Original Experimental

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The interaction between pain and cognition: on the roles of task complexity and pain intensity

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Abstract

Objectives: The interaction between pain and cognition includes a concurrent negative effect of pain on cognitive performance and an analgesic effect of cognitive distraction on pain experience. The purpose of this exploratory study was to investigate the role of pain intensity and task complexity on this interaction.

Methods: Two experiments were conducted in healthy volunteers. In both experiments, participants completed 3 conditions: a pain only condition (consisting of the cold pressor test), a cognition only condition (consisting of the cognitive task) and a combined condition (concurrent administration of the cold pressor and cognitive task). In experiment I, participants performed one out of three possible tasks that differed in cognitive load (low, medium, high). In experiment II the parameters of the pain stimulus, induced by a cold pressor test, were adapted and only the high load cognitive task was employed. Pain scores, reaction times, and accuracy rates were recorded.

Results: In experiment I, cognitive distraction significantly decreased pain scores, irrespective of the cognitive load of the task. Pain did not affect cognitive performance. In experiment II, pain diminished accuracy rates. No effect

of cognitive distraction on pain was observed. Individual characteristics did not noticeably influence the interaction between pain and cognition.

Conclusions: The results of this study suggest a two-way interaction, however no evidence for a simultaneous bidirectional relationship was found. Cognitive distraction successfully reduces pain, up until a certain point where this relationship is reversed, and pain starts to interfere with cognitive performance. This may imply that priorities shift at a certain pain-threshold, however further research should confirm this hypothesis. This study could contribute to further understanding of cognitive mechanisms related to pain perception.

Keywords: cognition; cognitive performance; distraction; pain.

Introduction

Pain is associated with reduced cognitive performance [1–9], and performing a cognitive task has been shown to reduce pain experience [4, 10–14]. Studies have reported decreased cognitive performance in chronic pain, acute pain and experimental pain [1–6, 15–20]. High intensity pain patients demonstrate worse cognitive performance compared to patients suffering from mild to moderate pain [21]. Commonly reported symptoms related to cognitive performance include attentional dysfunction, memory deficits and mental slowness [2, 3, 18, 19]. Cognitive tasks with a high cognitive demand, such as complex memory and inhibition, are more affected by pain than low load cognitive tasks [7, 8, 22]. On the other hand, cognition also influences pain perception: performing a cognitive task, particularly a high load cognitive task, reduces concurrent pain experience [4, 10–13, 23]. However, results are highly variable, and many studies failed to show that cognitive distraction reduces pain experience or that pain interferes with cognitive task performance, [e.g. 4, 8, 12]. We argue that this may in part be due to differences in load of the cognitive tasks employed as well as the intensity of the pain stimulus.

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Both the negative interference of pain on cognitive performance and the analgesic effect of cognitive distraction, i.e. the bidirectional relationship between pain and cognition, are summarized in the distraction hypothesis [24]. The general idea behind this hypothesis is that pain processing and cognitive performance both demand attention: a cognitive process during which sensory input is selected and assessed on its relevance [24, 25]. Since the attentional capacity in humans is limited, only the most relevant stimuli will enter awareness [25, 26]. According to the distraction paradigm, if a distracting stimulus is offered simultaneously with a pain stimulus, attention is divided between both stimuli, resulting in decreased pain perception and simultaneously decreased cognitive performance [24, 25].

To date, many studies have explored the domain of pain perception and cognitive performance. However, most studies investigated either the effect of cognitive distraction on pain, or the effect of pain on cognition [1, 17, 20, 21], whereas the bidirectional relationship has hardly been investigated simultaneously within one study population [4, 27, 28]. Furthermore, the diversity in cognitive tasks used hinders a proper comparison of study results. The tasks employed include different cognitive functions and cognitive load, and are measured with a diversity of tests. This diversity might contribute to the mixed results of previous studies: while some have reported decreased cognitive performance due to pain or a reduction in pain due to a distracting cognitive task [5, 7, 9, 12], others did not find any effect [4, 8, 12, 27, 29, 30]. Consequently, little is known regarding the cognitive load of a task that is required to indeed substantiate the potential interaction between pain and cognition. In addition, questions remain regarding individual pain-related characteristics, such as pain catastrophizing and anxiety, that might influence the interaction between pain and cognition [14, 31–34]. Again, most studies investigating these characteristics explored only one aspect of the bidirectional relationship between pain and cognition, underscoring the importance of examining these characteristics in this relationship.

