Universiteit Twente

The Influence of pain on attention: Influence of electrocutaneous stimuli on N-back task performance

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1. English Summary

The present experiment studied the effect of task-irrelevant distractive nociceptive stimuli on task performance in a 2-back and 3-back matching task. During the task participants were presented with an irrelevant electrocutaneous stimulus at 50% of the match- and non-match-trials. Participants were tested for their task performance, measured in reaction time and error percentage. In each trial stimuli were offered at memory consolidation, memory retrieval, both (consolidation and retrieval) or no stimuli were offered at all.

It was expected that task-irrelevant distractive nociceptive stimuli have a detrimental effect on task performance and that this effect would be less under high attentional load compared to low attentional load.

Analysis showed no significant effect of task-irrelevant distractive nociceptive stimuli on task performance in the N-back task. When having a closer look at the working memory processes of memory consolidation and memory retrieval, there was no difference in effect between the four stimuli conditions. Task performance did not differ among the conditions. The hypothesis that the detrimental effect of nociceptive stimuli on task performance would be less under high attentional load compared to low attentional load was not confirmed. A main effect was found for task-difficulty, showing that reaction times were higher for 3-back tasks than for 2-back tasks, which is the standard effect between 2-back and 3-back tasks.

The results can be explained in terms of bottom-up stimuli features such as intensity, novelty and dissimilarity between distractors and targets. Explanations can also come from top down 2-back and 3-back task demands or the experimental design that used pain stimuli of short duration versus continuous pain stimuli of long duration.

2. Dutch Summary

In dit experiment is het effect van taak-irrelevante pijnlijke distractor stimuli op prestaties in een 2-terug en een 3-terug taak onderzocht. Tijdens de taak kregen de participanten in 50% van match- en non-match-trials een irrelevante electrocutaneous stimulus toegediend. De participanten werden getest op hun taak prestaties, gemeten in reactietijd en accuratesse. In elke trial werd een stimulus aangeboden tijdens geheugen consolidatie, geheugen retrieval, zowel consolidatie als retrieval of er werd helemaal geen stimulus aangeboden.

De verwachting was dat de pijnstimuli een negatief effect op taak prestaties zouden hebben en dat dit effect minder zou zijn bij een hoge aandachts belasting dan bij een lage aandachts belasting.

De analyse liet geen significante effecten van taak-irrelevante pijnlijke distractor stimuli op N-terug taak prestaties zien. Er zijn ook geen verschillen in taak prestaties gevonden voor de vier verschillende stimuli condities betreffende de consolidatie en retrieval processen van het werkgeheugen. De hypothese dat het negatieve effect van pijn stimuli op taak prestaties minder zou zijn bij een hoge aandachts belasting dan bij een lage aandachtsbelasting is niet bevestigd. Er is een hoofdeffect gevonden voor taak moeilijkheid, reactietijden waren hoger voor 3-terug taken dan voor 2-terug taken. Dit is het standaard effect tussen 2-terug en 3-terug taken.

De resultaten kunnen verklaard worden aan de hand van bottom-up stimuli eigenschappen zoals intensiteit, nieuwheid en het verschil tussen distractors en targets. Verklaringen kunnen ook gevonden worden in top-down 2-terug en 3-terug taak belasting en de experimentele opzet van het experiment, waarbij gebruik is gemaakt van pijn stimuli van korte duur in tegenstelling tot continue pijn stimuli van langere duur.

3. Introduction

Pain is usually an unpleasant sensory experience, often paired with possible tissue damage. It is a biological safety mechanism; pain warns individuals when something is threatening by motivating individuals to direct attention to the possible danger and make attempts to stop it (Marks, Murray, Ewans, Willig, Woodall & Sykes, 2005; Kalat, 2007). Because attention is directed towards pain, attention towards ongoing activities might be disrupted (Melzack & Wall, 1988).

The disruptive effect of pain is documented by a number of studies by revealing that the delivery of a nociceptive "pain" stimulus deteriorates the performance of a pain-unrelated task (e.g. Vancleef & Peters, 2006a). In a study by Legrain, Perchet and Garcia-Larrea (2009) participants were instructed to pay attention to the visual stimuli (a number of Xs) and to count the number of Xs on each stimulus. Participants were encouraged to disregard nociceptive laser stimuli delivered throughout the task and to focus on the visual task. Their data showed that nociceptive processing competes with pain-unrelated cognitive activities for attentional resources and that the occurrence of nociceptive events during cognitive tasks affects behavior by decreasing attention allocation to ongoing cognitive processing. Studies by Van Damme, Legrain, Vogt and Crombez (2010) have demonstrated that attention determines how a nociceptive stimulus will be perceived. These results imply that attention is an important factor in studying the effect of nociceptive stimuli.

This study will examine the effect of distractive nociceptive stimuli on attention. Attention is controlled by two main control mechanisms. The first is top-down control of selective attention; this is a goal directed operation allowing for selectively processing information that is relevant to current cognitive goals (Corbetta & Shulman, 2002). In our experiment top-down selective attention is directed at the task at hand. The second control mechanism is bottom-up capture of selective attention; this is a mechanism by which

attention is shifted away from its current focus towards a stimulus that is sufficiently salient to modify cognitive priorities, even though it is unrelated to ongoing activities (Knudsen, 2007; Egeth & Yantis, 1997). This is particularly the case for stimuli that signal a potential danger for the individual, such as nociceptive stimuli. Further studies have shown that the salience and relevance of the stimuli, and not only pain per se, determine how attention is captured by the bottom-up mechanism (Legrain et al., 2009; Legrain, Iannetti, Plaghki & Mouraux, 2011). In addition to salience and relevance, novelty is known to be one of the most determinant factors to capture attention in a bottom-up way (Escera & Corral, 2007).

