

Title: “The interruptive effect of pain in a multi-task environment: an experimental investigation”

Short running title: “Pain in a multi-task environment”

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Abstract

Daily life is characterized by the need to stop, start, repeat, and switch between multiple tasks. Here, we experimentally investigate the effects of pain, and its anticipation, in a multi-task environment. Using a task switching paradigm participants repeated and switched between three tasks, of which one predicted the possible occurrence of pain. Half of the participants received low intensity pain ($N=30$) and half high intensity pain ($N=30$). Results showed that pain interferes with the performance of a simultaneous task, independent of the pain intensity. Furthermore pain interferes with the performance on a subsequent task. These effects are stronger with high intensity pain than with low intensity pain. Finally, and of particular importance in this study, interference of pain on a subsequent task was larger when participants switched to another task than when participants repeated the same task.

Perspective

This article is concerned with the interruptive effect of pain on people's task performance by using an adapted task switching paradigm. This adapted paradigm may offer unique possibilities to investigate how pain interferes with task performance while people repeat and switch between multiple tasks in a multi-task environment.

Keywords: Pain, task switching, task interference, attention, pain anticipation

Introduction

A key-component of successful goal-directed behavior in natural environments is the ability to switch attention flexibly between multiple demands, by preparing and protecting relevant actions from irrelevant actions. Whilst we usually experience such switches as relatively effortless⁴², a different picture emerges in the context of pain. Most often, attention is prioritized towards pain, which interrupts the smooth-running of goal-directed behavior.^{17,27}

Performance on a cognitive task is known to be hindered by the simultaneous presence of pain^{2,7,10,11,12,13,15,24,32,43}, but also see 31,36,45 or pain-related information (e.g. pain words).^{30,33} This ‘interference’ effect is especially pronounced when pain is intense, novel, unpredictable or threatening.^{9,17,22,26} To date, the interference effect of pain has only been investigated in a unitary task environment in which attention is directed toward or away from a primary task. Largely unexplored is the effect of pain in a multi-task environment. One exception is the study of Eccleston (1995) in which chronic pain patients were required to switch attention between different tasks.¹⁶ Results of this study show that patients with pain of high intensity were particularly impaired when they were instructed to switch between two tasks. It remains unclear how exactly pain interferes with task performance in such a multi-task environment. More systematic research about the effects of pain on behavior in a multi-task environment is necessary insofar as it offers unique possibilities to investigate

how people perform multiple tasks despite pain.²⁵ This line of research may further help identify the cognitive processes underlying memory and attentional problems often reported by patients with chronic pain.^{14,19}

Here, we adapted a standard task-switching procedure in which healthy volunteers are cued to repeat or to switch between three randomly presented tasks (see ^{24,42} for a review). One of the tasks sometimes co-occurred with pain and thus became a signal for possible pain. Half of the participants experienced high-intensity pain, the other half low-intensity pain. This study investigates two main questions. First we ask whether pain, or its anticipation immediately interfere with task performance (immediate interference effect). This is in line with previous literature on task interruption by pain.^{5,38} However, so far unexplored is the role of pain intensity on this interruptive effect. A second question is whether pain, or its anticipation during a task, also interferes with performance on a subsequent task (prolonged interference effect). Because switching requires greater cognitive effort in order to prepare the relevant task⁴², and pain is especially known to interfere with high cognitive demand⁴⁰, a larger prolonged-interference effect is predicted when switching between tasks than when repeating the same task. The prolonged interference effect is also expected to be larger in a context of high compared to low pain intensity.

Method

Participants

Sixty undergraduate students (48 females, $M_{\text{age}}=18.95$ years, $SD=2.63$; 59 Caucasian) from Ghent University participated for course credits. The majority reported good medical and psychological health (96.67%). Exclusion criteria included a self-reported current pain condition (e.g. dental pain, fibromyalgia, back pain) or a self-reported current psychiatric condition, (e.g., psychoses, anxiety disorders). We decided that participants would also be excluded from further analyses if they made errors on more than 20% of the trials.¹² However, no participants were excluded for these reasons. The experiment, including all instructions and stimulus materials, was undertaken in Dutch, and all participants were therefore required to have Dutch as a first language. All participants provided written informed consent and were fully debriefed after the experiment. The experiment was approved by the ethical committee of the Faculty of Psychology and Educational Sciences of Ghent University.