The aim of this study was to investigate the interaction between pain and cognition bidirectionally, and to study the roles of task complexity and pain intensity on this relationship. Furthermore, the influence of personal characteristics on the interaction was explored. We hypothesized that cognitive distraction reduces pain experience and that this effect increases with higher cognitive demands of the task. Furthermore, according to the distraction paradigm, we hypothesized that pain negatively affects cognitive performance (i.e. accuracy and reaction time), with the largest effects on high cognitive load tasks.

General methods

In this exploratory study, two experiments were conducted. In both experiments, all participants completed three conditions, namely a pain only condition (consisting of the cold pressor test), a cognitive task only (consisting of the cognitive task), and a combined distraction condition that included concurrent administration of the cold pressor and cognitive tasks. Pain scores were recorded during the pain only and combined distraction condition, accuracy rates and reaction times were recorded in the cognitive task only and the combined distraction condition.

In experiment I, three tasks that differed in cognitive load were employed in a parallel design. We investigated which cognitive task was most suited to explore the interaction between pain and cognitive performance, and which task provided most pain relief. The task requiring the highest cognitive load in experiment I was further examined in experiment II, in which we adapted the parameters of the pain stimulus, to further explore the relationship between pain and cognitive performance. In both experiments, we investigated whether personal variables influenced the interaction.

The experiments were carried out at the Radboud University, Donders Institute for Brain, Cognition and Behaviour. Ethical approval was obtained from the ethical committee of the Faculty of Social Sciences of the Radboud University (ECG 2012-1301-005). All subjects provided written informed consent.

Participants

Participants were healthy students of the Radboud University, aged 18 years or over. Participants were excluded if they used psychoactive medication, if they reported substance or alcohol abuse and if they were suffering from a condition known to influence pain perception and/or cognitive task performance, such as current depression, heart disease, diabetes mellitus or hypertension. Participants received course credit points or financial compensation (5 Euros). Previous studies employing distraction paradigms on the interaction between pain and cognition have revealed, overall, medium or even large effect sizes for pain reduction following cognitive distraction [14, 35] as well as pain interfering with cognitive task performance [9, 35], although some reported small effect sizes for the effect of distraction on reducing pain [36]. We expect therefore a medium effect size ($f=0.25$). For experiment 1 we were particularly interested in the interaction between cognitive load and condition, tested via repeated measures ANOVA. With an alpha of 0.05, power of 0.80, a medium correlation of 0.5 between the two measurements (baseline vs. distraction) and three groups (low, medium, high load), we can demonstrate a small to medium effect size by including 42 participants. We aimed to include at least 20 participants per group, and sensitivity analysis revealed that including 65 participants leads to a small-to-moderate effect size for the interaction. For experiment II, with an alpha of 0.05, power of 0.80, a medium correlation of 0.5 between the two measurements (baseline vs. distraction), we can demonstrate a small effect size by including 52 participants, and a medium effect size by including 34 participants, tested via repeated measures ANOVA.

Experiment I

Methods

Study procedure: This experiment includes three conditions: a pain only, a cognitive task only, and a combined distraction condition. In the cognitive condition, each participant performed one cognitive load task (randomization for task based on study entry). After randomization, each participant started with a training session consisting of 20 trials of the cognitive task to ensure that the subject had understood the instructions. Subsequently, each participant underwent three conditions in a counterbalanced order:

- (1) A baseline pain condition. In this condition, participants were instructed to maintain their non-dominant hand immersed into cold water (mean temperature $5.6 \pm 1.1^\circ\text{C}$) for as long as they could tolerate, with a maximum of 2 min. Afterwards, the participant reported a pain score, i.e. the pain they felt at the end of the task (immediately before they made their rating), on a Visual Analogue Scale (VAS), a 10 cm line ranging from “no pain” on the upper left side and “unbearable pain” on the upper right side. The score was determined as the distance from the left extreme to the mark, measured with a millimeter scale.
- (2) A baseline cognitive condition. During this condition, participants performed a cognitive task during 2 min without a pain stimulus. Reaction time and the number of errors were recorded.
- (3) A distraction condition; a combined condition including a cognitive task and a pain stimulus. Thus, participants completed a cognitive task while immersing the non-dominant hand in cold water. Afterwards, participants were asked to report their pain score (VAS). Again, reaction times and the number of errors were recorded. Subjects reported the amount of distraction provided by the computer task and the amount of distraction due to pain

on an 11-point numerical rating scale (NRS), with 0 corresponding to not-distracting and 10 corresponding to extremely distracting. In case a participant withdrew his hand from the water before the maximum time of 2 min had elapsed, the task was discontinued. Participants were also asked to fill in three pain-related questionnaires: the Fear of Pain Questionnaire (FPQ) [37], the Coping with pain questionnaire (CPQ) [38], and the Pain Catastrophizing Scale (PSC) [39]. The pain-related questionnaires were analysed using sum scores. Two subjective distraction ratings were collected separately for subjective rating of distraction in cognitive performance that was caused by pain ($\text{distraction}_{\text{pain}}$) and the amount of distraction in experiencing pain that was caused by the concurrent cognitive task performance ($\text{distraction}_{\text{cognition}}$). The procedure took about 25 min for each participant.

