, where those with recurrent pain scored lower (M = 13.80, SD = 7.60, 95% CI

17 [12.78, 14.81]) than those without recurrent pain (M = 15.18, SD = 8.95, 95% CI [14.45,

18 15.91], see Figure 2). There was no main effect of current pain on DOI scores, F(1,778) =

19 2.39, p = .123, η_p^2 = .003 (current pain M = 13.99, SD = 6.56, 95% CI [12.87, 15.12]; no

20 current pain M = 14.98, SD = 7.27, 95% CI [14.43, 15.53]), and no main effect of sex, F(1,778)

21 = 2.13, p = .145, η_p^2 = .003, (females M = 14.95, SD = 8.46; 95% CI [14.07, 15.84]; males M =

22 14.02, SD = 9.39, 95% CI [13.14, 14.91]. There were no significant interactions, all ps > .252.

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2   Insert Figure 2 here

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5   **Interim discussion**

6   Study 1 supported our hypotheses that current pain would be associated with lower

7   scores on the shopping task while recurrent pain would be associated with lower scores on

8   the DOI. However, due to the cross-sectional nature of Study 1, we cannot infer a causal

9   relationship. The effect of pain on DOI scores cannot be tested experimentally because this

10   would require sustained pain induction over the course of 10 years. However, the effect of

11   pain on shopping decisions can be tested experimentally, and this was done in Study 2.

12

13   **Study 2 Method**

14   Design

15   The experiment followed a within-participants design where participants completed

16   shopping deal questions in two conditions: with their non-dominant hand in painful cold

17   water (8°c) and with their non-dominant hand in non-painful warm water (30°c).

18

19   Participants

20   Participants were 44 students and members of staff at Loughborough University.

21   There were 32 females and 12 males, who ranged in age from 18 to 47 (M = 24.57, SD =

22   7.24). Our sample size was pre-determined to give us 90% power to detect an effect size of

23   d = 0.5 with a family-wise alpha level of 0.05 in a two-tailed paired-samples t-test. This

24   effect size was chosen as the smallest effect size of interest.

1   Participants completed a health screening questionnaire to ensure that they were

2   eligible for the study. Participants were ineligible for the study if they reported any of the

3   following: current pain, chronic pain, uncorrected vision problems, heart problems, a history

4   of fainting or seizures, serious cognitive impairment (e.g. dementia), asthma, a history of

5   frostbite, arthritis in their hands or forearms, a fracture in their hands or wrists, open cuts or

6   sores on their hands or wrists, a history of Reynaud's phenomenon, or having taken pain

7   killers in the previous 12 hours. These criteria were intended to ensure participants' safety

8   when taking part in the cold pressor task, and that the data would be of high quality.

9

10   Measures

11   *Shopping decisions task*

12   The shopping-decisions task was adapted for the cold pressor pain-induction

13   paradigm used in this study. We created 90 items, which each posed a question with two

14   answer options. For example:

15   Of the following options for buying grapes, which represents the best deal?

16   a) One 500g pack costing £2.00

17   b) Buy two get the third free deal on 500g packs costing £2.50 each

18   Reducing the number of answer options meant that participants would be able to complete

19   more questions in the timeframe allowed by the pain induction procedure, which in turn

20   increased the sensitivity of the measure. See

21   https://figshare.com/s/17f3800d66375b92fb71 for the full set of questions.

22   Six 15-item blocks were created from the 90 items, and the blocks were presented in

23   a fixed order. The starting condition (pain or control) was counterbalanced by participants,

24   meaning that the items were counterbalanced by condition. The 15 items within each block

1   were presented in a random order for each participant. If participants responded to all 15

2   items within the 90-second time limit, the list restarted. This occurred for five participants in

3   a total of 11 blocks (69 questions, 3.2% of the data). The analyses presented below include

4   these repeated questions, but the results remained the same when they were excluded.

