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Attentional interference, but no attentional bias, by tonic itch and pain stimulation

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Introduction: Attentional processes are involved in the experience of itch and pain. They interrupt task performance (ie, attentional interference) or bias allocation of attention toward the somatosensory stimulation, that is, attentional bias (AB). Research on AB toward pain is mostly focused on stimuli with short durations; hampering generalization to tonic pain sensations. Evidence for AB toward itch is lacking so far. This study investigated attentional interference by—and AB toward—experimentally induced tonic itch and pain.

Methods: Fifty healthy volunteers performed a somatosensory attention task (SAT), that measured attentional interference and AB during tonic (35 s duration) pain, itch and vibrotactile stimuli. In addition, a dot-probe task measured AB toward visual representations of itch and pain, a Flanker task was used to assess attentional inhibition, and self-reported characteristics were measured.

Results: Attentional interference during itch and pain stimuli compared with vibrotactile stimuli was found during the SAT. Exploration of shorter time segments within one tonic stimulus showed slowed responses for all three stimulus types during the first 5 seconds of stimulation. However, no prolonged interference in the following time segments was found. There was no AB toward somatosensory and visual stimuli. Furthermore, there was no association between any of the attentional measures and self-reported characteristics.

Discussion: These findings suggest that the beginning of any somatosensory stimulus is interfering with cognitive performance, but the results for prolonged interference by itch and pain are equivocal. There was no indication for biased attention allocation. Whether this pattern is different in patients remains to be investigated in the future.

Keywords: Attention, Pruritus, Pain, Interference, Cognitive bias

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Itch and pain signal potential threats to the body. In most situations, this is an adaptive mechanism that leads to behavioral adjustment. It has been suggested that itch and pain interrupt ongoing behavior, and that attention is drawn toward the location of these stimuli, that is, an attentional bias (AB) toward itch and pain occurs[1–4]. This is in accordance with the functional attentional system as described by Allport[5], which states that the attentional system makes a difference between stimuli that are irrelevant to the ongoing behavior (eg, distracting noises in the office) while relevant stimuli that adaptively interrupt behavior (eg, a fire alarm) are drawing attention.

Studies using somatosensory stimuli have shown that pain interferes with the performance of a concurrent task. These studies mostly used short (phasic) stimuli[6–9], but support also comes from studies with longer (tonic) stimuli[10–12], and from studies that used naturalistic pain[13–16]. Evidence for itch is lacking; the only 2 studies on interference by tonic itch on a cognitive task yielded conflicting results[11,17]. However, similarities in the physiology of itch and pain, and their shared protective function[18,19], suggest that itch also causes attentional interference.

Besides overall interference of itch and pain on task performance, people might show an AB toward itchy or painful somatosensory stimuli. Findings regarding AB toward painful stimuli are mixed for experimental pain in healthy participants, and AB toward itchy stimuli has not yet been demonstrated[11,17,20,21]. With regard to differences between phasic and tonic stimuli, an AB toward phasic pain has been shown[20,22], whereas an AB toward tonic pain is not yet supported[11]. Studies suggest that during tonic stimuli attention may fluctuate, which calls for a more fine-grained analysis of the time course of attention effects[11]. There is some evidence of an AB toward visual representations of itch and pain[4,17,23–26], but visual stimuli are inherently different from the somatosensory sensation of itch and pain, which promotes more research on actual somatosensory stimuli. In addition, inconclusive evidence has emerged from explaining the mixed findings by individual differences (eg, neuroticism or catastrophizing)[11,17,22,23,27]. Lastly, investigations of attentional inhibition, that is, inhibiting irrelevant information and attending to the relevant information[28], may predict how well people can adjust their task performance when experiencing pain or itch[29–31].