Cognitive tasks

Experiment I included three tasks with an increasing cognitive load: a low load task related to choice reaction, an intermediate load task which additionally included the occasional suppression of a predominant response, and a high load cognitive task that, next to choice reaction and suppression of predominant responses, required additional monitoring and updating functions. The design of the tasks was based on the exact same principle, namely indicating the direction of a single arrow presented on a screen, alternated by a fixation cross presented for 500 ms. This enabled a direct comparison between performance levels on the different tasks as well as their effect on pain experience. The tasks were developed in E-Prime Version 2.0 (Pittsburgh, PA: Psychology Software Tools Inc. (2002)). The cognitive tasks are illustrated in Figure 1.

Figure 1: Illustration of the tasks used in experiment I, with different cognitive loads ranging from low to high cognitive load, and correct responses, i.e. left or right mouse button, for each trial. (Experiment I).

During the low load task, the arrow was presented in the middle of the screen and pointed to either the right or the left side of the screen. Participants were instructed to press the corresponding mouse key as soon and as accurately as possible. During the intermediate load task, the arrow pointed again to the right or left side, but this time the arrow was located at either the left or the right part of the screen. Participants were instructed to indicate the direction of the arrow, regardless of the location on the computer screen, as soon and as accurately as possible. Thus, the right mouse key had to be pressed when an arrow pointed to the right, regardless of whether it appeared on the right side or the left side of the screen. Finally, the high load cognitive task was similar to the low load cognitive task, except that subjects were now instructed to press the opposite mouse button instead of the corresponding mouse button on every third trial. This condition therefore required not only the suppression of the predominant response on every third trial, but also the online monitoring and updating of the number of trials, a fundamental process of working memory [40]. In this task, feedback was provided after an error was made to prevent incorrect counting after a mistake.

Data preparation

Accuracy was calculated as the number of correct trials divided by the total number of trials completed by a participant. Reaction time included the mean reaction time of correct responses during the tasks. Trials with reaction times that exceeded the range of 200–1000 ms were excluded from the analysis. For each task one average reaction time and one average accuracy score was calculated. Delta outcome scores were calculated for the different outcome measures, reflecting the difference between the baseline and the combined distraction condition: $\Delta \text{pain} = \text{pain score in the distraction condition} - \text{pain score in the baseline pain condition}$, $\Delta \text{reaction time} = \text{reaction time in the distraction condition} - \text{reaction time in the baseline cognitive condition}$, $\Delta \text{accuracy} = \text{accuracy in the distraction condition} - \text{accuracy in the baseline cognitive condition}$ [14].

Statistical analysis

Normality of the data was based on kurtosis and skewness values, with standardized values < 2.58 being acceptable [41]. Outcomes on pain scores were normally distributed, after double square root transformation of the reaction time scores, these fell within normal range as well. Repeated measures analyses of variance (RM-ANOVA) were conducted to study differences in pain scores and reaction times between the baseline condition and the distraction condition. Here, condition (baseline, distraction) was the within-subjects variable, cognitive task (low, intermediate and high cognitive load) the between-subjects variable and reaction time or pain scores the dependent variable. Exploratory post hoc analyses were performed using parametric tests and Bonferroni correction for multiple comparisons. Accuracy rates were severely skewed and could not be normalized. This was mostly due to the very high accuracy in the low and intermediate load tasks ($\geq 96\%$; see Results section); these accuracy rates were therefore not further analyzed. Due to the non-normality of the data, for the high load task the Wilcoxon-signed-rank test was performed to study the effect of pain on accuracy rates (baseline cognitive condition vs. distraction condition).

Next, we examined how the delta outcome scores were related to each other, to the pain questionnaires and to the subjective distraction ratings ($\text{distraction}_{\text{pain}}$ and $\text{distraction}_{\text{cognition}}$). We calculated Spearman rank correlations (two-tailed) for correlations with delta pain, and Pearson's correlations for correlations calculated for delta accuracy and reaction times. As delta scores reflect the change between the baseline and the combined distraction condition, we can test whether e.g. changes in reaction time performance following painful distraction correlate with e.g. fear of pain. Since almost all participants completed the combined distraction condition at the maximum time of 2 min, we did not analyse the immersion time of the hand in the cold water.