5   In each trial, the question was presented in the upper centre of the computer screen

6   with the two answer options presented underneath on the left and right sides of the screen,

7   all in 28-point black Arial font on a white background. The question and answers remained

8   on screen until the participant responded by pressing the n or m key (to choose the left or

9   right answer, respectively) on the computer keyboard with their dominant hand. Once the

10 participant responded, the task moved immediately on to the next question.

11

12 *Visual analogue scales (VASs)*

13   After each block of the shopping task questions, participants responded to the

14 question "How much pain were you in during the block?" by clicking on a visual analogue

15 scale anchored by "No pain at all" on the left and "Worst pain imaginable" on the right.

16

17 Procedure

18   Participants took part individually in a quiet laboratory. They were sent an

19 information sheet and health screening questionnaire prior to the study session for their

20 reference. At the start of the session, they were asked to read the information sheet and

21 complete a consent form, then complete the health screening questionnaire to ensure

22 eligibility for the study (see "Participants" section for exclusion criteria).

23   The shopping task and VASs were presented on a desktop PC in E-Prime 3.0 with a

24 34cm x 27cm monitor. The study began with a practice VAS and a practice shopping task

1   question. Participants then completed six blocks of the shopping task, with each block

2   followed by a VAS. Each shopping task block lasted for 90 seconds, and during each one

3   participants had their non-dominant hand in either cold (8°c, pain condition) or warm (30°c,

4   control condition) water. The pain and control blocks alternated in order, and the starting

5   condition was counterbalanced. Due to experimenter error, one participant completed the

6   wrong counterbalanced order, meaning that 23 participants started with a pain block and

7   21 with a control block. In between blocks the participants had the opportunity to warm

8   their hand and only began the next block once they were pain-free. Participants were free

9   to withdraw their hand from the water at any time during a block, but none did.

10   At the end of the study, participants were thanked, debriefed, and given £5 in cash.

11

12   Study registration

13   In between the completion of the first study and the start of the second we

14   introduced into our labs the scientific practice of registering study protocols prior to study

15   initiation, in line with current recommendations[12]. Our hypothesis, sample size and

16   analysis plan for study 2 were registered at www.aspredicted.org (#8022; a pdf for peer

17   review is available at http://aspredicted.org/blind.php?x=rk2p33). Our hypothesis was that

18   "On a value-for-money shopping deal task, participants will give fewer correct answers

19   AND/OR more incorrect answers while experiencing pain compared to when they are pain

20   free." Our analysis plan was to conduct two paired-samples t-tests to see whether (a) the

21   number of correct responses and/or (b) the number of questions attempted but incorrect

22   differed between the pain and no pain conditions. To maintain a family-wise alpha level of

23   0.05, a Bonferroni correction was applied, making the alpha level 0.025 for each *t*-test. Any

24   a posteriori analyses that were not registered are labelled as 'Exploratory' below.

1

2 Ethics

3   The study received ethical approval from the Loughborough University Ethical

4 Approvals (Human Participants) sub-committee, and the University of Bath's Psychology

5 Ethics Committee and Research Ethics Approval Committee for Health.

6

7 **Study 2 Results**

8 All analyses were two-tailed.

9

10 Data access

11   Data files and analysis scripts are openly available at

12 https://figshare.com/s/17f3800d66375b92fb71

13

14 Data cleaning

15   In line with our study registration, we ran several checks on the data before the main

16 analysis was conducted. These checks resulted in four participants' data being removed and

17 replaced. Two participants were removed because their average pain rating in the pain

18 blocks was not significantly different to their average pain rating in the control blocks. One

19 participant was removed because their number of attempted but incorrect questions was

20 more than three standard deviations from the group mean in the control condition. Finally, one

21 participant was removed because their mean response time was more than three standard

22 deviations from the group mean response time in the control condition.