Therefore, the current study aimed to examine attentional interference by tonic itch and pain stimuli (ie, representing acute itch and pain) and an AB toward these stimuli in a healthy sample. It was hypothesized that responses on a concurrent task would be slowed down by somatosensory itch and pain compared with vibrotactile control stimulation. Secondly, it was hypothesized that people show an AB toward the itch and pain stimulation. In addition, it was explored whether fluctuations in attention occur during the stimulus and whether there is an AB toward visual representations of itch and pain.

Methods

Participants

Fifty healthy volunteers (10 males, 40 females) aged between 18 and 31 years [$M = 21.9$, $SD = 2.78$] participated in this study. The minimum required sample size was 42, based on power calculations using a power of 0.80, an α of 0.05, and an effect size of $d = 0.45$, that is, the smallest interference effect of itch on attention observed in a previous study with a similar SAT set-up with healthy participants[17]. Additional participants were included to account for potential data loss, for example, due to technical issues. Inclusion criteria were being aged between 18 and 30 years old (1 participant turned 31 between sign-up and the testing session) and being fluent in the Dutch language. Exclusion criteria were: severe or long-term morbidity (eg, diabetes mellitus, atopic eczema, rheumatoid arthritis), psychiatric disorders (eg, depression), use of a pacemaker or pregnancy as a safety precaution of the electrical stimulation, chronic pain or itch complaints [> 2 on a numeric rating scale (NRS) from 0 to 10; no pain/itch—worst imaginable pain/itch], and current medication use (eg, analgesics or antihistamines).

Participants were recruited via advertisements at the faculty of Social and Behavioural Sciences of Leiden University, the Leiden University Research Participation system (SONA systems Ltd, Tallinn, Estonia), and on a national website for the recruitment of research participants (http://www.proefpersonen.nl). All participants provided written informed consent. Research complied with all relevant national regulations, institutional policies and, is in accordance with the tenets of the Helsinki Declaration (as amended in 2013), and has been approved by the METC Leiden-Den Haag-Delft, local Medical Ethical Committee (NL54237.058.15).

Design

This is an experimental study with a within-subjects design, in which attentional processing of somatosensory itch and pain stimuli was investigated on a behavioral level with computerized attention tasks, combined with electroencephalography (EEG) measurements to investigate underlying neurophysiology (for which data will be presented in another paper).

Procedure

Potential participants received written information about the study procedures in which the study was described as an investigation of the perception of itch and pain. They were screened online via Qualtrics (Provo, UT) to obtain information on demographics, psychiatric and medical history, and current itch and pain levels. Moreover, participants filled in a battery of self-report questionnaires. Participants were instructed to refrain from medication, alcohol, and drugs 24 hours before the testing session and not to smoke or consume caffeine 1 hour before the testing session.

Testing sessions took place at the faculty of Social and Behavioural Sciences of Leiden University. The session started with a brief explanation of the procedures and a check of inclusion and exclusion criteria, after which participants signed the informed consent. Participants reported experience of current itch and pain (yes/no), rated their current levels of fatigue from 0 (no fatigue) to 10 (worst fatigue ever experienced) on an NRS and filled in a questionnaire on depression, anxiety, and stress levels via Qualtrics. Thereafter, participants performed a computerized task on attentional inhibition. Next, participants were prepared for EEG measures. Brain activity was recorded during rest, during somatosensory stimulation and during all attention tasks.

Thereafter, a comparable hand temperature between participants was induced with a warm water bath immersion and then the somatosensory electrodes were attached. During the whole procedure, participants were asked neither to touch the electrodes, nor to scratch the surrounding area to prevent displacement of the electrodes and invalidating the stimulation. Next, a step-up procedure was employed to determine an individually tailored intensity of the somatosensory stimuli followed by a 5-minute break in which participants engaged in filler tasks (ie, finding differences between 2 pictures[32]) irrelevant to the experiment. Participants then received stimulation-only baseline somatosensory pain, itch and vibrotactile stimuli, and subsequently the somatosensory attention task (SAT) was administered. During the step-up, the baseline and the SAT, participants received standardized instructions via headphones. After the SAT, the somatosensory electrodes were removed, and participants performed a computerized visual AB task. Thereafter, the EEG electrodes were removed. Lastly, participants answered an Exit questionnaire on paper, were debriefed, and obtained a monetary reimbursement. The complete procedure took about 3 hours.