Furthermore, we examined if someone's baseline score is predictive of the amount of distraction induced by that measurement. We reasoned that when a person shows a higher pain sensitivity (evident as a higher VAS score at baseline), this person is more likely to be distracted by this same pain stimulus when performing a cognitive task. As such, we expected higher pain VAS scores at baseline to relate to worse cognitive performance in the distraction condition. Likewise, we assumed that worse cognitive performance at baseline indicates more difficulty in and attention needed for performing the task. Consequently, we expected that when more attention is needed to perform the cognitive task per se, less attention is available for processing the pain stimulus during the distraction condition. Therefore, we hypothesized that worse cognitive baseline performance predicts a stronger decline in VAS pain ratings during the distraction condition. To this end, a Pearson correlation (one-tailed, because of directed hypotheses) was calculated between the VAS baseline pain score and the delta reaction time score, and between the VAS baseline pain score and the delta accuracy score (reflecting cognition differences due to distraction). Second, Spearman correlations were calculated between the baseline reaction time or accuracy and the delta VAS pain scores (the change in VAS pain score due to distraction).

Finally, since we did not succeed in perfectly balancing the order of the conditions (due to some drop-outs, because of technical issues and no-show), the potential confounding role of sequence of condition was analyzed using ANOVAs with sequence as between-subjects variable and the delta accuracy and delta reaction time as dependent variables. For the pain delta score, a Kruskal–Wallis H test was performed. Data analysis was performed using IBM SPSS statistics v22.0. A p value ≤ 0.05 was considered statistically significant.

Results

Descriptives

Sixty-five eligible volunteers, 18 men and 47 women (72.3%) were included. Mean age of the participants was 22.0 ± 2.3 years (range 18–28). The low load cognitive task was performed by 21 participants, the intermediate and high load tasks by 22 participants. In three participants, reaction times and accuracy rates of the baseline cognitive condition and the distraction condition were not recorded due to a technical failure (2 participants in the low load task, one participant in the high load task). These participants were excluded in the analyses of cognitive performance. One participant withdrew

Table 1: Cognitive performance and pain ratings of the participants in the baseline and in the distraction condition. (Experiment I).

Variable	Baseline condition	Distraction condition	F-value	p-value
VAS pain score (mean (SD), n=64)	5.65 (2.24)	5.10 (2.02)	3.88	0.05
Reaction time (median (IQR), n=61)	351.74 (85.63)	362.69 (70.18)	1.60	0.21
Accuracy (median (IQR), n=61)	0.96 (0.05)	0.96 (0.06)	-0.32 ¹	0.75
Distraction _{cognition}	–	5.31 (2.39)	–	–
Distraction _{pain}	–	5.07 (2.23)	–	–

VAS: visual analogue scale. 1: High load task only, Z-value.

during the study procedure and was, therefore, excluded from all data analysis (high load task). In 18 participants, the coping with pain questionnaire was not completed, therefore they were not included in the analyses of the personal characteristics related to this questionnaire. As can be seen in Table 1, on average participants found both the pain and the cognitive task moderately distracting (average rating of 5 out of 10).

Primary analyses

A significant main effect of condition on the reported pain scores was found ($F(1, 61)=3.88$, $p=0.05$, $\eta^2_p=0.06$), with lower pain ratings in the distraction compared to the baseline condition (see Table 1). No significant differences in pain scores between tasks were observed ($F(2, 61)=0.22$, $p=0.80$, $\eta^2_p=0.01$). No significant interaction between condition and cognitive task difficulty was observed, indicating that all cognitive tasks produced a comparable pain reducing effect ($F(2, 61)=0.93$, $p=0.40$, $\eta^2_p=0.03$). As can be seen in Figure 2, the task with the highest cognitive

load numerically induced the largest mean reduction in pain scores (-0.97 points), compared to the low cognitive load task (-0.24) and the intermediate load task (-0.25).

Reaction times during the baseline condition and the distraction condition were not significantly different ($F(1, 58)=1.60$, $p=0.21$, $\eta^2_p=0.03$) (Figure 2). A significant difference between tasks was found ($F(2, 58)=30.32$, $p<0.01$, $\eta^2_p=0.51$, showing that reaction times during the high load cognitive task were significantly higher ($p's<0.01$) compared to reaction times during the other tasks, which did not differ from each other ($p=0.45$). The interaction with the type of cognitive task was not significant ($F(2, 58)=2.06$, $p=0.41$, $\eta^2_p=0.07$).

