Forgetting to remember?

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Forgetting to remember? Prospective memory within the context of pain

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Abstract

Background: Pain interferes with cognitive functioning in several ways. Among other symptoms, pain patients often report difficulties with remembering future intentions. It remains unclear, however, whether it is the pain *per se* that impairs prospective remembering or other factors that often characterize people with pain (e.g. poor sleep quality). In this experiment, we investigated whether prospective memory is impaired within the context of pain, and whether this impairment is enhanced when the threat value of pain is increased.
Methods: Healthy participants engaged in an ongoing word categorization task, during which they received either experimental pain stimuli (with or without threatening instructions designed to increase the threat value of pain), or no pain stimuli (no somatic stimuli and no threatening instructions). Crucially, participants were also instructed to perform a prospective memory intention on future moments that would be signalled by specific retrieval cues.
Results: Threatening instructions did not differentiate the pain groups in terms of pain threat value; therefore, we only focus on the difference between pain and no pain. Pain and no-pain groups performed the prospective memory intention with similar frequency, indicating that prospective memory is not necessarily impaired when the intended action has to be performed in a painful context.
Conclusions: Findings are discussed in the framework of the multiprocess theory of prospective memory, which differentiates between the spontaneous and the strategic retrieval of intentions. Methodological considerations and suggestions for future research are discussed.
Significance: This laboratory study combines established methods from two research fields to investigate the effects of a painful context on memory for future intentions. Painful context did not impair performance of a prospective memory intention that is assumed to be retrieved by means of spontaneous processing.

1. Introduction

People with (chronic) pain report various cognitive complaints (McCracken and Iverson, 2001; Roth et al., 2005), including forgetfulness (McCracken and Iverson, 2001; Muñoz and Esteve, 2005). Forgetfulness may refer to impaired memory for past events [retrospective memory (RM)] or for future intentions [prospective memory (PM)]; (Dismukes,

2010, 2012). Although the effect of pain on RM has received scientific attention (e.g. Kuhajda et al., 2002; Landrø et al., 2013), its effects on PM remain vastly unexplored.

Prospective memory involves forming an intention to perform an action in the future and retrieving it at the appropriate moment, without help from external reminders (Ellis and Kvavilashvili, 2000; Dismukes, 2010; Einstein and McDaniel, 2010). In the interval between forming and performing the PM intention, people are engaged in other activities, which preclude rehearsal (Ellis and Kvavilashvili, 2000). The appropriate moment to perform the intention is indicated by a specific cue (event-based PM; e.g. exercise when the news is on), time point (time-based PM; e.g. exercise at 08.00 pm) or completion of an activity (activity-based PM; e.g. exercise after brushing teeth). PM consists of a prospective component, i.e. remembering to perform the intention, and a retrospective component, i.e. remembering its content (Dismukes, 2010, 2012). However, it is also assumed to involve attention, task management and goal setting (Dismukes, 2010, 2012).

Chronic pain patients report worse PM than healthy controls (Ling et al., 2007). Furthermore, pain was found to partly explain PM impairments in people with multiple sclerosis (Miller et al., 2014). Patient samples, however, are also characterized by other factors that may contribute to PM deficits, such as medication use (Schiltenwolf et al., 2014) or poor sleep quality (Scullin and McDaniel, 2010). Therefore, the degree to which pain explains the reported PM impairments is not clear. Although the impact of pain on multitasking, which requires PM in addition to other skills, has been investigated (Keogh et al., 2013; Moore and Law, 2017), experimental evidence purely on the link between pain and PM is lacking. The first aim of this study was thus to provide such evidence.

There are reasons to expect that a painful context impairs performance of a PM intention. Firstly, pain (Eccleston and Crombez, 1999; Moore et al., 2012, 2013) and the anticipation of pain (e.g. Van Damme et al., 2004a,b) impair attention. The attentional capture by (anticipated) pain may impair the selection of PM retrieval cues, i.e. the cues signalling the appropriate moment to perform the PM intention (Dismukes, 2012). Pain may also impair PM by interfering with working memory (Buhle and Wager, 2010; Berryman et al., 2013; Boselie et al., 2016), which has been shown to be important for the performance of (at least some) PM intentions (McDaniel and Einstein, 2000; Smith et al., 2000). Factors that increase the attentional capture by pain, such as the threat value of pain (Eccleston and Crombez, 1999; Crombez et al., 2005), may enhance the expected relationship between pain and PM. Therefore, our second aim was to investigate whether PM is further impaired when the threat value of pain is increased.