Apparatus

The experiment was programmed and presented by the INQUISIT Millisecond software package (Inquisit2.06, 2008) on an Excel computer (Pentium 4, 2.8GHz, 512MB) with a 60Hz, 17-inch color monitor. The viewing distance was approximately 60 cm.

Pain stimuli were delivered by a constant current stimulator (Digitimer DS7A, 1998) with an internal frequency of 50 Hz for duration of 300 ms. A train of square wave asymmetric 2-ms pulses (36 pulses; 6ms inter-pulse-

interval) was used. Pain stimuli were delivered at the median nerve on the wrist of the right arm. The skin area of the electrode sites was first rubbed with peeling gel (Nihon Kohden) to reduce skin resistance (similar as ⁴⁴).

Task-switching paradigm

We employed a task-cueing procedure, in which trials of three randomly presented reaction-time tasks are performed. In a first “shape” task participants were instructed to decide whether a target stimulus was a square or triangle. In a second “color” task participants were instructed to decide whether the target stimulus consisted of a pale grey or dark grey color. In a third “orientation” task participants were instructed to decide whether the target stimulus was vertically or diagonally oriented.

Figure 1 depicts an example of a trial. Each trial started with a cue indicating the task to be performed. The cues were the words “shape”, “color” or “orientation” presented in white courier-new font size 19. After 500 ms the task cue was replaced by a black screen for 500 ms, after which the target stimulus was presented. Target stimuli varied across three features: color (pale grey or dark grey), shape (triangle or square), and orientation (vertical or diagonal), resulting in eight different target stimuli. Each target stimulus was 34 x 34 mm in size. The target stimulus remained on the screen until participants made a response or 7000 ms elapsed.

Participants responded to the target stimulus by speaking aloud the particular shape (“square” or “triangle”), color (“pale” or “dark”) or orientation

(“vertical” or “horizontal”). Response latencies were recorded by a voice key (REACSYS R-51). Response errors were encoded by the experimenter on a trial to trial basis. Five hundred milliseconds after the response a new trial started. For one of three tasks, the pain-related task, the target onset sometimes co-occurred with an electrocutaneous stimulus (ECS). The task associated with the ECS was counterbalanced over participants.

INSERT FIGURE 1

Procedure

Preparation phase. Participants were individually tested in a dimly lit room. Half of the participants were randomly assigned to a low pain intensity group ($N= 30$; 29 females; $M_{\text{age}}= 18.77$; $SD= 1.96$), the other half to a high pain intensity group ($N= 30$; 19 females; $M_{\text{age}}= 19.13$; $SD= 3.18$). After giving informed consent participants were familiarized with the ECS. In the low pain intensity group participants were given three ECS (same stimulus parameters, except for its intensity: 0.5mA, 0.75mA, and 1 mA). Participants were then informed that the last stimulus of 1mA would be used in the experiment proper. In previous research this stimulus has been shown to be slightly painful.⁴⁴ In the high pain intensity group, a series of ECS (same stimulus parameters, except for its intensity) was assessed, in which the intensity increased stepwise until participant’s tolerance level was reached (0.5mA, 0.75mA, 1mA,

1.25mA, 1.50mA,...). Participants were asked to proceed with the tolerance procedure until they found that the pain level reached the maximum they could tolerate. Mean stimulus intensity of the ECS in the high pain intensity group was 3.98mA. Participants were informed that the stimulus at tolerance level would be used in the experiment proper. In both the low and high pain intensity group the last pain stimulus was the one that was used during the experiment.

Practice phase. Participants in the low and high pain intensity groups were informed that the ECS would be linked to one of the three tasks performed during the experiment. The experiment began with a practice phase, which consisted of 48 trials (16 times each task). Throughout the practice phase participants were familiarized with the tasks and learned which task was linked with the ECS. During this phase the ECS was presented together with the onset of the target of the pain-related task in half of the trials (independent of the features of the stimulus). Participants also received feedback concerning the correctness of their answer by presentation of the word “false” (500ms) when an error was made. At the end of the practice phase participants were asked which task was associated with the ECS. If they answered the question correctly they could start the test phase, otherwise they were prompted to repeat the practice phase. Nine participants requested one repetition of the practice phase; two participants requested a further repetition. No difference was found between both pain intensity groups for the number of repetitions needed in the practice phase, $\chi^2(3) < 3.51, p > .10$.

