Activity interruptions by pain impair activity resumption, but not more than activity interruptions by other stimuli

Research Paper

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Activity interruptions by pain impair activity resumption, but not more than activity interruptions by other stimuli: an experimental investigation

Rena Gatzounis[a,b,*], Martien G.S. Schrooten[a,c], Geert Crombez[d], Johan W.S. Vlaeyen[a,b]

Abstract

Interrupting ongoing activities whilst intending to resume them later is a natural response to pain. Whereas this response facilitates pain management, at the same time it may also disrupt task performance. Previous research has shown that activity interruptions by pain impair subsequent resumption of the activity, but not more than pain-irrelevant interruptions. Ongoing task complexity and pain threat value might influence interruption effects. In this experiment, we adjusted a paradigm from outside the field of pain to investigate how activity interruptions by pain affect task performance. Healthy participants (n = 69) were required to answer a series of questions, in a specific sequence, about presented letter-digit combinations. This ongoing task was occasionally interrupted by painful electrocutaneous or nonpainful vibrotactile stimulation (between-subjects), followed by a typing task. On interruption completion, participants were required to resume the ongoing task at the next step of the question sequence. Results indicate impaired sequence accuracy (less frequent resumption at the correct step of the sequence) but preserved nonsequence accuracy (similarly frequent correct responses to question content) immediately after an interruption. Effects were not larger for interruptions by pain compared with nonpain. Furthermore, participants in the 2 conditions reported similar task experience, namely task motivation, perceived difficulty, and confidence to resume the interrupted task. Pain catastrophizing did not influence the results. As in previous studies, activity interruptions by pain were shown to impair the resumption of a task that requires keeping to a step sequence, but not more than interruptions by nonpainful stimuli. Potential explanations are discussed.

Keywords: Pain, (Activity) interruption, Task performance, Task switch, Vibrotactile stimulus

1. Introduction

Pain is a threat signal that motivates protective actions. A natural response to pain is to suspend ongoing activities to escape from or avoid damage,[14] usually with the intention to resume the interrupted activities later. Activity interruptions by pain may facilitate pain management, but may also hold the risk of impairing subsequent performance of the interrupted activity.[18] Unfortunately, much remains unknown about the latter.

Guided by interruption models from other research fields,[2,5,7,35] we previously proposed a stage model describing how activity interruptions by pain could impair subsequent activity resumption.[18] We also showed that activities are performed less accurately and more slowly after being interrupted by pain.[17] This finding adds to the existing evidence that pain impairs performance of concurrent tasks[6,8,9,27,36] and switching to new tasks.[30] Furthermore, it parallels findings from other research fields, showing performance decrements after interruptions by pain-irrelevant demands (eg, Refs. 5, 35).

Theoretical accounts of the disruptive nature of pain[14] and research showing that pain during a task impairs performance more than other stimuli (such as aversive nontactile stimulation[16] or less aversive tactile stimulation[12,13,30]) imply that interruptions by pain produce worse outcomes than interruptions by nonpainful stimuli. To date, however, direct evidence supporting this hypothesis is lacking. Interruptions by painful and nonpainful (vibrotactile) stimulation have previously been shown to have a similar impact on task resumption.[17] The expected specific effects of interruptions by pain may depend on various characteristics of the interrupted task and the pain.

First, task complexity modulates the effects of pain on concurrent tasks,[8] but also the effects of pain-irrelevant interruptions.[32] Specifically, interruptions might even facilitate the performance of easy, boring, or repetitive tasks.[32] Because previous studies used relatively easy tasks,[17] which might have overruled the effects of pain, further research with at least moderately complex tasks is warranted.

Second, activity interruptions by pain might be more disruptive when pain is experienced as threatening, as it happens in high pain catastrophizers. High threat value enhances the attentional demands of pain,[12,14] thus potentially impairing information encoding and the subsequent resumption of the interrupted activity.[9,14,18] High pain catastrophizers have been shown to spend less time on an open-ended activity that is interrupted by pain,[31] indicating that pain catastrophizing indeed moderates interruption effects.

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

[a] *Faculty of Psychology and Educational Sciences, Research Group Health Psychology, University of Leuven, Leuven, Belgium,* [b] *Department of Clinical Psychological Science, Maastricht University, Maastricht, the Netherlands,* [c] *School of Law, Psychology and Social Work, Centre for Health and Medical Psychology, Örebro University, Örebro, Sweden,* [d] *Department of Experimental-Clinical and Health Psychology, Ghent University, Ghent, Belgium*

**Corresponding author. Address: Research Group Health Psychology, University of Leuven, Tiensestraat 102, Box 3726, B-3000 Leuven, Belgium. Tel.: +32 16 37 30 40; fax: +32 16 3 26144. E-mail address: Rena.Gatzounis@kuleuven.be (R. Gatzounis).*