Thus, this study aimed at investigating the performance of a PM intention within a painful context, especially when the threat value of pain is increased. Healthy volunteers performed an established PM paradigm (Einstein and McDaniel, 2005; Einstein et al., 2005), which required them to remember to respond to specific PM retrieval cues that would appear during a future ongoing task. Importantly, during the ongoing task, participants received either experimentally induced pain (accompanied by threatening instructions or no specific instructions) or no pain. We expected the performance of the PM intention to be impaired in the pain conditions, compared to the no-pain condition, and to especially deteriorate when pain was perceived as threatening, compared to less threatening pain.

2. Methods

2.1 Participants

Ninety-six volunteers participated in the experiment. Two persons made use of the option to terminate the experimental session prematurely, thus leaving our final sample with 94 participants randomly allocated either to a condition with painful stimulation and a threat manipulation (Pain Threat group, $n = 31$), or to a condition with painful stimulation but no threat manipulation (Pain No threat group, $n = 31$) or to a condition with neither painful stimulation nor threatening information (Nonpain group, $n = 32$).

Participants were students of the University of Leuven or members of the general population. Exclusion criteria were controlled by means of self-report and comprised: imperfect command of Dutch, dyslexia, pregnancy, cardiovascular disease, acute or chronic pain, lifetime diagnosis of a psychiatric disorder, use of an electronic implant (e.g. cardiac pacemaker), use of anxiolytic and/or antidepressant medication and impaired (uncorrected) eyesight. Participants signed informed consent and received monetary compensation (10 €) or partial course credit for their participation. The study protocol was approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences and by the Medical Ethics Committee of the University of Leuven (ML7324).

2.2 Painful stimulation

Two thirds of our participants received painful electrocutaneous stimuli (square-wave, 2-ms duration), generated by a constant current stimulator (DS7A; Digitimer Limited, Hertfordshire, UK) and delivered through two 8-mm surface electrodes (Bilaney, Düsseldorf, Germany). The electrodes were filled with electroconductive gel (K-Y gel; Johnson & Johnson, New Brunswick, NJ) and attached on the lateral side of the participant's right ankle, with an inter-electrode distance of ~1 cm.

Stimulus intensity was individually determined during a calibration phase that took place before the experimental task. Participants were administered a series of electrocutaneous stimuli, starting with an intensity of 2 mA and gradually increasing in steps of 2 mA. Participants rated each stimulus on a 0–100 tolerance scale (0 = no sensation, 100 = maximum tolerable; cf. Rhudy et al., 2009) until the participant did not wish to receive a stimulus of higher intensity or until a stimulus was rated as a 90. Upon agreement of the participant, the last stimulus was the one delivered during the experimental task or was readjusted.

2.3 Experimental task

In an experimental task that follows the guidelines for the laboratory study of PM (Einstein and McDaniel, 2005), participants were given a PM intention to perform in a future moment, during which they would normally be engaged in an ongoing activity. The ongoing activity required them to categorize word pairs, whereas the PM intention required them to remember to press a different button every time a word pair included one of two specific words (PM retrieval cues) and then to answer two questions about a presented picture. Participants assigned to the pain groups received painful stimulation during the ongoing task, whereas participants in the non-pain group received no electrocutaneous or other somatic stimulation. The specific task elements were as follows:

2.3.1 Ongoing task

A series of pairs of emotionally neutral (Dutch) words were presented on the screen (white on black background) (cf. Einstein et al., 2005). The word on the left, in upper-case letters, was the name of a category [e.g. 'FLOWER' (BLOEM in Dutch)], whereas the word on the right, in lower-case letters, was the name of an object [e.g. 'daisy' (madelief in Dutch)]. Our word pool consisted of 143 Dutch nouns belonging to 21 semantic categories (Storms and De Amicis, 2001). Participants were required to indicate, as fast and as accurately as possible, whether the object belonged to the category (match trials; 50% of total), or did not belong to the category (non-match trials; 50% of total). Responses were given with one of two buttons (marked as 'L' and 'R', respectively) of a six-button response box, and were counterbalanced across participants. Each word pair remained on the screen for 2000 ms, and was followed by an intertrial interval (ITI) of 1500 ms. The letters 'L' and 'R' were shown on the screen throughout the task and changed colour from white to orange after response, to indicate to the participant that the response had been registered. Responses given during the ITI were also registered.

2.3.2 PM intention

Every time participants encountered either the object word 'tuna' [tonijn] or the category word 'vehicle' [VOERTUIG] (PM retrieval cues), they were asked to remember to press a third button on the response box instead of categorizing the word pair. In order to not act as an external reminder of the PM intention, this button was unmarked. Every time participants successfully responded to a PM retrieval cue, the word categorization task was suspended and a picture of an emotionally neutral, single-coloured animate or inanimate object (e.g. a black umbrella) was presented on the screen. Participants were then required to answer two questions regarding the depicted object, namely whether it is white and whether it is a living organism. Responses to the questions were given by means of the 'L' and 'R' buttons, and were counterbalanced across participants. When the second response had been given, the picture disappeared from the screen and the next word pair of the ongoing task was presented.