Test phase. At the beginning of the test phase participants were informed that ECS would also be administered during the test phase. It was stressed that the ECS would be linked to the same task as previously experienced during the practice phase. They were also informed that they would no longer receive feedback on the correctness of their response. The test phase consisted of one randomly chosen task to start, followed by 240 test trials during which each task was to be performed 80 times. The number of switch trials and repetition trials was kept equal throughout the test phase. During the test phase, in a quarter of the pain-related task trials, an ECS was administered and this was equally divided over switch and repetition trials.

Manipulation check. After the test phase, using 11-point numerical rating scales (anchored 0= not at all and 10= very strongly), participants rated the extent to which they expected that an ECS would be administered following each task cue. Participants' fear at the moment of seeing each task cue was also rated on a similar 11-point numerical scale (anchored 0= not afraid and 10= very afraid). Finally, participants were asked to rate the experienced intensity of the ECS administered during the experiment on a similar 11-point numerical scale (anchored 0= not at all intense and 10= very intense).

Data reduction and handling. Response times (RTs) lower than 150 ms and higher than 3 SD above each participant's individual mean RT were considered as outliers and omitted (1.96 %). The first trial of a block, trials

with errors on the current task (5.67 %), and trials with errors having occurred during the previous task (5.42 %), were omitted from further analysis.³ Next, all trials were coded as being one of nine task pairs which are described in table 1. Two ANOVAs were performed. To investigate the hypotheses related to the immediate task interference, a 3 (Current Task: neutral [task unrelated to pain], pain-anticipation [Task in which the ECS is expected but not delivered, pain [Task in which the ECS is expected and delivered]) x 2 (Pain Intensity Group: high, low) ANOVA with repeated measures on the first factor was performed. For this ANOVA we selected only trials in which the preceding trial was neutral and in which the current task differed from the task on the preceding trial. In doing so, our results cannot be confounded by a possible prolonged interference effect stemming from the disruptive effects of pain or its anticipation on the preceding trial, or effects related to the difference between repeating and switching tasks (see ⁴² for a review). Contrast analyses were planned to compare trials in which the current task was neutral with both other conditions separately. To investigate the hypotheses related to the prolonged task interference effect, a 2 (Transition: repetition, switch) x 3 (Previous Task: neutral, pain-anticipation, pain) x 2 (Pain Intensity Group: low, high) ANOVA with repeated measures on the first two factors was performed. In this ANOVA we selected both repetition and switch trials. Again, planned contrasts were conducted to compare trials in which the previous task was neutral with both other conditions separately. Effect sizes were measured with

partial Eta-squared or wherever possible we calculated effect sizes for independent samples using the formula of Dunlap and colleagues²³, and the 95% Confidence Interval (95% CI). We determined whether Cohen's *d* was small (0.20), medium (0.50), or large (0.80).³⁷

INSERT TABLE 1

Results

Participants' characteristics

There were no age differences between the low pain intensity group and high pain intensity group ($t(59) < 1, p > .10$). A χ^2 -test showed no differences between both groups as a function of health status ($\chi^2(3) < 1, p > .10$) and socio-economic status ($\chi^2(3) = 5.12, p > .10$). A difference was found as a function of participants' gender ($\chi^2(1) = 10.41, p < 0.01$). No differences however were observed on the pain intensity rating and reaction times as a function of gender (All t 's < 1.63).

Manipulation check

Results of the post-experimental numerical rating scales indicated that the experimental manipulation was successful. First, participants reported more fear of the cue of the pain-related task ($M = 5.77, SD = 2.41$) compared to the cues of both neutral tasks ($M = 2.06, SD = 2.17$), $t(59) = 10.55, p < .001, d = 1.61$; 95% CI = 1.16: 2.09. Second, they expected to receive an ECS after a pain-related task cue ($M = 7.08, SD = 2.13$) more often than after a neutral task cue ($M = 1.78, SD = 1.89$), $t(59) = 13.56, p < .001, d = 2.63$; 95% CI = 2.00: 3.26. Third, participants of the high pain intensity group ($M = 6.50, SD = 2.01$) rated the ECS

they received during the experimental phase as more intense than the participants allocated to the low pain intensity group ($M=3.23$, $SD=2.14$), $t(58)=6.08$, $p<.001$, $d=1.58$; 95% CI =1.00: 2.15.