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The present experiment investigates the effects of activity interruptions by pain using a complex paradigm, previously used for the laboratory study of the effects of pain-irrelevant interruptions on sequential task performance.[1,3,20] In this paradigm, participants answer a series of questions in a specific sequence. This sequence is occasionally interrupted by painful or nonpainful stimulation followed by a different activity. After the interrupting activity, participants are required to resume the question sequence at the step where they left off. We hypothesized that interruptions would impair sequence accuracy and that this impairment would be greater for interruptions by painful (compared to non-painful) stimuli. We also expected that interruptions by pain would result in worse task experience (namely lower motivation and higher perceived difficulty to perform the interrupted task). Effects were also expected to be greater among high pain catastrophizers.

2. Methods

2.1. Participants

Seventy-two healthy volunteers participated in the experiment. Two participants were excluded before analyses (because of technical problems during the session or because of fulfilling the exclusion criteria as revealed after the session), thus leaving the final sample with 70 participants. Exclusion criteria were pregnancy, having an electronic implant (eg, a cardiac pacemaker), using anxiolytic or antidepressive medication, having ever been diagnosed with a psychiatric or neurological disorder, having had an operation on the ankle(s), having eyesight problems that were uncorrected by glasses or contact lenses, a native language other than Dutch, acute or chronic pain, a cardiovascular disease or other serious medical problems, and having been asked by one's doctor to avoid stressful situations. Exclusion criteria were checked by means of self-report. Participants signed informed consent and received partial course credit or monetary compensation in exchange for their participation.

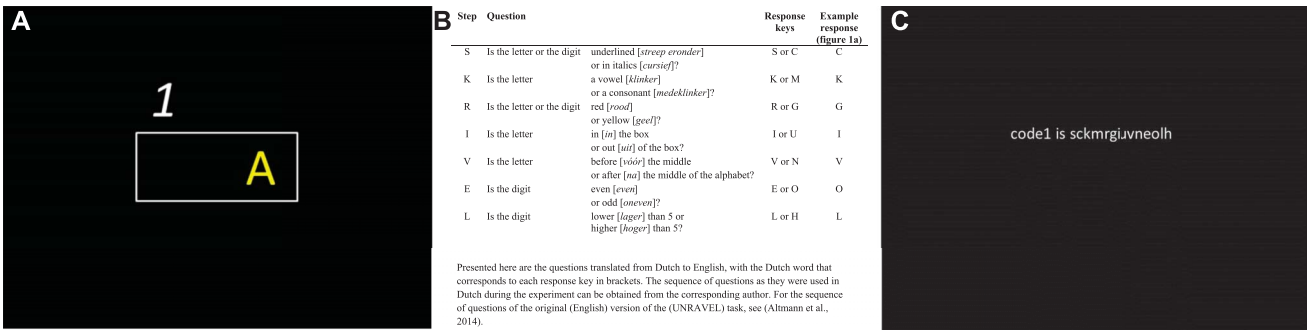
2.2. Experimental task

We used the "SKRIVEL" task, a modified version of the "UNRAVEL" paradigm, which has been designed for the study of the effects of interruptions on sequential task performance.[1,3,20] In this task, participants view stimuli and are required to answer about them a series of questions in a specific sequence. Participants are not prompted about the specific question to be answered on each trial. Instead, they are required to monitor where they are in the sequence to perform well. Occasionally, a painful electrocutaneous or a nonpainful vibrotactile stimulus is administered and followed by temporary ongoing task suspension and initiation of a different task, which we call the interruption task. After performing the interruption task, the ongoing task starts again, requiring participants to remember where they had left off in the question sequence. A detailed description of the specific experimental task follows:

2.2.1. Ongoing task

On each trial, participants were presented with a combination of a letter (A, B, U, X) and a digit (1, 2, 8, 9) on a black screen background. The 2 characters differed in font (1 character was underlined or italic, the other 1 was regular), colour (1 character was red or yellow, the other 1 was white), and position (1 character was above or below a white rectangular frame that was presented in the center of the screen, the other 1 was inside the frame) (**Fig. 1A**). For each letter-digit combination (eg, X 9), participants were required to respond to 1 of 7 questions, in a fixed sequence. This 7-step sequence was represented by the made-up acronym "SKRIVEL" (cf. "UNRAVEL" in the original English version[1,3,20]), each letter of which corresponds to a mnemonic for each of the questions (**Fig. 1B**). The questions were presented in Dutch and were as follows: whether the font style was underlined or italic (step S; from the Dutch "*Streep eronder*" for underline), whether the letter was a vowel or consonant (step K; from the Dutch "*Klinker*" for vowel), whether the colour was red or yellow (step R; from the Dutch "*Rood*" for red), whether the letter was located inside or outside the frame (step I; from the Dutch "*In*" for inside), whether the letter was before or after the middle of the alphabet (step V; from the Dutch "*Vóór*" for before), whether the digit was even or odd (step E; from the Dutch "*Even*" for even), and whether the digit was lower or higher than 5 (step L; from the Dutch "*Lager*" for lower). Each response option was assigned a specific keyboard key, resulting in the use of 14 distinct keys throughout the task.