Participants performed 226 trials, six of which (2.65% of total) contained a PM retrieval cue (three trials for each PM retrieval cue; three match trials). This is in line with existing PM literature, where PM retrieval cues are presented on fewer than 5% of the trials (e.g. Einstein et al., 2005; Hicks et al., 2005; Finstad et al., 2006; Mullet et al., 2013). PM retrieval cues were shown on preselected trials (trials 60, 90, 125, 175, 215 and 225) in order to ensure that they would appear at the same task point for every participant (cf. Einstein et al., 2005). Furthermore, participants assigned to the pain groups received a painful electrocutaneous stimulus on 33 trials

(14.6% of total; stimulus onset was 300 ms after trial onset). Trials with a painful stimulus were randomly preselected with the restriction that electrocutaneous stimuli would not be administered on trials with a PM retrieval cue and three trials before and after that. This restriction was imposed to assure that a *momentary* lapse of attention due to pain would not explain the expected effects of painful context on the PM intention performance. However, in order to prevent that participants would associate a relatively long pain-free period with the presentation of a PM retrieval cue, we chose to precede the second PM retrieval cue with an electrocutaneous stimulus, and subsequently exclude this trial from analyses.

2.4 Measures

2.4.1 Behavioural measures

Our main focus was the *rate of performance of the PM intention*, which reflects the prospective component of PM. It was expressed as percentage correct and calculated based on the number of times that participants pressed the indicated button on a trial that contained a PM retrieval cue or on the next trial (cf. Einstein et al., 2005), divided by five (recall that one PM retrieval cue was preceded by a trial with a painful stimulus for some participants and was thus excluded from analyses).

Secondarily, we also investigated *accuracy in the picture-related questions*, which reflects the retrospective component of PM. It was expressed as percentage correct and calculated based on the number of correct responses to each question, divided by the number of pictures viewed (recall that participants viewed a picture only when they had responded to a PM retrieval cue on time).

2.4.2 Reading span test

In order to explore the potential role of *working memory capacity* in the relationship between (threatening) pain and the performance of a PM intention, we administered the Reading Span Test (RST: Daneman and Carpenter, 1980; standardized Dutch version: Van Den Noort et al., 2008). Participants were shown sets of 2, 3, 4, 5 or 6 sentences and were required to read them aloud while storing in memory the last word of each sentence. After each sentence set, participants were asked to recall aloud the last word of each sentence. Sentence sets were presented in random order (i.e. not in order of increasing number of sentences). In total, one hundred sentences were presented, each until the participant initiated the presentation of the next sentence or for a maximum of 6.5 s. RST total score was calculated based on the total number of words that the participant recalled perfectly (one point) or imperfectly (half point) (total score range: 0–100 points) (Friedman and Miyake, 2005; Van Den Noort et al., 2008). The standardized Dutch version we used has shown very good psychometric qualities (Van Den Noort et al., 2008).

2.4.3 Self-report measures

In order to further investigate the role of threat of pain, we assessed *pain catastrophizing* by means of the Pain Catastrophizing Scale (PCS; Sullivan et al., 1995; Van Damme et al., 2002). The PCS consists of 13 items, each of which is rated on a 5-point scale, with higher scores indicating higher catastrophizing (total score range: 0–52). Previous research has shown good psychometric qualities in healthy Dutch-speaking samples (Van Damme et al., 2002). Reliability in the present sample was good ($\alpha = 0.894$).

In the end of the session, participants completed a surprise *recall test*, in which they were asked to report in detail the PM intention they had been given, i.e. the PM retrieval cues they were required to respond to and the picture-related questions they were required to answer (in the correct order).

For our manipulation check, participants assigned to the pain groups were required to retrospectively rate the *painfulness, unpleasantness and threat value of the electrocutaneous stimulus* on 11-point numerical scales (0 = not at all, 10 = to a high degree) and to complete a *state pain catastrophizing* measure. The latter consisted of an adjusted version of the original PCS (Sullivan et al., 1995; Van Damme et al., 2002) that referred to the electrocutaneous stimulation administered during the experiment (cf. Rhudy et al., 2009).

Additional self-report measures were administered within and after the session for exploratory reasons, and will thus not be further discussed.

2.5 Apparatus

A standard computer set up and screen were used for the presentation of the tasks. Responses to the prospective memory task were given by means of a six-button response box. Affect 4.0 (Spruyt et al., 2009) was used to run the prospective memory task, whereas E-Prime (Schneider et al., 2012) was used for the RST.