Another important factor in controlling the attention paid to a nociceptive stimulus is attentional load. Attentional load refers to the effort in terms of resource allocation that should be made to achieve goals adequately (Legrain, Van Damme, Eccleston, Davis, Seminowicz & Crombez, 2009). Attentional load is generally increased by task difficulty and their demands in terms of attentional resources allocation. Research shows that suppression of somatosensory distraction could be attributed to the specific involvement of working memory, independently of the attentional overload induced by task demands (Legrain, Crombez & Mouraux, 2011). This implies that the amount of attention paid to a cognitive task has an effect on the perception of nociceptive distractor stimuli. In studying the effect of distractive nociceptive stimuli on attention, this study will look at the effect under different attentional loads.

One way to operationalize attentional load is by introducing the term of working memory. According to Purves, Brannon, Cabeza, Huettel, Labar, Platt and Woldorff (2008) working memory is closely related to attention and is in fact sometimes considered to be a special category of attention that operates on internal representations rather than on the perceptual input. Working memory refers to the maintenance and manipulation of information for a brief period of time in order to achieve specific goals. It is assumed to

actively hold information and perform manipulations, that is, operations that organize, associate and transform the representations held in working memory. By manipulating working memory load it is possible to examine the effect of different attentional loads.

There are numerous ways to operationalize working memory; one of the most popular measures of working memory is the N-back task (Conway, Kane, Bunting, Hambrick, Wilhelm & Engle, 2005; Kane & Engle, 2002). The reason to prefer the N-back task over other traditional working memory span tasks lies in the appealing way to manipulate working memory load (Conway, Kane, & Engle, 2003). Working memory load can be varied by using 1-back, 2-back, 3-back or 4-back tasks, where 1-back tasks have the lowest load and 4-back tasks have the heaviest load. In N-back tasks, subjects must indicate whether each letter in a continuous stream of letters matches the letter presented one, two, three, four or more letters back in the series. This is thus a form of memory recognition; after having experienced the previous letters you will need to recognize if the present letters match the previous ones or not. Compared to simple delayed response and recognition tasks, N-back tasks are assumed to be more dependent on modification of the working memory store. With each new item presented, participants must incorporate the new item into working memory and drop the older item. This updating process is thus a form of working memory manipulation (Purves et al., 2008, p.411).

As explained above the N-back task is useful because attentional load can easily be manipulated. In relation to the N-back task, attentional load refers to task-difficulty. Another important factor in the control of attention paid to a nociceptive stimulus is the attentional set, referring to the mental set of stimulus features that are relevant to achieve ongoing cognitive goals (Legrain et al., 2009). In relation to the N-back task the attentional set refers to the goal of good performance on the task. This can also be seen as the top-down control mechanisms

in the N-back task. The bottom-up stimulus features in the attentional set will be the letters on the screen (Folk, Remington & Johnston, 1992).

Nociceptive distractor stimuli capture attention from a bottom-up perspective and as a result N-back task reaction times and accuracy are modulated by these nociceptive distractor stimuli. These effects can be reduced by working memory. For example, SanMiguel, Corral and Escera (2008) used auditory stimuli to distract participants from a 1-back working memory task. Their results showed that distraction caused by irrelevant novel sounds is reduced when a working memory component is involved in the task. This indicates that working memory can reduce involuntary shifts of attention towards irrelevant distractors. Load theory suggests that working memory controls the extent to which irrelevant distractors are processed (Lavie, Hirst, De Fockert & Viding, 2004). All this implies that the availability of working memory is important for the successful control of attention.

Working memory consist (among other mechanisms) of two memory mechanisms; memory consolidation and memory retrieval. Consolidation is the process of transforming a perceptual representation into a durable working memory representation that can survive the presentation of new sensory inputs. The consolidation process has been assumed to be highly capacity limited and very slow, with some theorists proposing that it takes as much as 500 ms to store a single item in working memory (Chun & Potter, 1995; Enns & Di Lollo, 1997; Jolicoeur & Dell'Acqua, 1998; Miller, Li & Desimone, 1993). However these estimates have been inferred primarily from dual-task paradigms and these paradigms may overestimate the duration of consolidation, other research showed that the rate of consolidation is approximately 50 ms per item, which is considerably faster than previous proposals (Vogel, Woodman & Luck, 2006). By retrieval we mean the recovery or accessing of memory traces (Purves et al., 2008, p.46). There are different types of memory retrieval; the one used in this

study is that of memory recognition, which involves identifying information after experiencing it again (Ashcraft, 2006).

The present study will examine the effect of task-irrelevant distractive nociceptive stimuli on task performance in an N-back task. The N-back task is used because attentional load can easily be manipulated. It is expected that task-irrelevant distractive nociceptive stimuli capture attention from a bottom-up perspective and have a detrimental effect on task performance. When attentional load is high there will be less bottom-up capture of attention by task-irrelevant distractive nociceptive stimuli, than when attentional load is low. Working memory is used to operationalize attentional load. Because it is interesting to gain insight into which processes of working memory are affected by task-irrelevant distractive nociceptive stimuli, the study focuses on the two mechanisms of memory consolidation and memory retrieval. These two mechanisms lead to four different conditions of moments at which the stimuli can be offered. The first condition is the baseline for analysis in which no stimuli are offered during consolidation and retrieval. In the second condition a stimulus is offered during consolidation, but not during retrieval. The third condition will be the opposite of the previous condition; a stimulus will be offered during retrieval, but not during consolidation. In the fourth condition a stimulus will be offered during both consolidation and retrieval. A relatively small detrimental effect of task-irrelevant distractive nociceptive stimuli on task performance is expected in conditions two and three where stimuli are only offered during consolidation or retrieval. This effect will be compared to the baseline condition in which no stimuli are offered during consolidation and retrieval. A larger effect is expected for condition four where stimuli are offered during both consolidation and retrieval.