Median accuracy rates in the baseline condition and the distraction condition were 1.00 [Q25 0.98–Q75 1.00] and 0.98 [0.94–1.00] for the low load task, 0.96 [0.96–0.98] and 0.97 [0.94–0.98] for the intermediate load task and 0.92 [0.89–0.95] and 0.92 [0.89–0.96] for the high load task respectively. As accuracy rates exceeded 95% in the low and intermediate load conditions, only the high load task was analyzed. Wilcoxon-signed-rank test showed that pain did not significantly affect accuracy during the high load task ($Z=-0.32$, $p=0.75$).

Sequence of conditions was not identified as a significant covariate in the analyses for pain ($F(2, 60)=0.27$, $p=0.76$, $\eta^2_p=0.01$), and reaction times ($F(2, 57)=0.01$, $p=0.92$, $\eta^2_p=0.01$).

Correlations

Delta pain was significantly correlated with delta accuracy: relative to the baseline conditions, in the distraction conditions a decrease in pain score significantly correlated with an increase in accuracy. Correlations between delta outcome scores of pain and reaction times, and reaction times and accuracy, were not significant.

Figure 2: Mean ($\pm$ SE) pain scores (2A), median(IQR) reaction times (2B), and median(IQR) accuracy scores (2C) during the baseline pain condition and the distraction condition (experiment I).

Table 2: Correlational analysis of the delta outcome scores, baseline scores, pain questionnaires and subjective distraction ratings. (Experiment I).

	Δ Pain	Δ Reaction time	Δ Accuracy
Δ Pain ¹	–	0.18	–0.28*
FPQ ¹	0.06	–0.14	–0.01
PCS ¹	0.05	–0.06	–0.08
CPQ ²	–0.27	–0.16	0.15
Distraction _{cognition} ¹	–0.15	–0.02	0.02
Distraction _{pain} ¹	0.01	–0.09	–0.17
Pain score at baseline ¹	–	0.01	0.12
Reaction time at baseline ³	–0.28*	–	–
Accuracy at baseline ³	0.24*	–	–

FPQ=Fear of Pain Questionnaire, PCS=Pain catastrophizing scale, CPQ=Coping with pain questionnaire. 1 n=64, 2 n=46, 3 n=61.

Furthermore, correlations with delta outcome scores and the pain questionnaires and distraction_{pain} and distraction_{cognition} were also not significant.

Finally, we tested the hypothesis that a baseline (e.g. pain score) predicts the distraction caused by that stimulus (e.g. the lowering in cognitive performance, evident in the delta score). The correlation analysis showed that the relationship between the baseline VAS score and the delta reaction time or delta accuracy was not significant, suggesting that higher baseline pain sensitivity is not associated with a larger distracting effect of pain on cognitive task performance. However, baseline performance in both reaction times and accuracy did correlate with the delta pain score, indicating that worse cognitive performance at baseline is associated with a stronger pain reduction effect in the distraction condition. Recalculating these correlations for each cognitive task separately, revealed no significant results for the correlation of baseline accuracy and delta pain separately for each task. However, baseline performance on reaction times predicted the pain reduction in the high load task ($\rho=0.49$, $p=0.01$) but not in the low ($\rho=0.0$, $p=0.39$) and medium ($\rho=0.14$, $p=0.27$) load tasks.

Results from the correlational analyses on the relationships between baseline scores, delta outcome scores, the pain questionnaires and the subjective distraction ratings distraction_{pain} and distraction_{cognition} are presented in Table 2.

Discussion

The aim of the first experiment was to investigate the relationship between pain and cognition, and to explore which cognitive task was most apt at reducing pain

intensity. All findings support the hypothesis that pain experience is reduced if a concurrent cognitive task is performed. First, we found that cognitive distraction indeed reduces pain scores. Second, better cognitive task performance correlated with more pain reduction in the distraction condition. This suggests that the more participants were able to maintain their cognitive performance level in the distraction condition, the larger the pain reducing effect was. Finally, worse cognitive performance at baseline related to a stronger pain reducing effect during cognitive distraction. This suggests that cognitive distraction for pain may be more beneficial for participants who perform worse at the cognitive task, potentially because these participants require more attentional processing to perform the task and therefore have less attentional capacity left for processing the painful stimulation. In contrast, we did not find evidence that pain interferes with cognitive task performance: No significant effect of pain on cognitive performance was found. Moreover, baseline pain scores did not predict worse cognitive performance in the distraction condition. Taken together, we found no evidence supporting the hypothesis of a concurrent relationship between pain and cognition; at the group level, pain and cognitive performance did not decline simultaneously during the distraction condition.