2.6 Procedure

The experiment was advertised as a study on the understanding of language. Participants were randomly assigned to one of three groups: (1) Pain Threat group (painful stimulation during the experimental task plus threatening instructions), (2) Pain No threat group (painful stimulation during the experimental task without threatening instructions) or (3) Nonpain group (neither painful stimulation during the experimental task nor threatening instructions). Participants were tested individually in a dimly lit room, in an experimental research laboratory at the Faculty of Psychology, University of Leuven, as follows:

2.6.1 Introduction

Participants filled in the PCS and read brief instructions about the tasks they would be asked to perform and, for participants assigned to the pain group, about the procedure regarding the electrocutaneous stimulation. Instructions given to the Pain No threat group participants reassured them about the safety of the electrocutaneous stimuli ('Because the electrodes stimulate the pain fibers, the stimuli can feel somewhat unpleasant and painful, but they are safe'). The Pain Threat group participants were informed that the experimenter would later measure their blood pressure.

2.6.2 Pain calibration (Pain Threat and Pain No threat group)

Subsequently, the intensity of the electrocutaneous stimulus to be used during the experimental task was individually determined (see 2.2).

2.6.3 Threat manipulation (Pain Threat group)

When the stimulus had been selected, participants of the Pain Threat group underwent a threat manipulation similar to that reported by Van Damme et al. (2008) and Vlaeyen et al. (2009). Specifically, the experimenter attached an electronic sphygmomanometer to the participant's left wrist for an alleged blood pressure measurement. Once the measurement had been taken, the experimenter told the participant that their blood pressure was 'at the highest acceptable limit for participation in the study' (cf. Van Damme et al., 2008), and mentioned that persons with high blood pressure were excluded from participation because the 'effects of the electrocutaneous stimuli on them are unknown', but that in the end they could go on with testing.

2.6.4. PM paradigm

This part of the experiment follows the suggested guidelines for the experimental investigation of PM (Einstein and McDaniel, 2005). First, participants read instructions for the ongoing task and performed six practice trials with accuracy feedback. Then, they read instructions for the PM intention (PM retrieval cues and how to respond to them, picture-related questions and in what order they had to be answered). In order to ensure that participants had understood the instructions, they were asked to repeat them aloud and were corrected if necessary. Subsequently, participants performed a filler task that aimed at creating a delay interval between forming and performing the intention (i.e. reading the instructions and engaging in the experimental task), while at the same time precluding the rehearsal of the instructions. During the filler task, the letters N, A and K were presented on the computer screen, one after the other, each for 60 s. Participants were required to generate as many words as they could that started with each letter (apart from proper names, repetitions and words with the same stem but different endings; cf. Audenaert et al., 2000; Ruff et al., 1996). After the end of this delay interval, which lasted for approximately 3.5 min, the word categorization task was reintroduced without participants receiving any reminder for the PM intention.

2.6.5 End session

Upon completion of the experimental task, participants completed the recall test and other ratings, and performed the RST. Participants of the Pain Threat group were told that the blood pressure measurement was part of the experimental procedure, but full debriefing was provided after data collection was completed.

2.7 Data analyses

An initial exploration of performance in the word categorization task showed that one Nonpain group participant performed poorly (<70% accuracy). This participant was removed from our analyses, thus leaving our sample with $n = 93$ participants equally spread over the three groups.

Descriptive statistics were computed for the sample characteristics, and the groups were compared by means of a series of χ^2-tests or one-way Analyses of Variance (ANOVAs) with group (3: Pain Threat, Pain No threat, Nonpain) as the between-subjects

variable. Similarly, descriptive statistics were computed for the manipulation check (electrocutaneous stimulus ratings and situational catastrophizing), and the Pain Threat and Pain No threat group were compared by means of a series of unpaired samples *t*-tests.

In order to ensure that the expected effects of (threatening) pain on PM intention performance would not be attributed to differences in word categorization task performance, we performed separate Repeated Measures (RM) ANOVAs with group (3: Pain Threat, Pain No threat, Nonpain) as the between-subjects factor and trial type (2:match, nonmatch) as the within-subjects factor on the accuracy (calculated as percentage correct responses) and the mean Reaction Times (RTs) in the word categorization task. For the RT analyses, we first excluded incorrect trials and trials with a PM retrieval cue and/or an electrocutaneous stimulus. Subsequently, we excluded trials with RTs that were 2.5 SDs above or below the individual mean for trials of that type (2.9%).