23

24 Effect of pain on shopping deal scores

1   Paired-samples t-tests were used to compare shopping-task performance between

2   the pain and control conditions, in terms of (a) number of questions answered correctly,

3   and (b) number of questions attempted and answered incorrectly (with the alpha level

4   Bonferroni corrected to 0.025). There was no effect of pain condition on number of correct

5   answers, $t(43) = 0.74$, $p = .464$, Hedges' g_{av} = .095 (Pain M = 18.89, SD = 9.23, 95% CI [16.08,

6   21.69]; Control M = 18.14, SD = 6.00, 95% CI [16.31, 19.96]). However, there were more

7   incorrect answers in the pain condition (M = 7.43, SD = 5.83, 95% CI [5.66, 9.21]) than in the

8   control condition (M = 4.66, SD = 2.47, 95% CI [3.91, 5.41]), $t(43) = 3.94$, $p < .001$, Hedges'

9   g_{av} = 0.608 (see Figure 3).

10

11   Exploratory analyses

12   VAS ratings were compared in the pain and no-pain conditions as a manipulation

13   check. VAS ratings were higher in the pain condition (M = 63.11, SD = 17.08, 95% CI [57.92,

14   68.31]) than in the control condition (M = 3.23, SD = 3.57, 95% CI [2.15, 4.32]), and the

15   difference was significant, $t(43) = 23.27$, $p < .001$, Hedges' g_{av} = 4.768.

16   To see whether the effect of pain on incorrect answers on the shopping task differed

17   between male and female participants, we ran a 2 (condition: pain, control) x 2 (sex: male,

18   female) mixed ANOVA. There was no significant interaction, $F(1,42) = 0.06$, $p = .815$, η_p^2 =

19   .001.

20

21   *****************************

22   Insert Figure 3 here

23   *****************************

24

1   In our main analysis we found that participants gave more incorrect answers in the

2   pain condition than in the control condition, but no evidence that they gave fewer correct

3   answers. This suggests that they may have answered the questions more quickly in the pain

4   condition than in the control condition, thereby attempting more items but increasing their

5   error rate. To test for this, we compared the total number of items attempted between the

6   pain and control conditions. As expected, participants attempted more questions in the pain

7   condition (M = 26.32, SD = 13.60, 95% CI [21.56, 31.08]) than in the control condition (M =

8   22.80 SD = 7.14, 95% CI [20.30, 25.29]), $t(43)$ = 2.35, p = .024, Hedges' g_{av} = 0.319.

9

10   **Discussion**

11   Chronic pain patients often report difficulty in attending, and studies with both

12   chronic and laboratory-induced pain have provided quantitative evidence that pain

13   negatively affects performance on varieties of attention tasks. Here, we investigated for the

14   first time whether pain disrupts performance on real-world and higher-level cognitive tasks

15   that require attention, namely numerical and everyday decision making, which can have real

16   and serious consequences for individuals.

17   In Study 1 we showed that people who were in pain at the time of completing an

18   online shopping-decisions task made more errors than people who were not in pain at the

19   time. Furthermore, people who reported a recurrent pain condition had experienced more

20   negative events over the past 10 years of their lives, possibly resulting from poor decision

21   making, than people who did not report a recurrent pain condition. In Study 2, we induced

22   pain in healthy participants while they performed an extended version of the shopping task

23   and found that they made more errors while they were in pain than while they were pain-

24   free, supporting our hypothesis of a causal effect of pain on shopping decisions. This effect

1   was driven by participants attempting to answer more questions in the time allowed. We

2   found no evidence of sex differences in any of these effects.

3   Our findings extend the literature showing that pain disrupts basic attention

4   processes [4,14,30,31,40] by showing that this disruptive effect translates into poorer

5   decisions in more complex and ecologically-valid contexts. This could have implications for

6   many aspects of daily life for people in pain, such as school, work, and managing finances.

7   The effects of pain on both tasks in Study 1 were small, but even a small effect of pain on

8   each of the many decisions we need to make every day can add up, over the course of

9   years, to substantially poorer quality of life in people with chronic pain. Indeed, in Study 2,

10   with a more sensitive measure and controlled environment, we observed a medium-sized

11   effect of pain on shopping decisions (Hedges g_{av} = 0.608).