Finally, with regard to the cognitive load of the task, the following was found: the pain reducing effects were largest in the high cognitive load condition, although this did not differ significantly from the pain reducing effects in the other cognitive load tasks. However, we also found that the relationship between baseline reaction time and the reduction in pain scores was significant in the high cognitive load group only. Based on these findings, we decided to use this task for a second, modified experiment. In this experiment we adjusted the parameters of the pain stimulus to make it more intense, to further explore the relationship between pain and cognitive performance. Specifically, we were interested to test if the lack of a distracting effect of pain on cognition in experiment 1 can be explained by the painful stimulus not being intense enough.

Experiment II

Methods

Study procedure: The study procedure was quite similar to experiment I. Each participant underwent three conditions; a baseline pain condition, a baseline cognitive condition and a combined distraction

condition. In experiment II, we employed only the high load task including aspects of working memory. We also adapted the pain stimulus by using ice cold water, with a temperature of 0.5 °C. Furthermore, the maximum immersion time was expanded to 3 min. Pain scores, reaction times, number of errors, and tolerance times (the time in seconds that the participant immersed his hand in cold water) were recorded. Participants also reported the level of distraction of the cognitive intervention and the level of distraction by pain (NRS). In case a participant withdrew his hand from the water before the maximum time had elapsed during the distraction condition, the cognitive task was terminated. Questionnaires used in experiment II were the Pain Anxiety Symptom Scale-20 [42], and the PCS [39].

In this second experiment, two counterbalanced sequences of conditions were possible: the pain baseline condition, followed by the cognitive baseline condition and the distraction condition; or the distraction condition, followed by the baseline cognitive condition and the pain baseline condition. These sequences were chosen to avoid two subsequent conditions with a painful stimulus, which might influence the second condition. Nonetheless, with these two sequences we could still randomize the orders of the baseline and distraction conditions. For half of the participants, the baseline condition preceded the distraction condition (e.g. cognitive baseline preceded the distraction condition), whereas for the other half of the participants this was reversed (e.g. distraction preceded the cognitive baseline condition; the same was the case for pain). The procedure took about 25 min for each participant.

Data preparation

Data preparation was similar to data preparation in experiment I. Reaction times and accuracy rates were calculated. In our main analysis, we included data from all participants. In subsequent, exploratory analyses, participants were divided in two groups based on tolerance time: one group who completed the task and one group who withdrew before 3 min had elapsed. Furthermore, some participants completed a very low number of trials before withdrawing their hand, which may reduce the validity of the task measurements. We therefore repeated the analyses while only including those participants who completed at least 20 trials.

Statistical analysis

Data of pain scores were normally distributed. Normality was also acceptable following double square root transformation of the reaction time measures. RM-ANOVAs with condition (baseline, distraction) as within-subjects variable were conducted to study differences in pain scores and reaction times between the baseline condition and the distraction condition. Because of severe non-normality of the accuracy scores, these scores were analyzed using Wilcoxon-signed-rank test.

Finally, Spearman rank correlations (two-tailed) were used to analyse the relationship between the delta outcome scores (for pain, reaction times and accuracy), the pain questionnaires and the subjective distraction ratings $\text{distraction}_{\text{pain}}$ and $\text{distraction}_{\text{cognition}}$. Spearman rank correlations (one-tailed) were also calculated for the relationship between baseline pain (VAS score) and delta reaction times and accuracy, and for the relationship between baseline reaction times and accuracy and delta pain (based on the VAS).

Results

Descriptives

Fifty eligible volunteers were included after screening, including 7 men and 43 women (86.0%). Mean age of the participants was 20.5 ± 1.4 years (range 19–25). In one participant reaction times and accuracy rates were not recorded due to a technical failure; therefore, this subject was excluded from data analysis of cognitive performance. Eleven participants did not complete the questionnaires, and they were not included in the analyses of the personal characteristics related to these questionnaires.

Twenty-eight participants (57.1%) completed the baseline pain condition to the predefined maximum tolerance time of 3 min, and 27 participants (55.1%) the distraction condition. Mean pain tolerance time was $136.02\text{s} \pm 58.18$ during the baseline pain condition and $132.33\text{s} \pm 60.7$ during the distraction condition.