For the testing of our hypotheses, we subjected the PM intention performance rate and the accuracy in the picture-related question to separate ANOVAs with group (3: Pain Threat, Pain No threat, Nonpain) as the between-subjects variable. The false alarm rate as regards the PM intention performance rate was very low. Only nine out of our 93 participants (9.7% of the whole sample) pressed the designated button on trials in which no PM retrieval cue was presented, for maximum three times (1.3% of total number of trials). We therefore decided to not analyse and interpret it. Responses to the second picture-related question were not analysed due to a programming error that rendered the reliability of their registration unclear. This error related to the timing of registration of the button press and had no influence on the other results. Lastly, we performed a χ^2-test to compare the groups (3: Pain Threat, Pain No threat, Nonpain) with regard to the percentage of participants who correctly recalled the PM retrieval cues and the questions (in the correct order) they were expected to respond to. In order to explore the role of pain catastrophizing and of working memory capacity in the relationship between (threatening) pain and PM, we repeated the above analyses with the centred PCS score and RST score as covariates (separate ANCOVAs). We also correlated the PCS and RST scores to performance in the recall test.

For RM ANOVAs, we report multivariate tests (Pillai's Trace), as recommended in case of possible violations of sphericity (e.g. McCall and Appelbaum, 1973; Howell, 2007). The (RM) AN(C)OVAs are followed by Helmert contrasts with Bonferroni correction. Where appropriate, we report mean differences with their 95% confidence intervals (CIs). Reported effect size is η_p^2. The analyses considering the PCS and RST scores produced no essentially changed results, and we therefore do not report them for the sake of brevity. Missing values were excluded listwise. Analyses were performed with SPSS version 22.0. IBM Corp. Armonk, NY.

3. Results

3.1 Sample characteristics

The Pain Threat group, the Pain No threat group and the Nonpain group did not significantly differ in gender distribution, mean age, pain catastrophizing and working memory capacity (Table 1).

3.2 Manipulation check

3.2.1 Electrocutaneous stimulus characteristics and situational pain catastrophizing

The Pain Threat group and the Pain No threat group rated the electrocutaneous stimuli as rather painful and unpleasant and as moderately threatening (Table 2). The differences between the two groups, however, were not statistically significant. Furthermore, the two Pain groups did not differ in self-reported levels of situational pain catastrophizing

Table 1 Sample characteristics (ratio or means with SDs and range in parentheses) per group, and group comparisons.

	Pain threat (n = 31)	Pain no threat (n = 31)	Nonpain (n = 31)	Group comparison
Females: Males	25: 6	24: 7	27: 4	$\chi^2(2) = 1.01$, $p = 0.708$
Age	20.1 (1.9, 18–24)	20.8 (3.0, 18–30)	20.7 (1.9, 17–24)	$F(2,90) = 0.7$, $p = 0.50$, $\eta_p^2 = 0.015$
PCS	18.5 (7.6, 5–39)	17.3 (7.0, 4–30)	18.8 (9.2, 5–37)	$F(2,90) = 0.3$, $p = 0.74$, $\eta_p^2 = 0.097$
RST	65.9 (7.7, 51.0–82.0)	61.5 (9.0, 43.0–83.3)	63.9 (11.0, 45.0–83.9)[a]	$F(2,89) = 1.8$, $p = 0.17$, $\eta_p^2 = 0.039$

PCS, Pain Catastrophizing Scale; RST, Reading Span Test.

[a]Based on n = 30 (one Nonpain group participant was excluded due to missing data).

Table 2 Objective intensity (in mA) and subjective ratings of the electrocutaneous stimulus, and situational pain catastrophizing (means, with SDs and range in parentheses) for the Pain groups, with group comparisons.

	Pain threat (n = 31)	Pain no threat (n = 31)	Unpaired sample t-tests
Objective intensity	29.4 (17.3, 10–99)	37.9 (17.9, 14–92)	$t(60) = 1.9$, $p = 0.06$
Threat value	4.5 (3.1, 0–10)	4.5 (2.9, 0–10)	$t(60) = 0$, $p = 1$
Painfulness	7.8 (1.0, 6–10)	7.8 (1.1, 4–9)	$t(60) = 0.60$, $p = 0.95$
Unpleasantness	8.5 (2.0, 1–10)	8.5 (1.6, 2–10)	$t(60) = 0.1$, $p = 0.89$
PCS Situational	12.0 (7.4, 1–30)	13.5 (9.7, 0–42)	$t(60) = 0.7$, $p = 0.52$

PCS, Pain Catastrophizing Scale.
Threat value/Painfulness/Unpleasantness were rated on 11-point numerical scales (0 = not at all; 10 = to a very large degree).

(Table 2). The Pain No threat group selected an electrocutaneous stimulus of higher objective intensity than that selected by the Pain Threat group (Table 2), potentially due to the somewhat more reassuring instructions that these participants had read at the beginning of the session. This difference, however, was not statistically significant ($p = 0.06$).

Taken together, these results suggest that, although we managed to create an unpleasant painful context during the ongoing task, our threat manipulation failed to increase the perceived threat value of the painful stimulation and thus to differentiate the two groups in this respect.