Each letter-digit combination remained on the screen until the participant's response. A response was followed by the presentation of the next letter-digit combination, during which the next question in the sequence had to be answered. For example, after responding to step S, participants saw a new letter-digit combination and were required to respond to step K. After responding to step L (last question in the sequence), participants saw a new letter-digit combination and were required to respond to step S (first question in the sequence), thus cycling through the sequence throughout the task. Some responses were followed by a painful electrocutaneous or a nonpainful vibrotactile stimulus (between-subjects; see



Step	Question		Response keys	Example response (figure 1a)
S	Is the letter or the digit	underlined [*streep eronder*] or in italics [*cursief*]?	S or C	C
K	Is the letter	a vowel [*klinker*] or a consonant [*medeklinker*]?	K or M	K
R	Is the letter or the digit	red [*rood*] or yellow [*geel*]?	R or G	G
I	Is the letter	in [*in*] the box or out [*uit*] of the box?	I or U	I
V	Is the letter	before [*vóór*] the middle or after [*na*] the middle of the alphabet?	V or N	V
E	Is the digit	even [*even*] or odd [*oneven*]?	E or O	O
L	Is the digit	lower [*lager*] than 5 or higher [*hoger*] than 5?	L or H	L

Presented here are the questions translated from Dutch to English, with the Dutch word that corresponds to each response key in brackets. The sequence of questions as they were used in Dutch during the experiment can be obtained from the corresponding author. For the sequence of questions of the original (English) version of the (UNRAVEL) task, see (Altmann et al., 2014).

Figure 1. (A) Example of a letter-digit combination presented during one ongoing task trial. (B) Sequence of questions to be answered during the ongoing task, with the corresponding response keys and an example. (C) Example of a letter string presented during one interruption task trial.

Interruption cues). On interruption cue offset, the ongoing task was suspended and the interruption task was initiated.

2.2.2. Interruption task

On each trial, participants were presented with a 14-letter string (white on black screen background; **Fig. 1C**), which they were required to type at their own pace. Participants saw what they were typing at the center of the screen and registered their response by pressing the Enter key. An incorrect response was followed by the presentation of an error sound through the speakers, indicating that the letter string had to be typed again. A correct response to the first letter string was followed by the presentation of a new letter string. A correct response to the second letter string was followed by interruption task suspension and the immediate presentation of a new letter-digit combination for the ongoing task.

Participants performed 4 blocks, each of which consisted of 80 ongoing task trials with interspersed 12 interruptions. Interruptions occurred semi-randomly, but every 6 ongoing task trials (range: 4-8) on average, in order to spread interruptions to all steps of the question sequence. To facilitate engagement in the task, the first interruption of each block occurred after the first run of 7 questions. To prevent participants from using strategies such as rehearsal during the interruption, letter strings were random permutations of the same 14 keys used in the ongoing task.

2.3. Interruption cues

2.3.1. Painful stimulation

Half of our participants (n = 34) received electrocutaneous stimuli (square-wave, 50 ms duration, 20 Hz frequency) as interruption cues. These stimuli were generated by a DS 5 constant current stimulator (Digitimer Limited, Hertfordshire, United Kingdom) and administered through 2 0.8 mm Ag/AgCl cutaneous electrodes (Bilaney, Düsseldorf, Germany). The electrodes were placed on the dorsal side of the right ankle (interelectrode distance ~1 cm). Before applying the electrodes, the experimenter rubbed the participant's skin with a commercial scrub cream to reduce skin resistance and filled the electrodes with an electroconductive gel (K-Y gel; Johnson & Johnson, New Brunswick, NJ).

After electrode application, stimulus intensity was individually determined as follows: the experimenter administered a series of electrocutaneous stimuli, starting with a stimulus of 0.5 mA and increasing in steps of 1 mA. The participant was asked to rate each stimulus on an 11-point "effort-to-tolerate" scale (0 = "no effort at all"; 10 = "maximum effort I can exert"). For stimuli rated as a 3, 5, and 7 or higher, participants were also asked to provide painfulness and unpleasantness ratings (0 = "not at all painful/unpleasant"; 10 = "the most painful/unpleasant that I can imagine"). The calibration procedure continued until the participant did not wish to be administered a stimulus of higher intensity or until they had rated a stimulus as an "8" on the "effort-to-tolerate" scale. On agreement of the participant, the intensity of the last stimulus administered during the calibration procedure was the 1 used during the experimental task. The mean intensity of the stimuli used was 6.9 mA (*SD* 3.10, range 2.50-14.50).