4. Method

4.1. Participants

In total 25 healthy subjects participated in the experiment, which lasted about 45 minutes for each participant. Participants with an error percentage above 50% were excluded from the dataset. The age of the remaining 24 participants ranged from 19 at a minimum to a maximum of 28 years. The mean age was 22.2 years. 10 of the 24 participants were female and 14 were male. Furthermore, one of the participants was left-handed, one showed ambidexterity and the rest of the participants were right-handed. It should also be noted that 3 participants were colorblind and that one participant had dyslexia, but this had no effect on task performance.

Before starting the experiment, participants were asked to read an information brochure with information on the task. All participants signed an informed consent form. The procedure used in this study was checked and approved by the METC of MST, Enschede, The Netherlands (project no. NL31474.044.11/P11-11).

4.2. Procedure

Before the experiment, participants completed a handedness inventory and the “Thayer mood scales” the latter was also completed after the experiment. In this mood questionnaire they had to indicate on an 11 cm scale ranging from “absolutely not” to “very much” how strongly they felt certain emotions such as “excited” or “fearful”. These scales were used to find out if the task or the stimuli have an effect on the participant’s moods (Thayer, 1989).

The stimuli were evoked by a constant current stimulator Digitimer DS5 (Digitimer, Welwyn Garden City, UK). A stainless steel concentric bipolar needle electrode developed by Inui, Tran, Hoshiyama and Kagiki (2002; Inui, Tsuji & Kagiki, 2006), consisting of a

needle cathode surrounded by a cylindrical anode, was placed on the left arm of the participants regardless of the handedness of the participant.

To account for individual differences in pain experience, three thresholds were identified before the beginning of the experiment: the sensation threshold, the pain detection threshold and the maximal pain the participant would tolerate during the experiment. Every threshold was measured three times with 5-pulse stimuli, with current amplitude increasing by steps of 0.1 mA starting at zero. First the pain detection threshold was measured. Participants were instructed to press the space bar when their personal pain detection threshold was reached. The pain detection threshold had a mean of 1.02 mA (SD 0.62). Secondly, the sensation threshold was measured; participants pressed the space bar when their personal sensation threshold was reached. The sensation threshold had a mean of 0.42 mA (SD 0.12). The maximal pain the participant would tolerate during the experiment was the last threshold to be measured. Again participants pressed the space bar when they reached the maximal pain they would tolerate during the experiment. The maximal pain the participant would tolerate during the experiment had a mean of 1.35 mA (SD 0.89).

Before the experiment and after each block a measurement of the pain experience was conducted. Two 1-pulse, two 3-pulse and two 5-pulse stimuli were presented in random order. Participants were asked to rate the intensity of the stimuli by using a visual analogue scale (VAS-scale). This scale was used to measure subjective attitudes by asking participants to indicate their level of agreement by marking a position on a continuous line. The scale ranged from “no sensation” to “extreme pain”. These measurements were used to follow possible changes in pain perception of the participants as the experiment continued.

4.3. Task

A standard N-back letter task was used in this experiment, with 2000ms between each letter. Participants had to focus on the middle of a computer screen where the letters would appear at a fixation point. All letters of the alphabet were used, except for the letters A, E, I, O and U. For example (in a 2-back task), the letter S appeared and stayed for 200ms and then disappeared. The next letter that appeared was the letter B. It was a match trial if after the letter B, the letter S appeared again. Every other letter would have been a non-match trial (see Figure 1). Using two keys (n=non-match; m=match), participants had to indicate if the trial was a match or a non-match trial.

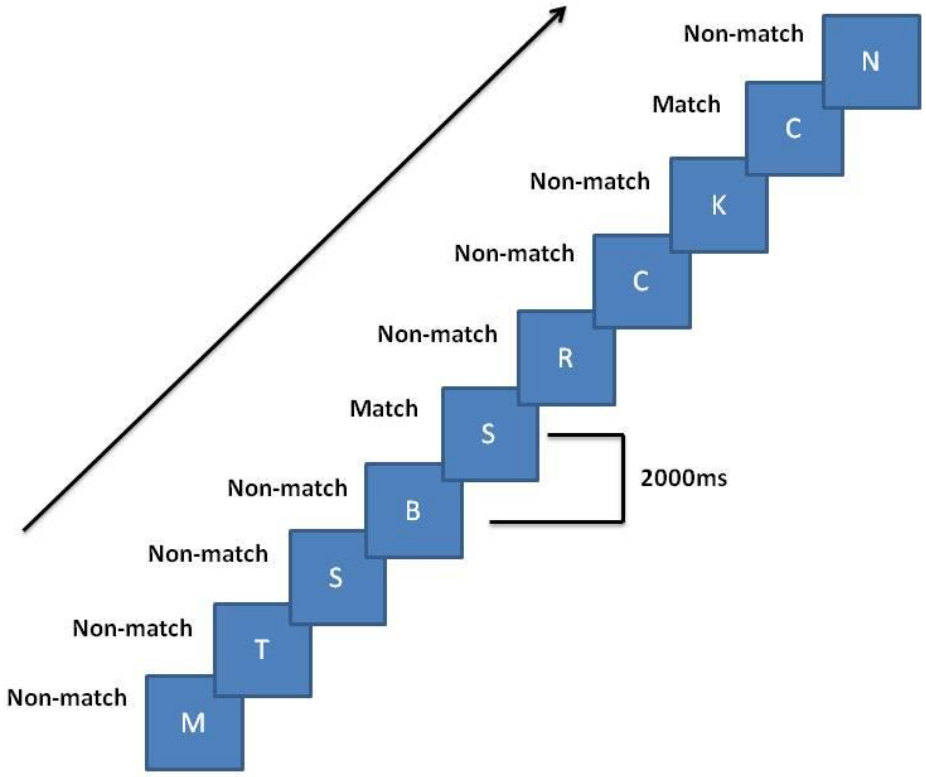

Figure 1. *Example of a part from a 2-back task sequence. The figure shows the correct response for each letter in the sequence that appeared 2000ms after the previous letter.*

Each participant completed a practice block before the experimental blocks started. The practice block consisted of three 2-back and three 3-back practice sequences.