3.2.2 Ongoing (word categorization) task performance

Overall, participants showed high accuracy in the word categorization task (Table 3). Accuracy was higher in nonmatch trials than in match trials, by approximately 3.5% [95% CI (2.7, 4.3)] [main effect trial type: $F(1,90) = 71.6$, $p < 0.001$, $\eta_p^2 = 0.44$]. Groups did not significantly differ in this respect [main effect group: $F(2,90) = 2.0$, $p = 0.14$, $\eta_p^2 = 0.04$; group*trial type interaction, $F(2,90) = 0.20$, $p = 0.82$, $\eta_p^2 = 0.004$].

Similarly, participants responded more slowly in nonmatch trials than in match trials by approximately 37.6 ms [95% CI (25.2, 50.0)] [main effect trial type: $F(1,90) = 36.2$, $p < 0.001$, $\eta_p^2 = 0.29$], but this did not differ between the groups [main effect group: $F(2,90) = 0.05$, $p = 0.95$, $\eta_p^2 = 0.001$; group*trial type interaction, $F(2,90) = 0.8$, $p = 0.47$, $\eta_p^2 = 0.02$]. A small, but nevertheless statistically significant correlation between speed and accuracy in match trials ($\rho = -0.22$, $p = 0.03$) and nonmatch trials ($\rho = -0.31$, $p = 0.003$) confirms a speed-accuracy trade-off.

Taken together, these results indicate that participants categorized the words similarly well irrespective of the group they belonged to, suggesting that ongoing task performance was not impaired in the context of pain.

Table 3 Performance in the ongoing (word categorization) task and performance of the PM intention [accuracies and PM intention performance rate: percentage (correct); reaction times (RTs): ms; means with SDs and range in parentheses], and retrospective recall of the PM retrieval cues and picture-related questions (number and percentage of participants that responded correctly), per group.

	Pain threat (n = 31)	Pain no threat (n = 31)	Nonpain (n = 31)
Ongoing (word categorization) task			
Accuracy in match trials	91.7 (3.6, 83.2–97.8)	90.5 (3.5, 82.6–96.9)	92.1 (3.6, 79.1–97.3)
Accuracy in nonmatch trials	95.4 (3.0, 89.1–100)	94.0 (4.8, 82.1–100)	95.2 (3.8, 83.6–100)
RTs in match trials	1144.4 (266.3, 868.6–2353.1)	1149.7 (163.2, 857.2–1550.2)	1151.6 (180.1, 851.8–1698.4)
RTs in nonmatch trials	1173.8 (275.2, 908.2–2411.3)	1185.1 (163.0, 918.7–1581.2)	1199.6 (188.5, 880.5–1733.2)
PM intention			
PM intention performance rate	80.6 (24.5, 0–100)	74.2 (29.8, 0–100)	80.0 (26.8, 0–100)
Accuracy picture-related question[a]	95.7 (9.1, 66.7–100)	89.4 (18.7, 16.7–100)	98.3 (6.8, 66.7–100)
Correct recall of PM retrieval cues	30 (96.8%)	30 (96.8%)	30 (96.8%)
Correct recall of picture-related questions	29 (93.5%)	29 (93.5%)	31 (100%)

[a]Sample sizes were: Pain Threat: n = 30; Pain No threat: n = 28; Nonpain: n = 29 (recall that participants viewed and responded to the questions only if they had successfully responded to the PM retrieval cue).

3.3 PM performance

3.3.1 PM intention performance rate

The rate of PM intention performance was relatively high, as participants pressed the designated button on approximately four out of five times that they saw a PM retrieval cue (Table 3). Contrary to our expectations, the groups did not differ in this respect [main effect group: $F(2,90) = 0.5$, $p = 0.59$, $\eta_p^2 = 0.01$].

Thus, our participants remembered to perform the PM intention at the appropriate moment quite often, irrespective of whether they were in a painful context when they performed the intention.

3.3.2 Accuracy in the picture-related question

Accuracy in the picture-related question was high (Table 3). A statistically significant effect of group arose, [$F(2,84) = 3.8$, $p = 0.026$, $\eta_p^2 = 0.08$]. Our planned Helmert contrasts showed that the difference lay between the Nonpain group and the mean of the two Pain groups, $p = 0.048$. A closer inspection of Table 3 indicates that this effect is carried by the Pain No Threat group, which not only showed lower performance, but also higher response variability.

Thus, memory for the content of the PM intention appeared to be somewhat impaired within the context of pain, especially when that context had not been accompanied by threatening information.