Reaction time data

Immediate task interference. We hypothesized that pain or the anticipation of pain would immediately impair task performance, especially when pain was highly intense. To test our hypotheses a 3 (Current Task: neutral, pain-anticipation, pain) x 2 (Pain Intensity Group: high, low) ANOVA was performed. As predicted, the main effect of Current Task was significant, $F(2, 57)= 3.65$, $p<.05$, $\eta_p^2 =.11$. The main effect of Pain Intensity Group was not significant, $F(1,58)<1$, $d= 0.17$; 95% CI = -0.34: 0.68. The interaction between Trial Type and Pain Intensity Group failed to reach significance, $F(2, 57)<1.17$, $\eta_p^2 =.04$. With regard to the significant main effect of Current Task, planned contrast analyses indicated that anticipation of pain during a current task did not hamper task performance compared to performance on a neutral task, $F(1,58)< 1.01$, $d=0.08$; 95% CI =-0.07: 0.23. But participants' performance was slower on a task when pain was experienced ($M= 707$, $SD= 207$), compared with performance on a neutral task ($M= 669$, $SD= 138$; $F(1, 58) =3.76$, $p= .06$, $d=0.20$; 95% CI =0.00: 0.40).

Prolonged task interference. We hypothesized that pain or the anticipation of pain during one task would interfere with performance on subsequent trials, in particular when participants were required to switch to

another task and when pain was of high intensity. In order to avoid confounding effects of immediate interference, trials in which pain was delivered in the current task were excluded (trials in which pain was merely anticipated in the current task were not excluded, as previous analyses showed no immediate interference effect in these trials). To test our hypotheses a 2 (Transition: repetition, switch) x 3 (Previous Task: neutral, pain-anticipation, pain) x 2 (Pain Intensity Group: low, high) ANOVA was performed. There was a main effect of Previous Task, $F(2,57)=21.63, p<.001, \eta_p^2 =.43$. With regard to the significant main effect of Previous Task, planned contrast analyses indicated that participants were significantly slower when the previous task was painful ($M=751, SD=194$), than when the previous task was neutral ($M=669, SD=134; F(1,58)=35.14, p<.001, d=0.43; 95\% CI =0.27: 0.59$). Participants' performance however did not differ between when the previous task was pain anticipating ($M=662, SD=137$) and when the previous task was neutral ($M=669, SD=134; F(1,58)=1.24, p>.10, d=0.05; 95\% CI =-0.04: 0.14$). There was also a main effect of Transition, $F(1,58)=5.88, p<.05, d=0.14; 95\% CI =0.02: 0.27$, showing that participants were slower on switch trials ($M=705, SD=156$) than on repetition trials ($M=683, SD=148$). Next, the interaction between Pain Intensity Group and Transition was significant, $F(1,58)=7.69, p<.01, d=0.62; 95\% CI =0.10: 1.13$, indicating that the difference in RTs between switch trials and repetition trials was significantly larger for the high pain intensity group ($M=45, SD=62$) than for low pain intensity Group ($M=0,$

$SD=81$). Furthermore the interaction between Previous Task and Pain Intensity Group, $F(2,57)=5.67, p<.01, \eta_p^2=.17$, as well as the interaction-effect between Previous Task and Transition, $F(2,57)=3.47, p<.05, \eta_p^2=.11$, were significant. The expected 3-way interaction between Previous Task, Transition and Pain Intensity Group failed to reach significance, $F(2,57)=1.01, p>.10, \eta_p^2=.03$.

The significant interaction-effect between Previous Task and Pain Intensity Group was explored by means of planned contrast analyses. Mere anticipation of pain during the previous trial was no more disruptive on the current task in the high pain intensity group than in the low pain intensity group, $F(1,58) < 1, d=0.06; 95\% CI = -0.45: 0.57$. As can be seen in Figure 2, performance was hampered on a task following a painful task in both, the high pain intensity group ($M=125, SD=135, t(29)= 5.09, p<.001, d=0.57; 95\% CI = -0.34: 0.81$) and the low pain intensity group ($M=38, SD=68, t(29)=3.07, p<.01, d=0.24; 95\% CI = 0.09- 0.40$). Pain experienced on the previous trial however was shown to be more disruptive in the high pain intensity group, than in the low pain intensity group, $F(1,58)= 10.05, p<.01, d=0.82; 95\% CI = 0.29: 1.35$.