12   The findings from Study 2 hint towards potential mechanisms of the effect of pain on

13   shopping decisions. When participants were in pain, they attempted more questions and

14   made more errors, but they did not give fewer correct answers. This is suggestive of three

15   possible explanations. First, it could be that participants felt the need to rush through the

16   questions when they were in pain in case it made the pain end sooner. Participants were

17   told that every block would last for 90 seconds, but it is possible that they still consciously or

18   subconsciously thought that going faster would make the pain end sooner. Second, it could

19   be that pain reduces our confidence in our thinking skills so that participants were less

20   willing to think through the arithmetic for items they found particularly difficult, and instead

21   guessed. This would lead to more questions being attempted, and more errors being made.

22   Third, it could be that pain increases confidence so that participants didn't check their

23   answers whilst in pain, whereas they may have checked them if they were not in pain. This

24   would also increase the number of items attempted in the time limit and lead to more

1   errors. Due to participants being aware that all blocks would last for exactly 90 seconds, we

2   suggest that the second and third explanations are more likely than the first. These are both

3   metacognitive explanations which could be tested using established paradigms from the

4   metacognition literature. For example, participants could be asked to indicate their initial

5   judgment of solvability for each item, and their interim and/or final confidence in each

6   answer they give [1].

7   We suggest that our pattern of findings is not well-explained by a mechanism

8   whereby pain disrupts participants' ability to perform arithmetic calculations. If that had

9   been the case, we would have expected fewer correct answers in the pain condition than in

10   the control condition. Nevertheless, in many studies, pain has been associated with lower

11   accuracies and/or slower response times on cognitive tasks. Thinking about these more

12   general patterns of findings, we can theorise mechanisms at the cognitive level as well as at

13   the metacognitive level. At the cognitive level, executive functions may be useful for

14   thinking about potential mechanisms. Executive functions are the processes by which we

15   regulate our attention, thoughts and actions [28]. When we complete a task whilst in pain,

16   we may repeatedly switch our attention between the pain and the task, focusing on each

17   fully but for short periods, which could have engagement and disengagement costs in both

18   time and accuracy: one 'loses track'. Alternatively, the pain and the task at hand may be

19   processed simultaneously rather than alternately. In this scenario, rather than the task

20   suffering from disengagement costs, it suffers from a continually lower working memory

21   capacity being available. Inhibition skills may be important in controlling our attention

22   deployment in either of these scenarios. Additionally, there are likely motivational [39] and

23   attentional bias [23] elements to the deployment of attention between task- and pain-

24   related goals.

1   If we can identify the mechanism(s) of the disruptive effect of pain on attention, and

2   these are found to be common across multiple tasks, then we may be able to develop

3   targeted interventions that mitigate its more extreme effects in everyday tasks that have

4   serious consequences of error [6]. Research is already making steps in this direction; Baker

5   et al [8] tested a broad programme of cognitive training as a way of improving cognition in

6   chronic pain patients, with some promising results.

7   In Study 1, we recruited participants reporting current pain and a history of pain.

8   Participants were blind to the task, and unaware of our hypotheses, but were not randomly

9   assigned to groups. This meant we could not test whether the relationships in question

10   were causal, and if so, in which direction. This shortcoming was remedied for the shopping

11   task in Study 2, where we found evidence for a causal effect of pain on shopping decisions

12   with a true experiment. Our finding that participants with a history of pain reported more

13   negative outcomes from real-life decisions should be conceptually replicated by giving the

14   DOI to a clinical chronic pain sample, with participants providing a more comprehensive

15   clinical history, and a matched control group. This would provide stronger evidence for a

16   claim that the effect is indeed due to the participants' pain and not due to a confound. Such

17   a study could consider how long a patient's pain has persisted, how often it occurs, and for

18   what proportion of time (e.g. per week) they generally experience pain. We would expect

19   that the more time a participant spends in pain per week, the greater the effect on their

20   decision making.