2.3.2. Nonpainful stimulation

The other half of our participants (n = 36) received nonpainful vibrotactile stimuli (50 ms duration) as interruption cues. The vibrotactile stimuli were generated by a custom-made device controlled through software by means of a transistor-transistor logic signal. The device consisted of a small commercially available CE-certified eccentric motor enclosed in a plastic egg-shaped case. The case was inserted into the pocket of an arm wallet typically used by joggers. The experimenter fastened the arm wallet around the participant's right ankle, with the pocket containing the motor being on its dorsal side and familiarized the participant with the vibrotactile stimuli. During this familiarization phase, 2 stimuli of the same intensity were administered and the participant was asked to rate them on an "effort-to-tolerate," "painfulness," and "unpleasantness" scales (the same scales as above, but reworded to refer to the "vibrotactile stimulus" instead of the "sensory stimulus").

2.4. Measures

2.4.1. Behavioural measures

Our main outcomes were sequence accuracy and nonsequence accuracy in the ongoing task. Sequence accuracy refers to responding to the correct step of the sequence and was registered in relation to the participant's response in the previous trial. For example, responding to step R after step K constituted a correct response, whereas responding to step R after step L constituted an incorrect response. For resumption trials, namely trials immediately after the interruption task, the previous trial was the 1 in which the interruption cue was delivered. Nonsequence accuracy refers to responding correctly to the content of the question and was registered irrespective of whether participants had also responded to the correct step of the sequence. For example, responding to "R" when 1 of the presented characters is red is a correct response, irrespective of whether the participant should respond to step R or another step. Because each possible response was assigned a specific key, we could easily identify the step that participants were responding to.

For our manipulation check, we looked at the interruption task performance, expressed as number of errors made and the time spent on the (self-paced) interruption task.

2.4.2. Self-report measures

We administered the Pain Catastrophizing Scale (PCS[11,34]) to investigate whether pain catastrophizing modulates the effects of interruptions by pain. The PCS assesses 3 factors of pain catastrophizing, namely rumination, magnification, and helplessness. Each of its 13 items is scored on a 5-point scale ranging from 0 ("not at all") to 4 ("all the time"). The Dutch version of the PCS has shown very good psychometric qualities in both clinical and nonclinical samples[11] and a good reliability in the present study (α = 0.90, n = 68).

We also assessed task experience, namely the motivation to perform the ongoing and the interruption tasks, the perceived difficulty to resume the ongoing task after an interruption, and the confidence in resuming the ongoing task at the correct step after an interruption. Ratings were given on 11-point scales ranging from 0 ("not at all") to 10 ("to a very high degree").

For our manipulation check, participants also rated the interruption cue characteristics (painfulness, unpleasantness, and threat value) on 11-point scales ranging from 0 ("not at all") to 10 ("to a very high degree").

2.5. Equipment

For the presentation of the computer task, we used a standard DELL computer setup consisting of a computer (Intel Core2 Duo CPU, 2.33 GHz) operating Windows XP (Microsoft), a 19-inch screen (set on a resolution of 1024 × 768 pixels), an AZERTY

keyboard, mouse, and a standard set of computer speakers. The task was programmed using Affect 4.0.[33] The platform LimeSurvey[25] was used for questionnaire administration.

2.6. Procedure

The study protocol was approved by the Social and Societal Ethics Committee of the University of Leuven (SMEC; reg. nr. G-2015 07 273). Participants were allocated either to the pain group or the nonpain group on the basis of a computer randomization list and were tested individually in 1 session lasting 60 to 75 minutes. Two days after the laboratory session, participants filled in a short online questionnaire battery containing the PCS (other questionnaires were administered for exploratory reasons and are thus not further discussed). The laboratory session was as follows:

2.6.1. Introduction

On arrival to the labortaory, participants read written information about the study, including the electrocutaneous or vibrotactile stimulation (depending on group membership). Exclusion criteria were checked and participants signed informed consent and provided demographic information.

2.6.2. Interruption cue calibration/familiarization

Subsequently, the experimenter applied the electrodes or the vibrotactile stimuli device, and the calibration of the painful stimulus or the familiarization with the vibrotactile stimulus (depending on group membership; see *Interruption cues*) took place.

2.6.3. Experimental task, practice phase

Participants read detailed instructions for and practiced the ongoing task in a step-by-step manner.[1,3] Instructions emphasized the acronym SKRIVEL as a tool to remember the questions and their sequence. Subsequently, participants read an explanation of the interruption task and practiced 1 trial. They then performed a combined practice phase consisting of 16 ongoing task trials intermixed with 2 interruptions, without any painful or vibrotactile stimulation. Participants were informed that in the test phase, the painful electrocutaneous or nonpainful vibrotactile stimuli would be administered during the ongoing task, but not during the interruption task. To ensure correct understanding of the instructions, the practice phase proceeded to the next trial only when a correct response was given. Whenever necessary, the experimenter repeated the explanation.