INSERT FIGURE 2

The interaction between Previous Task and Transition was further explored by means of planned contrast analyses in which the neutral task

condition was compared with the presence of pain or the anticipation of pain during the previous task separately. Analyses indicated that the prolonged interference effect of pain anticipation ($F(1,59)= 5.08, p<.05, d=0.36; 95\% CI =0.04: 0.68$) as well as actual pain ($F(1, 59)= 4.62, p<.05, d=0.33; 95\% CI =0.04: 0.62$) differed between switch trials and repetition trials. Paired sample t-tests showed no significant difference between repetition trials ($M=669, SD=139$) and switch trials ($M=669, SD=138$) when the previous task was neutral ($t(59)<1, d=0.00; 95\% CI =-0.17: 0.17$). A significant difference ($M=29, SD=89$) was found between repetition trials ($M=648, SD=155$) and switch trials ($M=676, SD=132$) when the previous task elicited the anticipation of pain, $t(59)= 2.51, p<.05, d=0.19; 95\% CI = 0.04: 0.34$. Also a significant difference ($M=39, SD=141$) was found between repetition trials ($M=731, SD=205$) and switch trials ($M=770, SD=208$) when pain was induced during the previous task, $t(59)= 2.13, p<.05, d=0.19; 95\% CI =0.01: 0.36$.

INSERT FIGURE 3

Discussion

The aim of the present study was to investigate the role of pain and its anticipation on task performance in a multi-task environment. This was investigated experimentally by means of a modified cued task switching procedure in which participants repeated or switched between three randomly

presented tasks, with one task being related to possible pain. We were interested in the effect of immediate and prolonged task interference of pain. For the immediate-interference effect, we observed that pain interferes with an ongoing task irrespectively of pain intensity. Merely anticipating pain did not hamper task performance. For the prolonged interference effect, the presence of pain during a trial impedes performance on the subsequent trial. The prolonged-interference effect was larger for pain of high intensity than for pain of low intensity. Finally, the prolonged interference-effect was larger when a switch between tasks was required than when the same task was repeated.

First we elaborate on the findings related to interference of pain. Task performance during the presence of pain was impaired. This finding is in line with research showing that task performance during the presence of pain was poorer.^{2,7,10,11,12,13,15,24,32,43}, but also see 31,36,45 This effect was, however, small and just failed to reach significance. This is in contrast with previous findings which mostly report that pain has a relatively large interference effect on concurrent tasks. One plausible explanation for this discrepancy may lie in the predictability of pain. In previous studies on immediate task interruption by pain, pain was delivered unannounced and was therefore temporally unpredictable (e.g.^{2,10,11,32}). Temporal predictability has been shown to decrease the interference of pain with task performance.⁹ In the present study, pain was predictable because it could only be delivered during a particular task at a given moment (onset of task stimulus). It seems that participants may be

able to partially protect their task performance from interruption by pain on some occasions. People might increase their effort or prioritize non-pain tasks when they expect that pain will interfere.^{9,12} However, it may be the case that the shielding of attention from pain may have some negative effects later on as was found in this study.

To our knowledge, our results are the first of their kind to reveal that pain can have a prolonged interference effect. Indeed, the disruptive effect of pain on task performance may not be limited to the pain experience itself, but may extend even when pain has already dissipated. In our study this prolonged effect varied with pain intensity. High intense pain resulted in a stronger prolonged interference effect than low intense pain. Several explanations are possible. First, the increase of effort to shield attention from immediate pain (see above), may temporarily deplete effort leading to a worse performance on the following trial.^{34,21} Second, it is possible that participants ruminate about pain immediately after completion of a trial with pain. Because rumination is known to be cognitively demanding²⁰, it may interfere with the preparation of the subsequent task, resulting in a decreased performance on the following task.¹ Of further interest is the finding that the prolonged interference-effect of pain was more pronounced when participants switched between tasks. Because switching between tasks is more demanding than repeating tasks⁴², we may indeed expect that switching between tasks will detrimentally affect task performance when cognitive resources are depleted or when task load is

heightened (e.g. during rumination).^{28,29,35,34,41} To conclude, we can state that although the ability of pain to disrupt current performance is already frequently researched, and its function has been variously described as an evolved interrupt forming part of a general defensive system^{4,18,40}, further research to clarify under which conditions pain interferes with task performance is still necessary.