Somatosensory stimuli and step-up procedures

Itch and pain stimuli were delivered in accordance with earlier studies[11,17,33], by an Isolated Bipolar Constant Current Stimulator DS5 (Digitimer, UK) to induce comparable itch and pain in the same modality. Vibrotactile (control) stimuli were delivered through 2 C-2 tactors (Engineering Acoustics Inc., Florida)[34]. As preparation for the somatosensory induction,

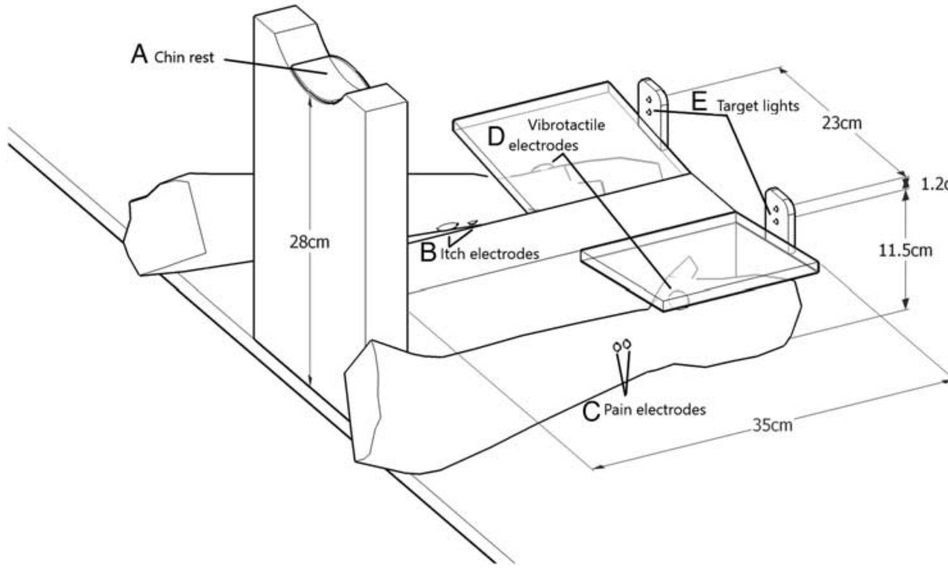

Figure 1. Experimental set-up showing the electrode locations (B: itch, C: pain, D: control) and the locations of the participant (A, chin rest) in relation to the target lights (E).

participants held both hands and wrists for a duration of 3 minutes in a warm water bath of about 34 °C to induce comparable baseline hand temperature[35]. **Figure 1** shows the experimental set-up. Electrodes for pain (**Fig. 1C**) and itch (**Fig. 1B**) stimuli were attached to the wrists, placement of itch and pain on the right or left hand was counterbalanced across participants, and vibrotactile (pulsating) stimuli (**Fig. 1D**) were attached on both hands. Participants were positioned with their head in a chin rest (**Fig. 1A**), their arms symmetrically on a platform, and their left and right foot on a left and right foot pedal, respectively.