2.6.4. Experimental task, test phase

Subsequently, the participant performed 4 blocks, each of which consisted of 80 ongoing task trials intermixed with 12 interruptions. A self-paced break could be taken between blocks. During the break, personalized feedback was presented on the screen, depending on the participant's general accuracy, that is, the combined sequence and nonsequence accuracy, in the last block.[1,3] Specifically, when general accuracy was lower than 70%, participants were asked to respond more accurately. When general accuracy was higher than 90%, participants were asked to respond faster. When general accuracy was between 70% and 90%, participants read that they are doing fine. The purpose of the variable feedback was to maximize the obtained error variance. Throughout the experiment, participants could read a sheet containing the list of questions (in the correct sequence) for the ongoing task, which was placed on the desk. This way, all participants had the same access to knowledge regarding the content and sequence of the questions. However, they had to remember their place in this sequence as this was not prompted throughout the task. Therefore, potential effects could only be attributed to forgetting one's place in the sequence, but not the sequence itself.

2.6.5. End session

On task completion, participants rated their task experience and the interruption cue characteristics. The experimenter removed the electrodes or the vibrotactile device. Participants received either course credits or monetary compensation as a token of appreciation and were debriefed about the real purpose of the study when the whole sample had been tested.

2.7. Statistical analyses

For the sample characteristics, we computed descriptive statistics and investigated group differences by mean values of χ^2-tests or univariate analyses of variance (ANOVAs) with group (2: pain vs nonpain) as the between-subjects factor. For our manipulation check, we performed a series of ANOVAs with group (2: pain vs nonpain) as the between-subjects factor on the self-reported interruption cue characteristics, the average number of errors in the interruption task, and the average duration of the interruption. Groups were compared on the latter 2 variables to ensure that potential group effects in the main outcome variables would not be explained by interruption task performance.

Before hypothesis testing, we excluded participants and/or blocks with accuracy below a certain threshold that would indicate that the accuracy instruction was not followed (cf.[1,3,20]). Specifically, we excluded participants if (1) their sequence accuracy on the resumption trials of the ongoing task was significantly below the chance level (1 participant of the nonpain group) or (2) their general accuracy was equal to or lower than 70% in 2 or more SKRIVEL task blocks (0 participants). Furthermore, (3) we also excluded individual blocks where general accuracy was equal to or lower than 70% (4 blocks from 4 participants). One more block from another participant had to be excluded because of a technical error that led to the suspension of the computer task, some trials before its completion.

For our hypotheses, we focused on impairments in sequence accuracy, expressed as responding to an incorrect step in the sequence, in resumption trials (ongoing task trials immediately after an interruption) compared with baseline trials (all other ongoing task trials). Given that the interruption cues were effectively administered only after the participant's response, we decided to also consider the trials with an interruption cue, that is, the trials immediately preceding an interruption as baseline trials. We did not expect to observe interruption effects on nonsequence accuracy, namely incorrect responses to the content of the questions. Sequence and nonsequence accuracy were subjected to separate repeated measures ANOVAs with group (2: pain vs nonpain) as the between-subjects factor and trial type (2: baseline trial vs resumption trial) as the within-subjects factor, followed by simple contrasts. Subsequently, we investigated our participants' self-reported motivation to perform the ongoing and the interruption tasks by means of a repeated

Table 1

Sample characteristics (ratio or mean values, with SD and range in parenthesis) and group comparisons.

	Pain group (n = 34)	Nonpain group (n = 35)	Comparison
Females/Males	24/10	25/10	$\chi^2(1) = 0.006$, $P = 0.939$
Age	21.44 (3.04, 18-30)	20.91 (2.42, 17-28)	$F(1, 67) = 0.64$, $P = 0.427$, $\eta_P^2 = 0.009$
Pain Catastrophizing Scale	16.65 (8.75, 5-34)	17.18 (8.24, 0-39)	$F(1, 66) = 0.07$, $P = 0.798$, $\eta_P^2 = 0.001$

One nonpain group participant did not fill in the online questionnaires, leaving the group size at n = 34 for the PCS.

measures ANOVA with group (2: pain vs nonpain) as the between-subjects factor and task type (2: ongoing task vs interruption task) as the within-subjects factor. Finally, the self-reported difficulty of and confidence in resuming the ongoing task were subjected to 2 separate univariate ANOVAs with group (2: pain vs nonpain) as the between-subjects factor. To explore the role of pain catastrophizing in the relationships studied, the (centered) PCS score was added to the above analyses as a continuous variable. Statistically significant PCS effects were followed up by correlation analyses with Holm sequential Bonferroni correction.[22]

For all analyses of variance, we report Pillai trace multivariate test results as recommended in case of violation of the assumption of sphericity.[23,26] The reported effect size is η_P^2. Where appropriate, we report mean differences with their 95% confidence interval. Analyses were performed with SPSS version 22.0.[24]

3. Results

3.1. Sample characteristics

The pain group and nonpain group did not differ in sex ratio, age, or PCS score (**Table 1**). The obtained mean PCS scores are similar to those previously found in samples of healthy Dutch-speaking university students (16.6, *SD* = 7.8[11]).