21   It is possible that the effect we observed on the DOI reflects a memory or

22   interpretation bias. For example, compared to people without recurrent pain, people with

23   recurrent pain may remember past experiences in a more negative light, or have a better

24   recollection of negative events, or be more likely to mis-remember events as having bad

1   outcomes due to an expectation that their pain will have disrupted their decision making. A

2   longitudinal study regularly measuring decision outcomes in a chronic pain sample and

3   matched control group would help to differentiate these explanations from our proposal

4   that pain disrupts decision making.

5   These studies begin to address an important gap in our knowledge. Although

6   numeracy, reasoning and decision making are core skills embedded in almost all everyday

7   tasks, we know little about the effects of embodied distractions on them. We know that

8   time pressure [17,37], perceptual disfluency [38], and working memory load [19,22,34] can

9   detrimentally affect performance on reasoning and decision-making tasks, but the effects of

10   embodied (interoceptive or proprioceptive) distractions such as pain, itch, imbalance,

11   hunger, thirst and fatigue are less investigated [16].

12   In summary, we have shown that both naturally-occurring and experimentally-

13   induced pain is associated with poorer decisions when making grocery purchasing decisions,

14   and that the negative effect of pain on cognition may accumulate over time in people with

15   recurrent or chronic pain. People with pain frequently report that the cognitive

16   consequences are fatiguing, distressing, and disruptive. Here we provide data that suggest

17   that the consequences of that disruption are not only psychological, but also financial.

18

19

1   **Acknowledgments**

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22   interruptive effect of pain in a multitask environment: an experimental investigation.

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24

1 **Tables**

2 Table 1. Type of current and recurrent pain conditions reported in the Study 1 sample.

3 Percentages are of the number of participants reporting current/recurrent pain. Participants

4 were able to select multiple options so the total is greater than 100%.

5

Type of pain	Current	Recurrent
Arthritis	45 (12%)	61 (15%)
Back (non-muscular)	90 (27%)	103 (26%)
Lower back	59 (18%)	63 (16%)
Upper back	57 (17%)	42 (10%)
Hangover	7 (2%)	19 (5%)
Headache	90 (27%)	89 (22%)
Joint	69 (21%)	86 (21%)
Menstrual	24 (7%)	62 (15%)
Muscular (non-back)	27 (8%)	21 (5%)
Migraine	12 (4%)	60 (15%)
Nerve	24 (7%)	21 (5%)
Post-surgical	5 (1%)	9 (2%)
Sciatica	21 (6%)	33 (8%)
Stomach	33 (10%)	44 (11%)
Throat	11 (3%)	6 (1%)
Tooth	39 (12%)	39 (10%)
Other	37 (11%)	33 (8%)

6

1   Table 2. Duration of current and recurrent pain conditions reported in the Study 1 sample.

2

Duration of pain	Current	Recurrent
Up to one hour	39 (12%)	-
Up to 24 hours	71 (21%)	-
Up to a week	47 (14%)	18 (4%)
Up to a month	28 (8%)	21 (5%)
Up to 3 months	18 (5%)	22 (5%)
Up to 6 months	12 (4%)	23 (6%)
Up to a year	45 (13%)	78 (19%)
Up to a decade	52 (15%)	146 (36%)
Over a decade	24 (7%)	93 (23%)

3

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1   Table 3. Mean amount of money spent per unit for each item in the shopping decision task

2   in the current pain and no current pain groups in Study 1.