Individual stimulus intensities of the somatosensory stimuli were determined through step-up procedures aiming at inducing perceived pain, itch and vibrotactile sensations of at least 5 on a slider box with NRS ranging from 0 (not at all) to 10 (worst imaginable) (**Table 1**). During stimulation, participants continuously rated their perception of the stimuli on this slider box on *painful, itchy intensity*, and *unpleasantness*. Each step-up procedure was finished as soon as the targeted NRS ≥ 5 on the scale of interest for the specific stimulus type (eg, $NRS_{pain} > 5$ after a pain stimulus) was reached or the maximum stimulus strength (mA) was delivered (**Table 1**). Whenever NRS ≥ 7, the intensity of the previous step of the procedure was taken as target intensity, for example, the rating suddenly increased from NRS = 4.7 to NRS = 7.5. For the pain stimulus *painful* was the scale of interest (NRS_{pain}), for the itch stimulus *itchy* (NRS_{itch}) was the scale of interest and for the vibrotactile stimulus *intensity* ($NRS_{intensity}$) was the scale of interest. The intensity was defined as an increasing/stronger sensation that is not specifically painful or itchy. Participants who did not exceed an NRS ≥ 2 for both, itch and pain stimuli during the step-up procedure were excluded from the study right after the step-up procedure and were replaced by another participant. After the step-up procedure, 2 blocks of 35 seconds per stimulus type at the individual determined target intensities were subsequently applied as baseline stimuli. During these baseline stimuli, no tasks were administered to the participants. After every stimulus during baseline and during the SAT, participants rated their mean experience of the whole stimulus on the same slider box once. Thereafter, participants rated their current sensation again, at 30 seconds and again at 60 seconds after the stimulation has ended. In between blocks of different stimulus types, that is pain, itch or control, current sensations were rated every 30 seconds until a total of 180 seconds, that is at 30, 60, 90 seconds, etc. If participants scored NRS > 2 at 60 seconds after a stimulus or at 180 seconds after a block, they were asked to rate their current sensations again every 30 seconds until scores were NRS <2, which means

Table 1

Specifications of somatosensory stimuli and the employed step-up procedures to determine individual stimulus intensities.

	Electrodes	Frequency, Pulse Duration	Step-up Procedure	Maximum Intensity	Targeted NRS
Pain	Two disk electrodes of ø 1 cm attached to the dorsal side of the wrist	50 Hz, 0.4 ms	20 s stimuli starting at 1 mA, building up in steps of 1 mA	6 mA	≥ 5 NRS_{pain}
Itch	One disk electrode of ø 1 cm and a reference electrode of ø 2 cm attached to the ventral side of the wrist	50 Hz, 0.1 ms	120 s stimuli with continuous ramping of 0.05 mA, starting at 0 mA	6 mA	≥ 5 NRS_{itch}
Control	One C-2 tactor of ø 3.05 cm attached on the dorsal side of each hand (between thumb and index finger)	220 Hz, ~	20 s stimuli, increasing in 6 steps (arbitrary unit)	Step 6	≥ 5 $NRS_{intensity}$

Technical set-up and procedures adapted from Vanden Bulcke et al[34] and van Laarhoven et al[11].

the ratings were continued until the NRS of interest (eg, NRS_{pain} after a pain stimulus) were sufficiently low to continue with the task to minimize the risk of carry over effects of previous stimuli.

Attentional tasks

All computerized tasks were designed and administered using E-prime software version 2.0 (Psychology Software Tools Inc., Sharpsburg). Responses were collected with a regular keyboard or with foot pedals (Marquardt GmbH, Rietheim-Weilheim, Germany) that were connected with E-Prime via a Chronos box (Psychology Software Tools Inc.). Also, the audio output and the self-made slider box for NRS ratings were connected to the computer via the Chronos box.

SAT

Interference by and AB toward induced somatosensory stimuli were measured with a SAT[11,17]. The 12 blocks of the SAT consisted of 4 consecutive blocks of 1 of the 3 somatosensory stimuli type (ie, pain block, itch block, control block). The order of stimulus type was randomized across participants to minimize possible interactions of stimuli. Stimulation side of itch and pain stimuli were randomized across participants, but stayed constant within each participant. The first and third block of the vibrotactile stimuli were delivered on the right hand and during the second and fourth block on the left hand or vice versa (randomized).

While delivering the somatosensory stimuli for a duration of 35 seconds each, each block contained 15 trials in which 1 or 2 visual targets (green LED lights) were turned on at once on either the left or right side for 200 ms with a maximum response window of 1500 ms (**Fig. 1E**). Randomized intertrial intervals of 300, 500, and 1100 ms were used. Participants were asked to focus on the visual targets and indicate whether 1 or 2 lights lighted up via foot pedals (correct response mapping was randomized across the sample).