3.2. Manipulation check

3.2.1. Interruption cue characteristics

The electrocutaneous stimuli were rated as significantly more painful, unpleasant, and threatening than the vibrotactile stimuli, the average ratings of which were close to zero (**Table 2**). Altogether, this finding indicates that the vibrotactile stimuli were an appropriate control to pain.

3.2.2. Interruption task performance

The pain group and the nonpain group did not differ in their performances on the interruption task. Specifically, there were no differences in the average number of errors made during the interruption task, $F(1, 67) = 0.002$, $P = 0.965$, $\eta_P^2 = 0$ (pain group: 0.13, *SD* 0.08, range 0.02-0.33; nonpain group: 0.13, *SD* 0.11, range 0.0-0.50) or in the average time spent on the interruption task, $F(1, 67) = 0.14$, $P = 0.712$, $\eta_P^2 = 0.002$ (pain group: 17.33 seconds, *SD* 4.49, range 10.06-26.96; nonpain group: 16.88 seconds, *SD* 5.63, range 9.80-28.71).

3.3. Interruption effects: behavioural outcomes

3.3.1. Sequence accuracy

Overall, the sequence accuracy was lower in resumption trials (pain group: 70.16%, *SD* 18.59, range 22.22-93.75; nonpain group: 75.67%, *SD* 16.52, 18.75-93.75) compared with baseline trials (pain group: 97.08%, *SD* 1.73, range 92.65-99.26; nonpain group: 97.21%, *SD* 1.73, range 91.67-99.26). This difference of approximately 24.23% (95% confidence interval [20.00-28.46]) was statistically significant, $F(1, 67) = 130.84$, $P < 0.001$, $\eta_P^2 = 0.661$. However, there was no statistically significant group difference (main effect group: $F(1, 67) = 1.75$, $P = 0.191$, $\eta_P^2 = 0.025$; group × trial type: $F(1, 67) = 1.62$, $P = 0.208$, $\eta_P^2 = 0.024$). Thus, participants responded to the wrong step in the question sequence more often when they resumed the task than when they were in the flow of the task. This, however, did not depend on whether the ongoing task had been interrupted by pain or by nonpain. Adding the PCS score to the analysis did not essentially change results.

3.3.2. Nonsequence accuracy

Overall, nonsequence accuracy was very high, both in resumption trials (pain group: 97.49%, *SD* 3.83, range 85.42-100.00; nonpain group: 97.70%, *SD* 3.68, range 80.56-100.00), and in baseline trials (pain group: 97.06%, *SD* 2.79, range 86.03-100.00; nonpain group: 97.77%, *SD* 1.77, range 93.01-100.00). The analysis yielded no significant effects (main effect trial type: $F(1, 67) = 0.26$, $P = 0.611$, $\eta_P^2 = 0.004$; main effect group: $F(1, 67) = 0.47$, $P = 0.495$, $\eta_P^2 = 0.007$; group × trial type: $F(1, 67) = 0.50$, $P = 0.483$, $\eta_P^2 = 0.007$), indicating that interruptions, either by painful or by nonpainful stimuli, did not impair accuracy in the content of the questions.

When the centered PCS score was added to the analysis, a statistically significant group × trial type × PCS interaction emerged, $F(1, 64) = 5.68$, $P = 0.020$, $\eta_P^2 = 0.082$. However, a follow-up correlational analysis between the PCS score and nonsequence accuracy in baseline and resumption trials for each group did not yield any statistically significant results ($-0.27 < r < 0.28$, $0.126 < P < 0.856$).

Table 2

Self-reported characteristics of the interruption cue (mean values, with SD and range in parenthesis) and group comparisons.