A further aspect of these results relates to the influence of pain anticipation. Based on previous studies indicating that pain anticipation increases attention for pain and results in task interference^{6,12}, we expected that anticipation of pain would interfere with task performance in the present study. This prediction was not supported. It may well be that the interference by pain anticipation is more subtle than the interference related to pain. The fact that the pain was temporally predictable might even have further reduced the interference-effect of pain anticipation. Furthermore, interference by pain anticipation may also be more limited in time than interference related to pain. In line with this, Van Damme et al (2002) found interference effects for pain cues that were very close in time to the onset of the next experimental event (100ms). Effects were absent for large intervals (e.g., 500ms and 900ms).³⁹ In the present study the interval between the task cue – which indicates if pain is impending – and the stimulus onset was 1000ms, which may have been too long to observe an immediate-interference effect for pain anticipation. The absence of an overall prolonged-interference effect on the basis of pain anticipation

may be explained in a similar way. Although we did not find an overall prolonged interference effect of pain anticipation during the previous task, results did show that switching between tasks compared with repeating tasks was more impaired when the previous task involved pain anticipation than when the previous task was neutral. This finding may be explained by the fact that the task which is associated with pain anticipation (and also pain) becomes more arousing and more active than the other tasks.⁴⁶ It may then be more difficult to switch from a dominant task towards another task, whereas repeating the dominant task may become easier. Further investigation is warranted on exactly when anticipation of pain interferes with task performance.^{6,8,47}

Several theoretical implications emerge from the present study. First, pain not only decreases performance on single tasks, but also when multiple tasks are presented. This interruption extends beyond current tasks to the performance of subsequent tasks. Effect size indices indicate that this prolonged interference-effect may be important to take into account, especially when pain is intense ($d=0.57$; moderate effect size). Although this has been suggested for a number of years¹⁷, a suitable paradigm has only now been created to allow for the disaggregation of these effects. Task environments of greater complexity are needed in order to observe the interruptive function of pain. Not only will complex environments improve the validity of findings, they will also enable the observation of attentional strategies created in

response to multiple demands. Finally, it is worth noting that the prolonged interference effect observed in complex environments was sensitive to alterations in the characteristics of the pain stimulus, specifically here its intensity. Further investigation is warranted on the effects of other characteristics of pain, both bottom up (e.g., novelty) and top down (e.g., motivational significance).²⁷

This study has some limitations. First, the use of this task switching paradigm in a pain context is novel, so replication is necessary. Second, different calibration criteria were applied for the low and high-level pain stimulus for practical reasons. The low-level pain stimulus was stimulus-locked for all participants, whereas the high-level pain stimulus was individually determined as a stimulus at tolerance level. Future research may opt to use a more sophisticated calibration procedure (e.g. ⁴⁸). Third, the present study was conducted with students using experimental pain stimuli. Therefore one should be cautious in generalizing these results to other non-clinical populations and clinical populations in a daily life context. Fourth, post-hoc power analyses indicated that small effects may have been missed due to a lack of statistical power, in particular interaction-effects related to the between group manipulation of pain intensity.

Despite these considerations, the present investigation expands our understanding of the influence of pain on task performance in a multi-task

environment and provides methods for the further investigation of attention toward and away from pain in complex environments.

Disclosures

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Figure legends

Figure 1. Graphical presentation of the experimental paradigm.

Figure 2. Reaction times on trials in which pain is present during the previous task compared with trials in which the previous task is neutral, for the low pain intensity group and high pain intensity group. ***= $p < .001$, **= $p < .01$, *= $p < .05$

Figure 3. Reaction times for both repetition and switch trials when previous task was painful, pain-anticipating or absent of pain. ***= $p < .001$, **= $p < .01$, *= $p < .05$

Table legends

Table 1. Exhaustive list of each trial type and the tasks performed during each trial type; *Pain task = pain-related task + electrocutaneous stimulus (ECS), ** Pain-anticipation task= pain-related task without ECS. Additionally reaction times (ms) of each trial type for the low pain intensity group and high pain intensity group are added.

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