Congruent trials were trials in which the visual target(s) appeared ipsilateral to the side of the somatosensory stimuli and incongruent trials were trials in which the visual target(s) appeared contralateral to the side of the somatosensory stimuli. Semi-randomization of visual targets was used for each block so that no more than 2 incongruent or 2 congruent trials would be presented sequentially. Two practice blocks of 15 trials with the visual targets, but without any somatosensory stimulation, preceded the actual SAT. The total task took ~30 minutes to administer. Reaction times (RT) and accuracy to respond to the visual targets were measured.

Dot probe task for itch and pain

A previously used pictorial dot-probe task was used as a measure of AB for pain-related and itch-related information[36]. Validated pain, itch, and negative (eg, garbage) pictures of comparable valence were paired with neutral pictures of skin or objects (eg, pencil), matched in color and brightness as much as possible[36]. Neutral skin pictures depicted body parts (eg, knee, head, back) of nonidentifiable individuals (male and female). The itch and pain pictures showed either scratching (itch pictures) or supporting/holding (pain pictures) these same body parts. One trial consisted of the presentation of a central fixation cross for 500 ms, after which 2 pictures were simultaneously presented for 500 ms on the screen followed by the appearance of 2 horizontal or 2 vertical dots (target stimulus; maximum response window 1500 ms). Participants were instructed to respond to the orientation of the target stimulus by pressing foot pedals (eg, left pedal for horizontal dots and right pedal for vertical dots, counterbalanced across the sample). First, 16 practice trials and 2 first trials were administered containing only neutral-neutral pairs that were not used for analyses, followed by 240 experimental trials in which a pain, itch or negative picture was always shown with a neutral picture. A 30 seconds break was included after every 40 trials and in total the task took 10–15 minutes. RTs and accuracy to respond to target stimuli were measured.

Attentional inhibition

The Flanker task was used to measure inhibitory control, which is part of selective attentional processing, in the following called general attentional inhibition unrelated to pain or itch[6]. After presentation of a central fixation cross of 500 ms, participants were presented with a target stimulus "2" or "4." The target stimulus was flanked by 2 nontarget stimuli on each side, which were either congruent (ie, same as target stimulus) or incongruent (ie, different from target stimulus). Participants were instructed to indicate which target stimulus had appeared on the screen. Participants responded by pressing the correct button on a standard keyboard with their index finger (left arrow key if the target was "2" and right arrow key if the target was "4"). Participants first completed 8 practice trials, followed by a total of 120 trials (randomized 50% congruent, 50% incongruent) with a break halfway. The entire task lasted ~5 minutes. RT and accuracy to respond to target stimuli were measured.