	Pain group (n = 34)	Nonpain group (n = 35)	Comparison
Painfulness	6.88 (1.27, 3-9)	0.17 (0.45, 0-2)	$F(1, 67) = 860.15$, $P < 0.001$, $\eta_P^2 = 0.928$
Unpleasantness	7.71 (1.31, 3-10)	0.31 (0.72, 0-3)	$F(1, 67) = 846.25$, $P < 0.001$, $\eta_P^2 = 0.927$
Threat value	5.03 (2.15, 0-8)	0.40 (0.81, 0-3)	$F(1, 67) = 141.21$, $P < 0.001$, $\eta_P^2 = 0.678$

3.4. Interruption effects: task experience

Self-reported motivation to perform the ongoing task and the interruption task during the experiment were quite high (**Table 3**) and did not differ between tasks, $F(1, 67) = 0.16$, $P = 0.688$, $\eta_P^2 = 0.002$, or groups (main effect group: $F(1, 67) = 0.19$, $P = 0.669$, $\eta_P^2 = 0.003$; group × task type: $F(1, 67) = 0.44$, $P = 0.511$, $\eta_P^2 = 0.006$). Adding the centered PCS score to the analysis yielded a significant task type × PCS interaction, $F(1, 64) = 9.73$, $P = 0.003$, $\eta_P^2 = 0.132$, but the follow-up correlational analysis did not indicate any statistically significant correlations between the PCS score and motivation to perform the ongoing task or the interruption task for either of the 2 groups ($-0.12 < r < 0.30$, $0.087 < P < 0.506$).

Furthermore, participants reported a high degree of perceived difficulty to resume the ongoing task immediately after an interruption (**Table 3**). There were no group differences in this respect, $F(1, 67) = 0.39$, $P = 0.532$, $\eta_P^2 = 0.006$, but when the PCS was added to this analysis as a continuous variable, a statistically significant PCS effect emerged, $F(1, 65) = 6.14$, $P = 0.016$, $\eta_P^2 = 0.086$. The follow-up correlational analysis showed a moderate positive correlation between pain catastrophizing and perceived difficulty to resume the ongoing task in the nonpain group ($r = 0.56$, $P = 0.001$), but not in the pain group ($r = 0.01$, $P = 0.967$). A post hoc explanation is that high pain catastrophizers who received no pain might have contemplated that they could have received pain and that this thought might have been interfering. Self-reported confidence in resuming the ongoing task correctly was low to moderate and did not differ between groups, $F(1, 67) = 0.003$, $P = 0.958$, $\eta_P^2 = 0$.

4. Discussion

The aim of the present experiment was to investigate the effects of activity interruptions by pain on activity resumption and performance of a relatively complex task. Healthy volunteers performed an ongoing task, in which they responded to a sequence of questions in a specific order.[1,3,20] Occasionally, this ongoing task was halted either by a painful electrocutaneous or by a nonpainful vibrotactile stimulus, immediately followed by the interruption task. The latter required letter typing and was self-paced. After interruption task performance, participants were required to resume the initial task at the step of the sequence where they had left off when the interruption occurred. Accurate resumption demanded that participants remember their positions in the predetermined step sequence.

First, the idea that interruptions impair sequence accuracy was confirmed. Participants were less accurate in resumption trials (ie, the ongoing task trials immediately after an interruption) compared to baseline trials (ie, all other ongoing task trials). When participants came back to the task after an interruption, they appeared to forget *which step* of the predetermined sequence they were required to perform, but had no trouble performing the *content of the step* that they thought they should perform. Interruptions thus appeared to impair the placekeeping ability, that is, the ability to maintain one's position in a sequential task,[20] but not other processes required for task performance, such as recognition of the (perceptual) characteristics of the stimulus. This finding is in line with the computer–human interaction literature in which the same experimental paradigm was used[1,3,20] and with a theoretical model predicting that activity interruptions by pain have negative consequences for performance.[18]

Contrary to our expectations, however, the negative effects of interruptions were not greater for interruptions by painful stimulation as compared to nonpainful stimulation. Rather, participants exhibited a performance decrement of similar magnitude irrespective of whether they had been interrupted by painful electrocutaneous or by nonpainful vibrotactile stimuli and irrespective of their level of pain catastrophizing. Moreover, the type of interruption cue (pain vs nonpain) had no effect on the task experience. The latter was expressed as the self-reported motivation to perform the ongoing task and the interruption task and the self-reported difficulty to and confidence in resuming the ongoing task after an interruption.

Our findings mirror these of 2 other experiments on the effects of activity interruptions by pain on the resumption of the interrupted activity.[17] In these studies, healthy participants performed an ongoing task that required a sequence of joystick movements. Occasionally, they received painful electrocutaneous or nonpainful vibrotactile interruption cues followed by an interruption task. Just as the present study, these experiments showed impaired performance (expressed as lower accuracy and longer response latency) in resumption trials, but of a similar magnitude for interruptions by pain and interruptions by nonpain. Taken together, these 3 studies indicate that activity interruptions by pain do indeed impair activity performance on resumption, but not more than interruptions by other external, nonpainful stimuli. This is in contrast to theoretical accounts of the disruptiveness of pain[14] and to our expectation of a specific pain effect on activity resumption and performance. Furthermore, the (expected) pain effect appeared to be influenced neither by the complexity of the ongoing task, which increased across the 3 studies discussed here, nor by the level of pain catastrophizing(cf.[28]). A number of potential explanations warrant consideration.