3.3.3 PM intention recall

Almost all participants were able to recall the PM intention they were required to perform (Table 3). There were no group differences in the number of participants who correctly recalled the PM retrieval cues, $\chi^2(4) = 3.0$, $p = 1$, and the picture-related questions (in the correct order), χ^2 $(4) = 2.1$, $p = 0.72$.

Thus, participants showed similarly good memory for an intention they had encoded under pain-free conditions, irrespective of whether they had been required to perform that intention in a context of pain.

4. Discussion

An association of pain with poorer prospective memory (PM) has previously been reported (Ling et al., 2007; Miller et al., 2014) but not experimentally studied. In a study following the suggested guidelines for the laboratory investigation of PM (Einstein and McDaniel, 2005), healthy participants were given a PM intention to perform in the future. The appropriate moments for the performance of the intention were signalled by PM retrieval cues that were presented during an ongoing task, in which participants either received painful electrocutaneous stimulation or no somatic stimulation.

Results showed that PM was independent of the painful context. Participants responded to the PM retrieval cues with similar frequency, irrespective of whether they had received painful stimulation or not, suggesting that a painful context does not influence the prospective element of PM, i.e. remembering to perform the intention at the appropriate time. This finding is inconsistent with our original hypothesis and with existing patient studies linking chronic pain to PM problems (Ling et al., 2007; Miller et al., 2014).

Although unexpected, our finding can be readily explained within the context of the multiprocess framework of PM (McDaniel and Einstein, 2000; Einstein and McDaniel, 2010). This framework postulates that different processes are used to retrieve planned intentions depending on factors such as the so-called 'focality' of the PM retrieval cue (Goonen-Yaacovi and Burgess, 2012). When the PM cue is 'focal', i.e. processed in the same way for the PM intention as for the ongoing task (as in our study, with the PM intention and ongoing task requiring semantic processing), spontaneous retrieval of intentions is favoured over the more demanding strategic monitoring for the PM retrieval cue (Einstein and McDaniel, 2005, 2010). Although even in spontaneous retrieval the performance of PM intentions is often impaired under conditions of divided attention (e.g. Einstein et al., 2003; McDaniel et al., 2008; Harrison et al., 2014), it is possible that our painful context failed to induce such demanding conditions, despite the painfulness and unpleasantness of the electrocutaneous stimuli.

Our findings do not reveal a PM impairment in a context where pain can be anticipated any moment and painful stimuli are presented near, but not at the same time as the PM retrieval cues. Given the propensity of pain to capture attention (Eccleston and Crombez, 1999; Van Damme et al., 2010; Moore et al., 2012), larger effects on PM intention performance rate might have been observed if pain was administered concurrently with the PM retrieval cues. The processing of pain would then likely be prioritized over that of the PM retrieval cue (Eccleston and Crombez, 1999; Van Damme et al., 2010),

impairing the detection of the latter and, eventually, the execution of the intention. The concurrent presentation of pain and PM retrieval cue, however, reflects the situation where one feels pain *at the exact moment* that they had planned to do something. This situation is not only methodologically, but also conceptually different from the one that we focussed on, which refers to *the broader context* within which the intention must be performed.

Alternative explanations for the lack of context effect can also be found in PM task characteristics. Following common practice in PM research (Smith, 2003; Einstein et al., 2005; Finstad et al., 2006; Rummel et al., 2017), we presented few PM retrieval cues. It is likely that presenting more PM retrieval cues would yield different results. Conceptually, though, a high number of PM cues would reflect a habitual PM task. Such tasks are assumed to rely on different cognitive processes than episodic PM tasks, like the current one, and are therefore much less studied in PM research (Dismukes, 2012).

Findings indicate that the retrospective element of PM, i.e. remembering the content of the intention, was quite high. This lends further support to the proposal that the most common PM deficits regard the prospective component, i.e. forgetting to execute an intention at the appropriate time, rather than remembering that one had an intention but forgetting its content (Dismukes, 2010). Unexpectedly, we also found that accuracy in the picture-related question was somewhat lower for participants who had received electrocutaneous stimulation without the threatening instructions. It is unclear why that was the case. In light of the lack of a theoretical explanation, this finding warrants replication and further investigation.

Pain catastrophizing did not modulate the relationship between pain and the performance of the PM intention. This finding is in line with a recent meta-analysis showing negligible effects of pain catastrophizing on the attentional capture by pain (Crombez et al., 2013). Working memory capacity was also not shown to influence PM intention performance in any way. It has been postulated that working memory capacity might only influence retrieval that requires strategic processing (McDaniel and Einstein, 2000; Smith and Bayen, 2005), but not spontaneous retrieval, such as in our study. Functions other than working memory, such as inhibitory control (Kliegel et al., 2008), attention, goal setting, planning and task management (Dismukes, 2010, 2012), might play a more crucial role in the execution of planned intentions. These functions were not tested in this study.