3

	Best price available	No current pain average spend	Current pain average spend	Pain/no pain spend difference
Milk (per pint)	25p	27p	27p	0p
Lemons (per kilo)	£2.10	£2.26	£2.27	1p
Ketchup (per kilo)	£2.45	£2.61	£2.65	4p
Eggs (each)	11p	12p	12p	0p
Cheese (per kilogram)	£9.20	£9.64	£9.67	3p
Cola (per litre)	75p	80p	80p	0p

4

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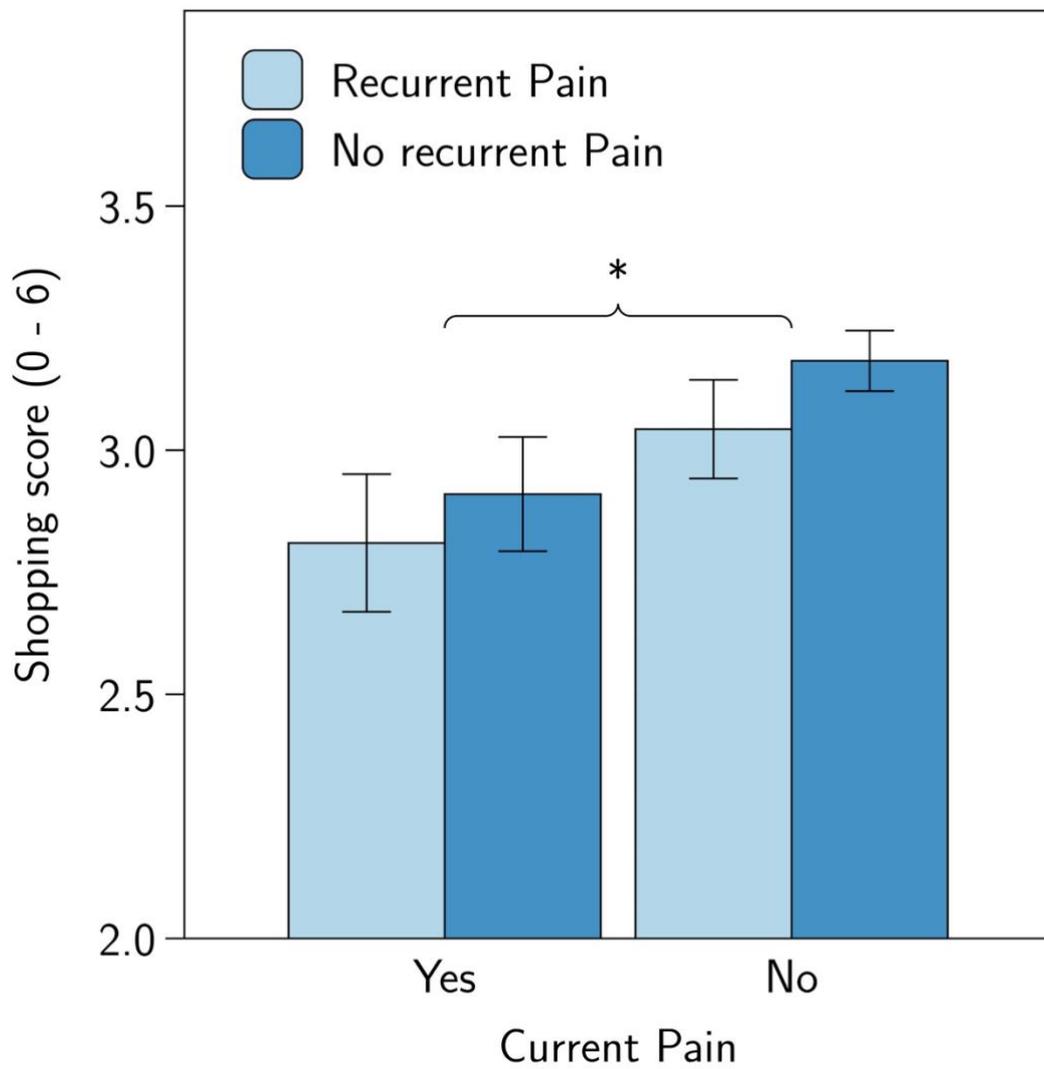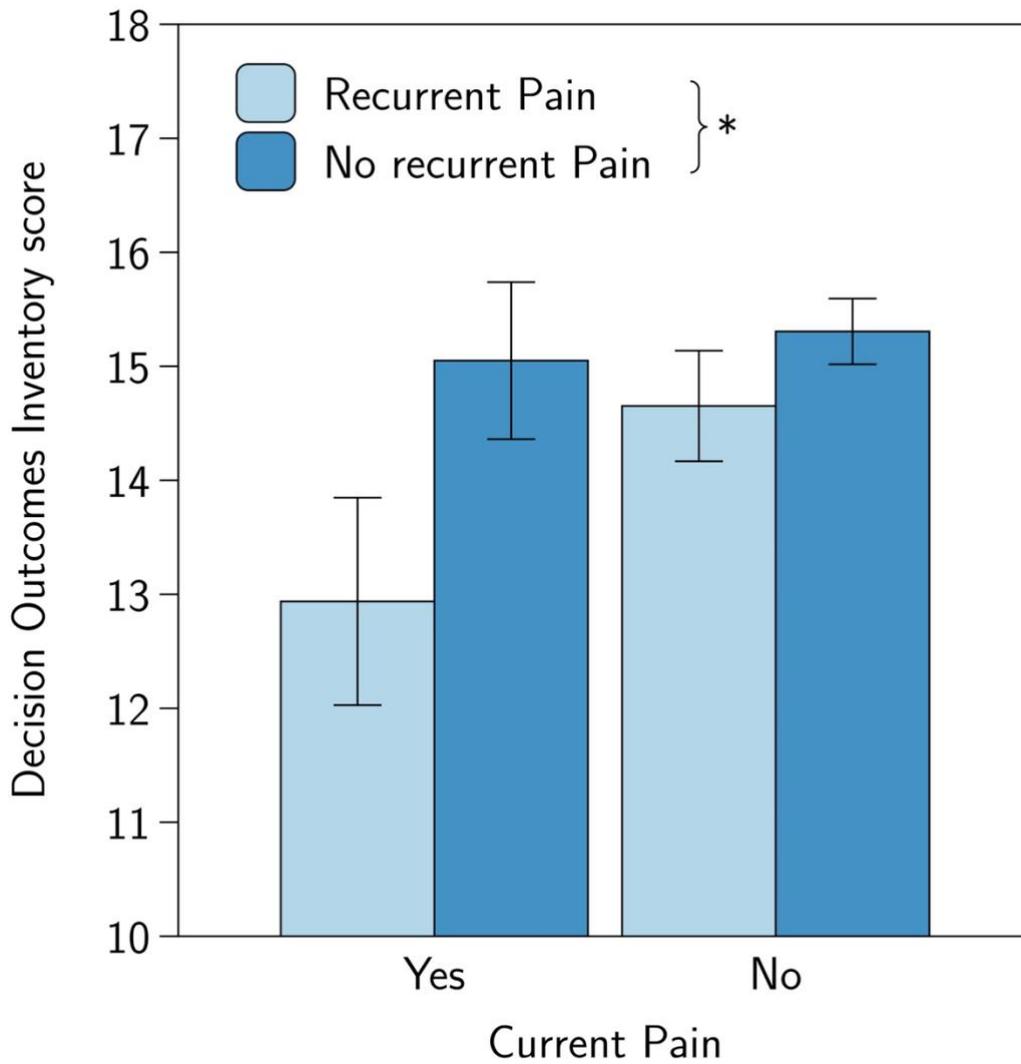1   **Figures**