First, pain might lead to interrupting activities in a reflexive manner, thus limiting the time and opportunity to encode information about the task at the moment of interruption.[18] In the present experimental paradigm, the sequence of events following the interruption cue was similar for the 2 conditions. Therefore, participants in the pain group and the nonpain group were provided with a similar opportunity to encode task-related information. Also, specific effects of the painful interruption cue might have been overruled by optimal information encoding which might have taken place. This can happen, for instance, when people adjust their strategy because they expect decrements in task performance.[21] Indeed, more than 80% of our participants in both groups reported that they used some type of rehearsal as a strategy that helped them perform the task (cf.[1]).

Second, the disruptive effects of pain might not be long lived, but, rather, only appear in the beginning of the pain experience.[10] Thus, pain might impair performance in a concurrent task[6,8,9,27,36] or in an immediately subsequent task,[30] but its

Table 3

Task experience (mean values, with SD and range in parenthesis).

	Pain group (n = 34)	Nonpain group (n = 35)
Motivation to perform ongoing task	8.56 (1.21, 5-10)	8.51 (1.31, 4-10)
Motivation to perform interruption task	8.68 (1.20, 5-10)	8.49 (1.17, 6-10)
Difficulty to resume ongoing task after an interruption	8.15 (1.78, 0-10)	7.86 (2.05, 1-10)
Confidence in resuming ongoing task correctly after an interruption	3.97 (2.17, 0-9)	3.94 (2.24, 0-9)

Ratings were given on an 11-point numerical scale (0 = not at all; 10 = to a very high degree).

effects on a task that is resumed after a longer time might in the meantime be washed out, for example, because they are countered by compensation strategies that make up for the impairment that has occurred. A careful examination of the time course of pain effects will offer insight into this issue.

The experimental paradigm we used is more complex than those of previous studies on the effects of activity interruptions by pain.[17] In fact, the original UNRAVEL paradigm has been designed specifically to produce an error variance high enough for the meaningful investigation of interruption effects on sequence accuracy.[1] The similarity of the present results with those of previous experiments[17] indicates that ongoing task complexity might not moderate the (expected) effects of pain. To provide a clear answer regarding the role of ongoing task complexity, however, future research may consider it as a separate factor in the experimental design.

This study is not without limitations. First, our sample consisted of healthy university students. It is unclear whether results generalize to other samples, including clinical populations. Furthermore, SKRIVEL is a made-up acronym but not an actual Dutch word. When adjusting the original UNRAVEL task[1,20] to match the needs of our Dutch-speaking sample, we prioritized staying close to the original stimulus type (the letter-digit combinations) and question content. However, we highlighted the acronym by visually emphasizing it in the instructions and by consistently referring to the task as the "SKRIVEL task." Nevertheless, this shortcoming might explain the somewhat higher error rate in resumption trials in the present study, in relation to studies using the original paradigm.[1,20]

In addition, our participants received a brief electrocutaneous or vibrotactile stimulation. Tonic pain (such as that produced by the cold pressor or a blood pressure cuff) is by definition present for a longer time and might thus lead to larger impairments in information encoding (potentially also in other processes taking place at different stages of an interruption[18]). Such longer lasting painful stimulation may allow for the specific effects of pain to become more apparent. It is worthwhile to consider different parameters of the pain stimulus, such as the type or duration of pain. Of course, task parameters other than task complexity (such as task importance or degree of engagement in the task) might also constitute interesting avenues for future research.

Knowledge from the systematic investigation of activity interruptions by pain is relevant for the better understanding of processes taking place when people in pain take breaks from their activities. Taking breaks and alternating activity with rest are parts of a therapeutic technique called Activity Pacing,[4,29] which calls people with (chronic) pain to regulate their activity level and/or rate to achieve adaptive goals.[29] One theoretical approach to Activity Pacing stems from the operant learning theory[15,19,29] and suggests that patients take breaks contingent on the completion of an activity goal, rather than on pain. However, if interruptions by pain are indeed not more impairing than interruptions by nonpain as suggested by the present and by previous findings,[17] it may well be that break contingency is irrelevant to activity resumption and performance. Future research needs to examine these issues in detail to shed light on the type of breaks that may be useful for people with pain.

In conclusion, the present study provides additional evidence that activity interruptions by pain impair activity performance on resumption, but not more so than activity interruptions by other, nonpainful stimuli. It extends previous research on activity interruptions by pain using an adaptation of a well-founded paradigm that has been successfully used for the laboratory study of interruptions in the field of computer–human interaction.[1,3,20] Future research may investigate the role of other parameters relating to the interrupted or the interruption task, the pain stimulus, and the person being interrupted by pain, which may make activity interruptions by pain, especially disruptive.

Conflict of interest statement

The authors have no conflicts of interest to declare.

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