There were two experimental blocks; one 2-back block and one 3-back block. The 2-back and the 3-back blocks consisted of 12 sequences of letters. These sequences contained 21 trials per sequence. 1/3 of these trials were match-trials and 2/3 were non-match trials. The 3-back tasks were considered to have a heavier attentional load than 2-back tasks. 2-back and 3-back blocks were counterbalanced.

During the experiment participants were presented with an irrelevant electrocutaneous stimulus at 50% of the match- and non-match-trials. The nociceptive stimuli were always 5-pulse intensity stimuli; consisting of the individual level of maximal pain that the participant would tolerate during the experiment, measured before starting the experiment. Stimuli could be presented at two moments in each trial; during memory consolidation and/or during memory retrieval. Nociceptive stimuli during consolidation were presented right after a letter disappeared from the screen. Nociceptive stimuli during retrieval were presented at the same time a letter appeared on the screen. Stimuli were never offered at consolidation or retrieval of the first letter of each sequence.

4.4. Data-analysis

Task performance was measured in response accuracy and reaction time. Response accuracy was measured by the percentage of errors (error score) made by each participant in each of the four conditions. Reaction time was measured by the mean reaction times for response speed for each participant at each of the four conditions of the 2-back and 3-back tasks (excluding incorrect responses, anticipated responses [RT<100 ms], and missed responses [RT>2000 ms]).

Analyses of reaction time and error scores were done using repeated measures ANOVA with two within-subject factors. These within-subject factors were *condition*, which had four levels (no stimuli, consolidation, retrieval and consolidation + retrieval) and *task-difficulty*, which had two levels (2-back and 3-back). Additional contrast analysis was used when appropriate. Significance level was set at $p<0.05$.

Scores on the VAS-scales were analyzed to see if there were changes in participant's pain perception as the experiment went on. The means of the pain perception measurements of pain perception before the experiment and after every block were calculated and then compared using repeated measures ANOVA. Hereby, the stimulus intensity with three levels (1-pulse, 3-pulse, and 5-pulse) and the time with three levels (before the experiment and after the two blocks) acted as within-subject factors. Contrast analysis was used for further analysis when appropriate.

Thayer mood scales were analyzed using a paired samples T-test to assess if participant's moods were significantly different before and after the experiment.

5. Results

5.1. Thayer mood scales

Mean scores and standard deviations were computed for the Thayer mood scales and are shown in Table 1.

Table 1. *Mean scores and standard deviations from the Thayer mood scales*

	Mean	Std. Deviation		Mean	Std. Deviation
tense before	25,04	20,36	tense after	28,13	19,85
positive before	82,96	13,05	positive after	77,03	15,99
excitable before	27,58	19,06	excitable after	30,81	20,04
excited before	38,25	18,58	excited after	38,60	21,39
relaxed before	69,98	17,87	relaxed after	66,38	21,93
tired before	42,73	20,03	tired after	42,31	18,63
indifferent before	38,94	22,01	indifferent after	37,96	20,09
fearful before	18,75	16,31	fearful after	15,50	11,71
cheerful before	74,02	16,22	cheerful after	76,31	14,42
energetic before	60,88	17,71	energetic after	63,06	17,58

Analysis of the Thayer mood scales showed that participants were more positive before the experiment than after the experiment ($p = 0.007$). The other difference scores showed no significant changes ($p > 0.136$) (see Table 2).

Table 2. *Results of a paired samples T-test of the Thayer mood scales. The table shows mean difference scores and standard deviations from the Thayer mood scales and t-values and the significance level of the difference scores.*

Pair	Mean	Std. Deviation	t	Sig.
tense before - tense after	-3,08	21,22	-,712	,484
positive before - positive after	5,93	9,77	2,974	,007
excitable before - excitable after	-3,23	16,06	-,985	,335
excited before - excited after	-,35	18,05	-,096	,924
relaxed before - relaxed after	3,60	23,03	,767	,451
tired before - tired after	,42	18,71	,109	,914
indifferent before - indifferent after	,98	15,53	,309	,760
fearful before - fearful after	3,25	10,31	1,544	,136
cheerful before - cheerful after	-2,29	10,99	-1,021	,318
energetic before - energetic after	-2,19	16,18	-,662	,514

5.2. VAS-scales

Repeated measures ANOVA showed a main effect of time ($F(2,46) = 53.27$, $p < 0.0005$), indicating that VAS-scores were not the same at each time. Furthermore a significant main effect of stimulus intensity ($F(2,46) = 120.66$, $p<0.0005$) was obtained, showing that mean VAS-scores were not the same for each intensity. Interaction effect of time and intensity was not significant ($F(4,92) = 1.32$, $p = 0.268$).

Contrast analysis for relevant main effects confirmed that the differences between all three levels of time were significant and linear ($p<0.0005$). The differences between the three levels of stimulus intensity were also significant and linear ($p<0.0005$). Repeated contrast

analysis and mean VAS-scores showed that VAS-scores were higher after block 1 than before the experiment and higher after block 2 than after block one. VAS-scores were higher for 3-pulse stimuli than for 1-pulse stimuli and higher for 5-pulse stimuli than for 3-pulse stimuli.

In the 1-pulse trials the mean of the intensity scores was 2.8 before and 1.0 after the experiment. For the 3-pulse scores the mean went down from 5.5 before and 3.1 after the experiment and the mean for the 5-pulse scores dropped from 6.1 before to 4.5 after the experiment.