Taken together, our findings suggest that, given adequate explicit encoding in pain-free conditions, a painful context does not influence acting on an intention at the appropriate time or retrieving the content of an intention. This echoes previous findings that pain does not necessarily impair performance of complex tasks that rely heavily on PM – at least not for people resilient to cognitive intrusions by pain (Moore and Law, 2017). Thus, PM impairments reported by chronic pain patients (Ling et al., 2007) may be partly explained by other factors, such as attention deficits (Oosterman et al., 2011), medication use (McCracken and Iverson, 2001; Schiltenwolf et al., 2014), sleep deprivation (Scullin and McDaniel, 2010) and depression or anxiety (McCracken and Iverson, 2001; Muñoz and Esteve, 2005; Roth et al., 2005) (but see also Attree et al., 2014). In order to further understand the role of pain in PM deficits, the contribution of such factors merits further examination.

We argued that PM would be especially impaired when pain is perceived as threatening. In order to test this hypothesis, we used a blood pressure measurement with bogus feedback to increase the threat value of pain in half of the participants who received electrocutaneous stimulation. A very similar procedure has previously been used successfully with a different pain induction method (Van Damme et al., 2008; Vlaeyen et al., 2009), but in this study it failed to increase pain threat value. There are more reports of similar threat manipulations being effective with one (Boston and Sharpe, 2005) but not on other type of experimental pain (Moore et al., 2013). Matching the threat manipulation to the type of painful stimulus likely increases its chance of success. For electrical stimuli, follow-up studies could seek to manipulate their threat value by referring to the alleged sensitivity of the skin (cf. Wiech et al., 2010), which might be a more credible manipulation than a reference to blood pressure.

The failure of our threat manipulation to increase the threat value of pain precluded the proper evaluation of our second hypothesis. However, in order to be able to at least explore the effects of the threat value of pain on PM, we performed a median split on the self-reported pain threat value, based on which we redistributed the participants who received electrocutaneous stimulation into two new groups of pain and high or low threat. We then repeated our analyses on these newly defined groups. These analyses (not reported here) did not yield any additional or otherwise essentially changed results, suggesting that a context of threatening pain does not

necessarily impair the performance of PM intentions that are retrieved spontaneously. The role of pain threat value on PM warrants further investigation.

Some other limitations of this study must be noted. First, as part of the threat manipulation, the two Pain groups received slightly different instructions before pain stimulus intensity calibration. As a result, the chosen intensity differed between groups, although not significantly so. Future researchers should introduce threat-inducing manipulations after determining pain threshold, tolerance, etc. Second, our findings cannot be readily generalized to populations of (chronic) pain patients because our sample comprised healthy volunteers. Third, in order to create the painful context, we used intermittent electrocutaneous stimuli of brief duration. It is unclear whether a more tonic pain model (e.g. cold pressor pain) would yield the same results. Pain of long duration might be more disruptive (cf. Sinke et al., 2015), but on the other hand it might also facilitate habituation and thus interfere less (cf. Moore et al., 2013). Replication of this study with a different pain model is thus warranted.

Despite its shortcomings, this study is a first important step in the experimental investigation of whether PM is impaired by (threatening) pain. PM failures can have detrimental consequences for goal-directed activities and, in patients, may interfere with treatment, e.g. by decreasing adherence to a medication schedule (Woods et al., 2008b). PM failures can thus be debilitating for independent living (Woods et al., 2008a). In light of the study limitations mentioned above, it would be worthwhile for future research to replicate the current findings.

In order to further understand the role of pain in PM deficits, the contribution of other factors, such as the type of PM task, merits examination. We used an event-based PM task, i.e. a task intended to be performed in response to a specific cue (Dismukes, 2010). Time-based tasks, namely tasks intended to be performed at a specific time or after a specific time interval (Dismukes, 2010), are also highly relevant for patients (e.g. take medication after 8 h) and, since they are performed in response to more subtle triggers that may favour resource-demanding strategic processing, they may also be more sensitive to pain effects. Similarly, future research may investigate whether pain influences PM differentially when it is presented within the broader context in which retrieval must occur, at the exact moment of retrieval, or, potentially, at the moment of intention encoding (cf. Kuhajda et al., 2002; Naveh-Benjamin et al., 2006; Forkmann et al., 2016). Further investigation of the effects of pain on PM is likely to enhance our understanding of the cognitive effects of pain episodes in pain patients.

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Author contributions

Conception of the study: R.G., M.S., J.V. Data collection and analyses: R.G. Discussion of the analyses and results: R.G., M.S., G.C., J.V. Preparation of manuscript: R.G. Essential commentary on the manuscript: M.S., G.C., J.V. All authors have discussed the results and commented on the manuscript.

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