Primary analyses

Mean scores and standard deviations are summarized in Table 3. Engaging in a cognitive task did not significantly influence pain scores ($F(1, 48)=1.78$, $p=0.19$, $\eta^2_p=0.04$), showing similar pain ratings during the baseline and the distraction condition. No significant effect of pain on reaction times was found ($F(1, 48)=0.11$, $p=0.75$, $\eta^2_p<0.01$). However, accuracy levels were significantly lower in the painful distraction condition compared to the baseline cognitive condition ($Z=-4.68$, $p<0.01$). Our exploratory analyses, based on tolerance time, did not show differences in results between participants who completed the task and participants who withdrew before 3 min had elapsed; in both groups results were similar to those of the entire group of participants.

Table 3: Cognitive performance and pain ratings of the participants in the baseline and in the distraction condition. (Experiment II).

Variable	Baseline condition	Distraction condition	F-value/ Z-value	p-value
VAS pain score (mean (SD), n=50)	6.13 (2.29)	5.88 (2.30)	1.48	0.19
Reaction time (median (IQR), n=49)	380.51 (133.83)	394.98 (129.76)	0.11	0.75
Accuracy (median (IQR), n=49)	0.93 (0.10)	0.90 (0.12)	−4.68	<0.01
$\text{Distraction}_{\text{cognition}}$	–	5.54 (2.17)	–	–
$\text{Distraction}_{\text{pain}}$	–	5.70 (1.99)	–	–

VAS: visual analogue scale.

Table 4: Correlational analysis of the delta outcome scores, pain questionnaires and subjective distraction ratings. (Experiment II).

	Δ Pain ¹	Δ Reaction time ²	Δ Accuracy ²
Δ Pain	–	–0.07	0.13
PASS-20 ³	–0.11	0.03	0.01
PCS ³	–0.00	0.15	0.01
Distraction _{cognition}	–0.11	–0.06	0.15
Distraction _{pain}	0.26	0.06	–0.34*

PCS=Pain catastrophizing scale, PASS=Pain Anxiety Symptom Scale
n=50, 2 n=49, 3 n=39.

Repeating the analyses while only including those participants who completed at least 20 trials, also did not influence the results.

Correlations

Results of the correlational analyses are displayed in Table 4. No significant correlations were found of the delta pain scores with the delta reaction times or delta accuracy. For delta pain, accuracy and reaction times, no significant correlations with the pain-related questionnaires were found.

Delta accuracy was significantly correlated with distraction_{pain}; an increase in the perceived distraction caused by pain related to lower cognitive performance levels during the distraction condition. Finally, baseline accuracy or reaction time performance was not related to delta pain ($\rho=0.06$, $p=0.33$ and $\rho=-0.01$, $p=0.49$ respectively), and vice versa (baseline VAS pain and delta accuracy $\rho=-0.16$, $p=0.14$ and delta reaction times $\rho=0.19$, $p=0.09$ resp.); suggesting that higher baseline pain sensitivity is not associated with a larger distracting effect of pain on cognitive task performance, or that worse cognitive performance at baseline is not associated with a stronger pain reduction effect in the distraction condition.

General discussion

This exploratory study investigated the interaction between pain and cognition, and the influence of task complexity and pain intensity on this interaction. First, with regard to the interaction between pain and cognition, in experiment I a decrease of pain scores due to cognitive distraction was found. Pain did, however, not affect cognitive performance. Some evidence was found suggesting that effects were strongest for the task with the highest cognitive load: only for this task did baseline cognitive performance predict the pain reducing effect during distraction, and numerically this task induced the greatest pain reducing effects (although this

latter effect was not significantly different from the pain reducing effects by the other load tasks). Using a more intense painful stimulation, in experiment II we did find that pain significantly reduced accuracy rates, but this time no significant effect of cognitive distraction on pain perception was found. As such, we were unable to confirm the interaction between pain and cognition within a single study population.

Previous studies on this topic have shown conflicting results. In line with our results, one study reported no simultaneous interaction between pain and cognition [27]. Contrastingly, Buhle and Wager (2010) reported lower pain scores during a working memory task compared to a control condition, and simultaneously reduced cognitive performance during painful stimuli, indicating a concurrent bidirectional relationship between pain and cognition [4]. However, comparisons with our study results should be interpreted with caution, since performance levels in that study were not measured in a baseline condition without a painful stimulus. In addition, we have not manipulated pain intensity levels or cognitive load at a within-subjects level, which may be needed to truly detect the bidirectional relationship, as was the case in the study by Buhle and Wager [4].