It can be concluded that pain perception was lowest for 1-pulse stimuli and highest for 5-pulse stimuli and that pain perception decreased after each block. Results can be seen in Figure 2.

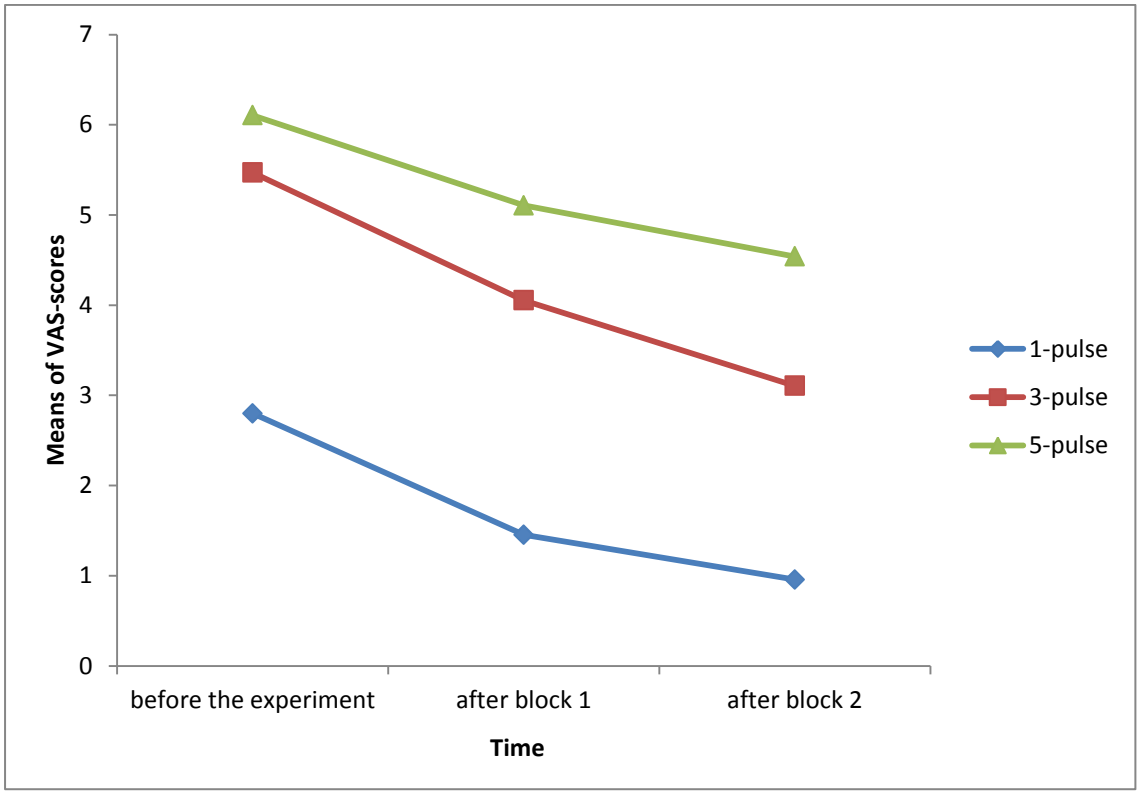

Figure 2. *Main effect of VAS-scores. Mean VAS-scores obtained through measurements before the experiment and after each block. The different lines show mean VAS-scores for 1-pulse, 3-pulse and 5-pulse stimulus intensity. VAS-scores were lowest for 1-pulse stimuli and highest for 5-pulse stimuli. VAS-scores decreased after each block.*

5.3. Reaction Time (RT)

Repeated measures ANOVA showed a significant main effect for task-difficulty ($F(1,23) = 4.387$, $p = 0.047$, which means that mean reaction times were not the same for 2-back and 3-back tasks. No main effect was found for condition ($F(3,69) = 0.257$, $p = 0.856$, indicating that mean reaction times did not differ among conditions. Analysis also showed no interaction effect between task-difficulty and condition ($F(3,69) = 0.241$, $p = 0.868$).

Contrast analysis of the task-difficulty main effect confirmed the significant linear main effect of task-difficulty. Simple contrast analysis showed no significant differences between the condition where no stimuli were offered during consolidation and retrieval and condition two (($p = 0.758$), three ($p = 0.930$) or four ($p = 0.461$). Repeated contrast analysis and mean reaction times showed that reaction times were longer in 3-back trials compared to 2-back trials (see Figure 3).