2

3   Figure 1. Shopping decision scores in Study 1 by current (yes/no) and recurrent (yes/no)

4   pain with age as a covariate. There was a significant main effect of current pain, but no

5   effect of recurrent pain and no interaction. Error bars show $\pm$ 1 standard error of the mean.
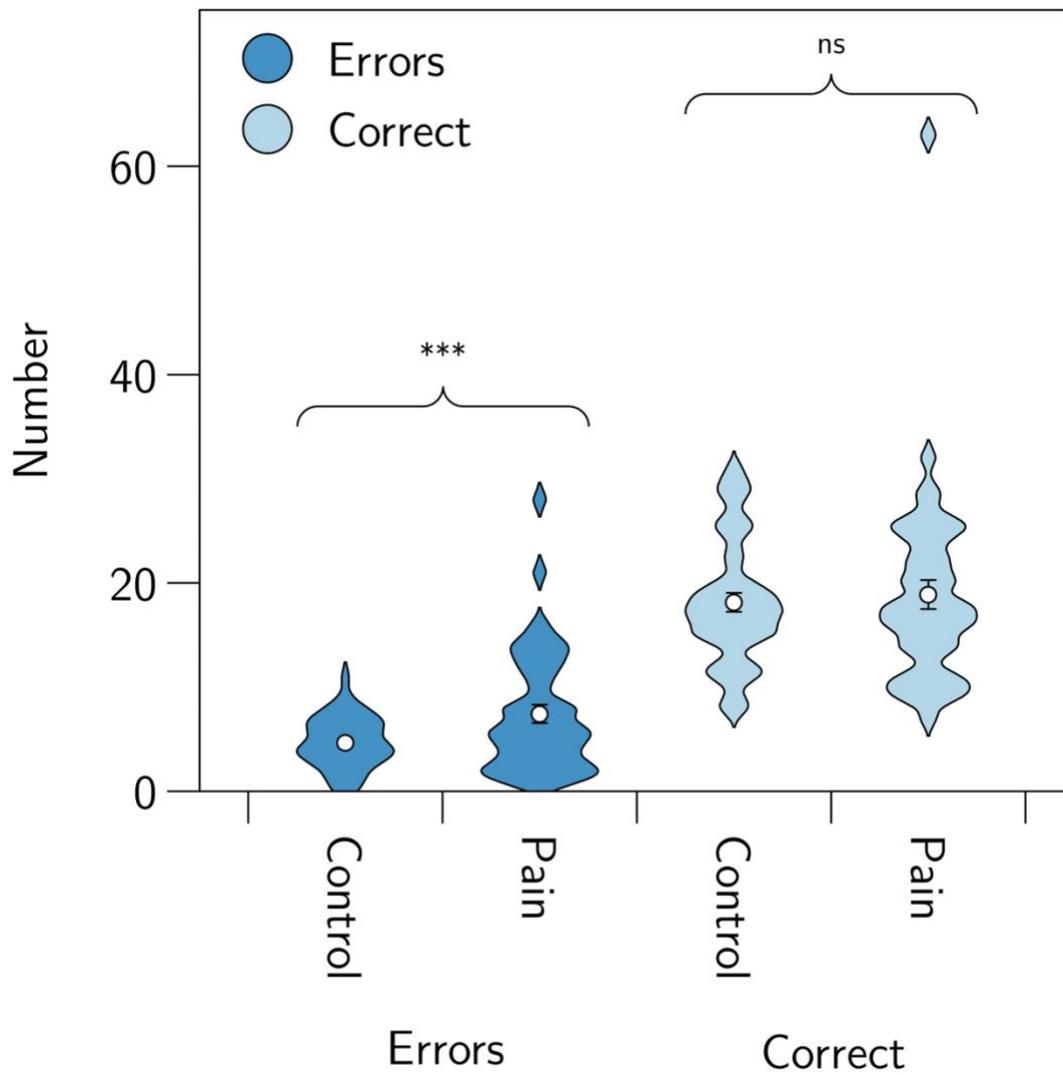
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1   Figure 2. Decision Outcome Inventory scores in Study 1 by current (yes/no) and recurrent

2   (yes/no) pain with age as a covariate. There was a significant main effect of recurrent pain,

3   but no effect of current pain and no interaction. Error bars show $\pm$ 1 standard error of the

4   mean.

5

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7

1   Figure 3. Violin plot showing distributions and means of number of errors and number of

2   correct answers on the shopping decisions task by pain condition in Study 2. There was a

3   significant main effect of pain condition on errors but not on number of correct answers.

4   Error bars show $\pm$ 1 standard error of the mean.

5

6