The results of this study did not meet our predefined hypotheses. An explanation for our findings could be that pain and cognition share overlapping cognitive resources, and attention might be divided to a certain extent. The distribution of attention might depend on the degree of salience or importance of both the pain stimulus and the distracting stimulus [4, 24, 43, 44]. Pain is a biological warning signal which involuntary captures attention: the perception of a pain stimulus with high pain intensity requires a large amount of cognitive capacity [24, 43]. In experiment II, during which the pain stimulus was adapted in such a way that it was more painful, this stimulus strongly decreased cognitive performance, reflected in accuracy levels. Vice versa, particularly high load cognitive tasks might be effective to distract from pain, since these tasks also require a large amount of cognitive capacity. Albeit non-significant, findings from experiment I seem to support this assumption, as the largest pain reducing effects were observed in the task with the highest cognitive load. Moreover, only in the high load cognitive task did baseline performance predict the reduction in pain during the distraction condition, which may suggest that when more attention is needed to perform the cognitive task (reflected by worse cognitive baseline performance), its pain reduction effect during distraction is larger. Therefore, particularly high load tasks might be suitable to demonstrate the interaction between pain and cognition [4, 12, 45].

Taken together, our findings suggest that priorities are shifting, at the moment the level of pain exceeds a certain threshold: cognitive distraction from pain might be possible

up until a certain intensity of pain is experienced, i.e. a mild to moderate pain can be reduced by distraction, whereas the perception of a moderate to severe pain stimulus cannot be modulated by cognitive distraction. This hypothesis in accordance with the statements on pain and distraction by McCaul and Malott, who concluded that distraction was more effective for pain stimuli of low intensity, whereas it was less effective for intense pain stimuli [46]. Our hypothesis is further supported by the methodology of the experiments: the main difference between experiment I and II was the intensity of the pain stimulus (i.e. longer duration and colder water temperature in experiment II). Except for an adjustment in the number of possible sequences of conditions, no other factors that might have explained our results were changed during the second experiment.

Remarkably, we found only very little evidence for the influence of personal and pain-related characteristics on the relationship between pain and cognition. Pain catastrophizing, pain anxiety, fear of pain and pain coping strategies, measured with validated questionnaires, did not relate to the distracting effect of pain on cognition or to the effect of performing a cognitive task on pain experience [37–39, 42]. This is in contrast to previous studies reporting that individuals with high levels of pain catastrophizing or pain anxiety are less susceptible for the analgesic effects of distraction [32–34, 47, 48]. The perceived distraction of the painful stimulus during the combined condition significantly affected accuracy rates in experiment II, however this effect was not found in experiment I.

The pain stimulus that was used, induced by the cold pressor test, is a potential limitation of this study. This pain stimulus might have been not intense enough to study the distractive nature of pain on cognitive performance, as was the case in experiment I. The cold pressor test also offers a possibility to escape from pain, by withdrawing the hand from the water. This possibility to escape, or the knowledge that the pain stimulus ends within a few minutes, is different from clinical pain patients, for whom pain is a continuous factor. Exploration of our study concept, i.e. investigating the relationship between pain and cognition bidirectionally in the same study population, in patients with pain might give further information about the relationship between pain perception and cognitive processes in clinical pain conditions. Furthermore, varying levels of both pain and cognitive load within a subject could provide more insight in the bidirectionality of the interaction at individual level; instead of a between groups level, as in this study.

Finally, it should be noted that accuracy levels of our cognitive tasks, including the presumed high load task, were very high. This indicates that ceiling effects were

present for our tasks, and that therefore our study might underestimate the true attentional distraction that a more difficult cognitive task could provide in distracting attention away from pain. Likewise, the interruptive effects of pain may be stronger in case the cognitive task is more difficult, as it requires more cognitive resources for intact performance, making it more sensitive to disruption via pain. Our study results should therefore be interpreted with caution, and further studies are needed that incorporate more difficult tasks (to have a more proper distribution of accuracy rates) as well as a more broader range of different cognitive tasks including those sensitive to disruptions in attention (such as the Paced Auditory Serial Addition Test) [9].

Conclusions

In conclusion, the results of this study suggest a two-way relationship, however no evidence for a bidirectional interaction was found: at a group level, the analgesic effect of cognitive distraction on pain perception and the negative influence of pain on cognitive performance did not occur at the same time. Cognitive distraction successfully reduces pain, up until a certain point where this relationship is reversed, and pain starts to interfere with cognitive performance. This may imply that priorities shift at the moment the level of pain exceeds a certain threshold. This study could contribute to further understanding of cognitive processes and mechanisms related to pain perception.

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