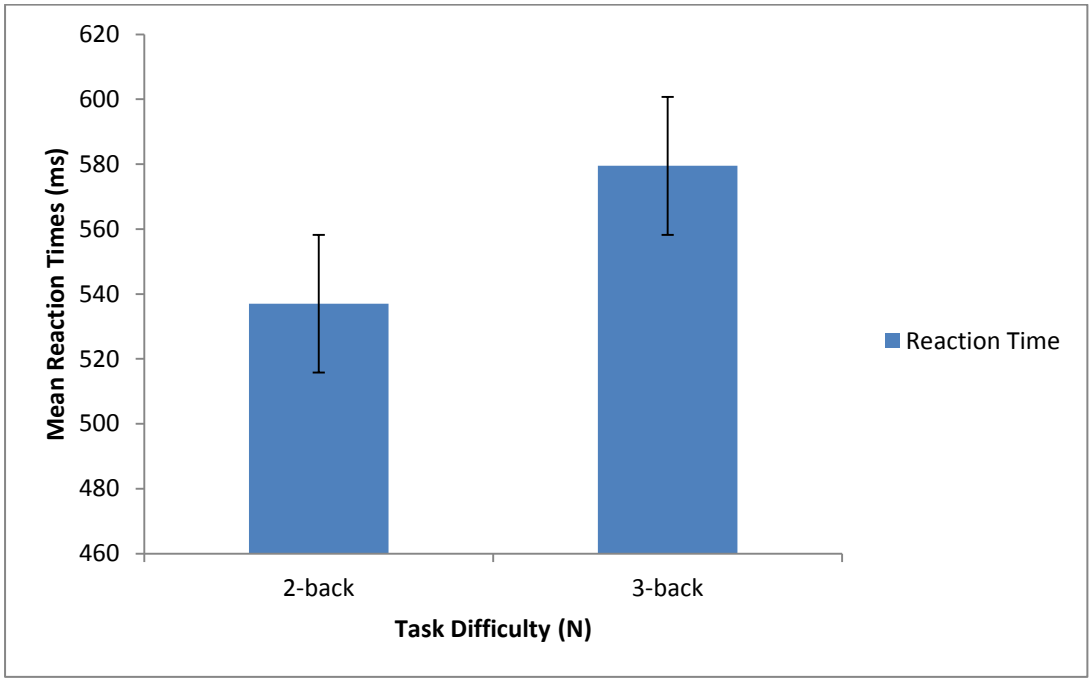

Figure 3. *Main effect of task-difficulty. Mean reaction times in ms for correct responses for 2-back and 3-back tasks. Standard error bars show the standard error for the two levels of task-difficulty. Reaction time was longer for 3-back tasks than for 2-back tasks.*

After the initial analysis another repeated measures ANOVA analysis was done. A new within-subject factor, *stimuli in between trials*, with two levels (no stimuli in between trials and stimuli in between trials) was added. Results showed no significant main effect for stimuli in between trials ($F(1,23) = 3.520$, $p = 0.073$), indicating that there was no convincing evidence that mean reaction times were different for the two conditions. Stimuli in between trials did not interact with task-difficulty ($F(1,23) = 3.251$, $p = 0{,}084$) or condition ($F(3, 69) = 2.686$, $p = 0.053$). There was no interaction effect between task-difficulty, condition and stimuli in between trials ($F(3,69) = 0.967$, $p = 0.414$).

5.4. Accuracy

Repeated measures ANOVA showed no significant main effect for task-difficulty ($F(1,23) = 4.434$, $p = 0.077$. Mean error scores were not significantly different among 2-back and 3-back tasks. Analysis also showed no main effect for condition ($F(3,69) = 0.704$, $p = 0.553$), indicating that mean error scores did not differ among the four conditions. Analysis also showed no interaction effect of task-difficulty and condition ($F(3,69) = 1.407$, $p = 0.248$).

The repeated measures ANOVA with the additional factor *stimuli in between trials* was done for accuracy as well. There was no significant main effect for stimuli in between trials ($F(1,23) = 1.027$, $p = 0.321$), indicating that error scores were not different for the two conditions. The results showed a significant interaction effect for task-difficulty and stimuli in between trials ($F(1,23) = 4.563$, $p = 0{,}044$), which means that the relation between task-difficulty and mean error scores is moderated by stimuli in between trials. No significant interaction effects were found for condition and stimuli in between trials ($F(3, 69) = 0.117$, p

= 0.950) and task-difficulty, condition and stimuli in between trials (F(3,69) = 1.841, p = 0.148).

Contrast analysis of the relevant interaction effect confirmed a linear significant interaction effect of task-difficulty and stimuli in between trials. Simple contrast analysis showed no significant differences between the condition where no stimuli were offered during consolidation and retrieval and condition two (p = 0.061), three (p = 0.355) or four (p = 0.507).

Figure 4 shows the interaction effect between task-difficulty and stimuli in between trials. It can be concluded that for 2-back tasks error scores were lower when stimuli were offered in between trials than when no stimuli were offered in between trials. The opposite effect was shown for 3-back tasks; error scores were lower when no stimuli were offered in between trials than when stimuli were offered in between trials.

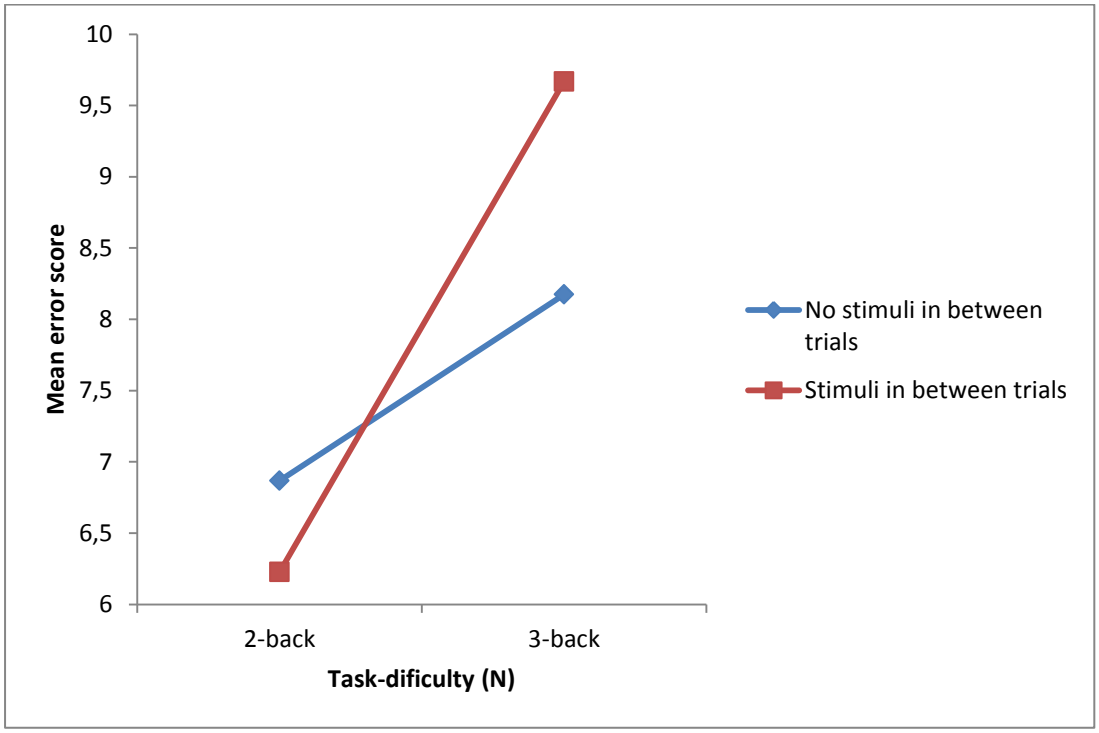

Figure 4. *The interaction effect of task-difficulty and "stimuli in between trials". Mean error scores obtained through measurements on 2-back and 3-back tasks. The two different lines show mean error scores for stimuli in between trials and no stimuli in between trials.*

6. Conclusions and Discussion

The present study examined the effect of task-irrelevant distractive nociceptive stimuli on task performance in a 2-back and 3-back task. Furthermore, it was examined which processes of working memory (consolidation and retrieval) are affected by task-irrelevant distractive nociceptive stimuli. It was expected that task-irrelevant distractive nociceptive stimuli have a negative effect on task performance. This negative effect was expected to be less when attentional load was high, than when attentional load was low. A relatively small negative effect was expected for the conditions in which nociceptive stimuli were offered during consolidation or retrieval, while a larger negative effect was expected for the condition in which nociceptive stimuli were offered during both consolidation and retrieval. Results showed no significant effect of task-irrelevant distractive nociceptive stimuli on task performance in either a 2-back or a 3-back task. The hypothesis that the expected negative effect of task-irrelevant distractive nociceptive stimuli would be less when attentional load was high, than when attentional load was low, was not confirmed. No significant differences in task performance were found between the four different stimuli conditions of working memory processes, which did not confirm the relevant hypothesis. A main effect was found for task-difficulty; reaction times were significantly higher for 3-back tasks than for 2-back tasks in all conditions. This is a standard effect between 2-back and 3-back tasks and it shows that the task used in the study was good and had a normal effect on reaction times. The same main effect was not found for accuracy, although it almost did reach the required level of significance.

The additional analysis, which compared *trials with no stimuli in between trials* and *trials with stimuli in between trials,* showed the opposite of what was expected. The results showed that for 2-back tasks (low attentional load) error scores were lower when stimuli were offered in between trials than when no stimuli were offered in between trials. The opposite

effect was shown for 3-back tasks (high attentional load); error scores were higher when no stimuli were offered in between trials than when stimuli were offered in between trials. Similar results were found by Dalton, Lavie and Spence (2009) who conducted two experiments to investigate the role of working memory in tactile selective attention. Participants had to focus on continuous target vibrations, while attempting to ignore pulsed distractor vibrations. Their experiments demonstrated increased interference by tactile distractors under high working memory load, compared to a low working memory load. This can be explained by reasoning that the availability of working memory is important for the successful control of tactile attention and also by the claim that working memory is important for the maintenance of task priorities, which would thus be impaired under high working memory load (e.g. Lavie, 2005; Lavie et al., 2004). The distractor stimuli used by Dalton et al. (2009) were in the same sensory (tactile) modality as the target stimuli, while the present study used more irrelevant distractor stimuli in a different sensory modality than the target stimuli.

Interestingly, no differences were found between the "baseline for analysis" condition, where no stimuli were offered during consolidation and retrieval and the other three conditions where stimuli were randomly offered during consolidation and/or retrieval. This implies that task-irrelevant distractive nociceptive stimuli have no effect on N-back task performance at all, which contradicts many previous findings (e.g., Legrain et al., 2009; Vancleef & Peters, 2006a). For example, research on distractive nociceptive stimuli by Legrain, Crombez, Verhoeven and Mouraux (2011) revealed that working memory can prevent distraction triggered by unexpected task-irrelevant novel nociceptive stimuli. It shows that working memory protects the processing of task-relevant pain-unrelated targets. When participants were working on an N-back task and were rehearsing the features of the

preceding visual targets, the occurrence of a novel nociceptive distractor was less able to disrupt ongoing behavior.

The findings of the present study can be explained from four different points of view. The first explanation comes from the N-back task itself and the goal-directed attention it demands. It can be argued that task demands in the 2-back and the 3-back tasks were too high and that attentional load was too high for nociceptive stimuli to capture attention and have an effect on task performance. Or in other words, top-down (goal directed) control over attention was too strong for bottom-up (stimulus-driven) control mechanisms to capture attention. Other studies are in line with this explanation. For example, Dalton et al. (2009) found that the availability of working memory is important for the successful control of tactile attention. It is well established that distractors are ignored more effectively when attentional load is high, than when it is low (e.g., Lavie, 1995). Research has also shown that when people are unable to use their full working memory capacity on the task at hand, they are more prone to interference by distractor stimuli (e.g., Lavie & de Fockert, 2005; Lavie et al., 2004). It can be suggested that in further experiments the 2-back or 3-back task should be replaced by a 1-back task, because it is less demanding.

The second explanation comes from the stimuli characteristics. In the section above, it was explained that top-down control of attention might have been too strong for a shift towards bottom-up control mechanisms. However, it could also be argued that the nociceptive stimuli were not strong enough to cause this stimulus driven shift towards bottom-up control of attention. Attentional interference by pain is larger when stimulus intensity is higher, when nociceptive stimuli are new and unfamiliar to the individual and/or when the nociceptive stimuli hold implicit or explicit threats (Vancleef & Peters, 2006a). It is possible that the intensity of the stimuli was too low to capture attention, but results from the VAS-scales show that the 5-pulse intensity stimuli were perceived above or around the pain

detection threshold and intensity should thus be high enough. A better account for the results can be found in the novelty of the nociceptive stimuli. Novel stimuli consist of events that were never presented before, i.e. new stimuli, or infrequently occurring events, i.e. deviant stimuli (Legrain et al., 2009). Novelty is acknowledged to constitute one of the most determinant factors to capture attention (Legrain et al., 2011; Escera & Corral, 2007). In the present study nociceptive stimuli of the same intensity were used throughout the whole experiment, which indicates that the nociceptive stimuli were not novel and thus not salient enough to capture attention (Legrain et al., 2009).

Closely related to stimulus intensity and novelty are habituation and desensitization effects. Since all the stimuli that were offered during the experiment were of the same intensity, participants might have got used to the feeling of pain and therefore did not perceive it as strongly as at the beginning of the experiment, this is known as the "habituation effect" (Melzack & Wall, 1988). Desensitization effects occur when participants do not perceive stimuli as strong as in the beginning, because their pain preceptors do not fire at the same rate anymore, because the stimuli were not perceived as an acute thread before. Results from the VAS-scales show that pain perception diminished significantly during the experiment, which shows that participants indeed did not perceive the nociceptive stimuli as strongly as in the beginning of the experiment. Randomly offering stimuli of different intensities might reduce these effects, which also enhances the novelty of the stimuli.

Another explanation regarding stimulus characteristics involves the exact moments at which the stimuli were offered. Maybe the division between consolidation and retrieval was not clear enough or maybe there were too many stimuli offered throughout the experiment. Stimuli were offered in 50% of the trials, which only strengthens habituation and desensitization effects and lessens novelty. The last explanation regarding the stimuli comes from studies that show that some type of distracters are not able to capture attention, because

they are too dissimilar from the target and can thus easily be ignored (Visser, Bischof & Di Lollo, 2004). Dell'Acqua, Jolicoeur, Sessa and Turatto (2006) found that distractors are more likely to capture attention if they share features with the target. It is thus possible that the nociceptive stimuli were too different and task-irrelevant compared to the target letters to capture attention. Because they were so irrelevant for the task, they could be ignored easily.

The third explanation might be found within the experimental design. This experiment used pain stimuli of short duration, while other experiments used more continuous distractors. A study by Veldhuijzen, Kenemans, de Bruin, Olivier and Volkerts (2006) used a cold pressor pain that was continuously present during the task. Other studies have shown that the capture by pain on attention is largest immediately after pain onset, after which the interruptive effect diminishes quickly (Crombez, Eccleston, Baeyens & Eelen, 1996; Crombez, Eccleston, Baeyens & Eelen, 1997; Crombez, Eccleston, Baeyens & Eelen, 1998a). Immediately upon pain onset, an automatic orienting reflex occurs and attention is captured by pain. After that a fast evaluation of the meaning and severity of the pain is made. When the result of this evaluation reveals that the pain is not threatening, attention will be devoted again to the task and performance will no longer suffer (Vancleef & Peters, 2006a). Due to its long duration a continuous stimulus might lose its meaningfulness and novelty to the participants earlier than pain stimuli of short duration, making it easier to distract from.

The fourth explanation might come from the participants. Several studies have demonstrated that attentional capture by pain is enhanced in persons with high levels of pain catastrophizing, fear of pain or somatic awareness (Crombez, Eccleston, Baeyens & Eelen, 1998b; Crombez, Eccleston, Van den Broeck, Van Houdenhove & Goubert, 2002; Crombez, Vlaeyen, Heuts & Lysens, 1999; Eccleston, Crombez, Aldrich & Stannard, 1997; Vancleef & Peters, 2006b). Analysis of the Thayer mood scales somewhat surprisingly showed that participants were not significantly more fearful before than after the experiment, even though

they knew they were to perceive pain. In addition to that, overall fear scores were considerately low. It is possible that this partly explains why nociceptive stimuli did not capture enough attention in the participants used in this study.

This study's finding that task-irrelevant distractive nociceptive stimuli have no effect on 2-back and 3-back task performance has been explained from four different points of view. The 2-back and 3-back tasks demands might have exerted too much top-down control over attention for bottom-up (stimulus driven) mechanisms to capture attention. Nociceptive stimuli might have been not strong enough to cause this stimulus driven shift towards bottom-up control of attention. Stimulus intensity could have been too low. Stimuli could have been not novel or familiar enough to capture attention. Explanations can also be found within the experimental design; pain stimuli of short duration were used instead of continuous pain stimuli of longer duration. The last explanation might be that participants did not fear pain enough for pain to capture attention in the participants used in this study.

A suggestion for further research would be to conduct experiments that not only use 2-back and 3-back tasks, but also 1-back tasks because these are less demanding. Other suggestions would be to use nociceptive stimuli that are of different intensities, novel, less frequent and more familiar to the target stimuli. Furthermore, the experimental design can be adapted to use stimuli of different durations.

To conclude, results showed no significant effect of task-irrelevant distractive nociceptive stimuli on task performance in either a 2-back or a 3-back task. The hypothesis that the expected negative effect of task-irrelevant distractive nociceptive stimuli would be less when attentional load was high, than when attentional load was low, was not confirmed. Results showed no insight into which processes of working memory are affected by task-irrelevant distractive nociceptive stimuli. Effects of task-irrelevant distractive nociceptive stimuli were not different in the baseline for analysis condition where no stimuli were offered during the

consolidation and retrieval, than in the three other conditions where stimuli were offered. The hypothesis that the negative effect of task-irrelevant distractive nociceptive stimuli on task performance would be larger when stimuli were offered during both consolidation *and* retrieval processes than when stimuli were offered during consolidation *or* retrieval processes was not confirmed.

7. References

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