Self-report questionnaires

Self-reported attentional disengagement from pain, itch and fatigue was assessed with 3 Likert scales ranging from 1 (not at all) to 5 (always) (eg, If you feel pain, to what extent are you able to continue with your daily routine as if you did not feel pain?)[11]. Attentional focus on bodily sensations was assessed with the Body Vigilance Scale (BVS; 4 items)[37]. The fourth item of the BVS is originally divided into 15 sub-items, each measuring attentional focus on a specific anxiety-related bodily sensation. Only sub-items about bodily sensations were included and therefore 2 sub-items about dissociation were omitted and replaced with 2 items to measure attentional focus on itch and pain[11]. Attentional focus on itch and pain was measured with the Pain Vigilance and Awareness Questionnaire (PVAQ; 16 items)[38], and the PVAQ adjusted for itch (PVAQ-I, 16 items)[36]. Catastrophizing was assessed with the Pain Catastrophizing Scale (PCS; 13 items)[39] and PCS-adjusted for itch (PCS-I, 13 items)[33]. Cognitive intrusion was measured with the scale Experience of Cognitive Intrusion of Pain (ECIP; 10 items)[40] and ECIP-adjusted for itch (ECIP-I; 10 items)[17]. Neuroticism was measured with the subscale neuroticism of the Eysenck Personality Questionnaire—revised short form (EPQ-RSS; 12 items)[41]. Psychological distress was measured with the Depression Anxiety Stress Scale short version (DASS-21; 21 items)[42]. For all questionnaires, total scores were used for analyses with higher scores indicating higher levels of the specific trait measured with the questionnaire, for example, higher total PCS score indicates more pain catastrophizing and higher total BVS score indicates more body vigilance. Due to a technical error, both versions of the ECIP were recorded on a 6-point Likert-scale instead of a 7-point Likert-scale and the DASS-21 could not be used. All other questionnaires were recorded properly. A short set of questions was given as Exit questionnaire after the experiment concerning how much they were able to ignore the stimulation during the concurrent task on Likert scales from 0 (never) to 6 (always), as well as whether other factors (ie, itch, pain, vibration, environment, experimenter, temperature, own thoughts, fatigue, and hunger/thirst) influenced their concentration during the task on a scale from 1 (not at all) to 5 (very much), and how threatening the stimuli were experienced on an NRS from 0 (not threatening) to 10 (very much threatening).

Statistical analyses

Mean RT and accuracy for each participant on the attention tasks were extracted from E-prime. From the SAT data, trials with RTs > 150 ms and only correct responses were included. From the dot-probe task and the Flanker task, only trials with 150 <RT <1500 ms and correct responses were included[11]. In addition, data from participants making > 30% mistakes in the Flanker task, SAT or the dot-probe task were excluded from the statistical analyses of the corresponding task (N = 2 for the SAT, N = 2 for the dot-probe task)[11,17]. Due to time constraints caused by technical issues, data of the itch blocks during the SAT and the dot-probe task could not be collected for 1 participant. Statistical tests were carried out using SPSS version 23.0 (IBM SPSS Statistics for Windows, Armonk, NY). For all analyses, if not stated otherwise, a significance level of $\alpha < 0.05$ was considered significant. As a measure of effect size for each repeated measures analysis of variance (RM ANOVA), η_p^2 was used. All values are represented as mean ± SD ($M \pm$ SD) unless stated otherwise.

Manipulation check of somatosensory induction

The manipulation was checked by verifying that the somatosensory induction of itch and pain were indeed perceived as painful and itchy, respectively. Inspection of the distribution of the different NRS variables showed that the assumption of normality was not met and log transformation could not solve this issue. Therefore, nonparametric tests were employed. Separate Friedman tests were used to compare the ratings on pain, itch and intensity for each stimulus type separately, for example, the mean *pain*, *itch*, and *intensity* ratings of the *pain* stimuli were compared. In addition, Wilcoxon Signed Ranked tests were done as planned comparisons to compare the different ratings separately with each other, that is, comparing *pain* and *itch* ratings, *pain* and *intensity* ratings and i*tch* and *intensity* ratings. A Bonferroni correction was applied due to multiple testing with the Wilcoxon Signed Rank test (ie, $\alpha = 0.05$ divided by 3 tests, resulting in an $\alpha_{corrected} = 0.017$). These analyses were done for the baseline stimuli and the SAT stimuli separately. Furthermore, a Friedman test was employed to compare unpleasantness ratings of the 3 different stimulus types during baseline and the SAT, again followed by Wilcoxon Signed Ranked tests with Bonferroni correction for planned comparisons. Similarly, the experienced threat value for each stimulus type was compared with a Friedman test and post hoc Wilcoxon Signed Rank tests, again with a Bonferroni correction.

Attentional interference and AB

One outlier (step of 1.5 × interquartile range) in mean RT of incongruent trials during the SAT pain blocks was identified and all SAT analyses were therefore performed including and excluding data of this participant. RTs for visual targets during the SAT were compared between itch and pain stimulation and vibrotactile stimulation by means of planned simple contrasts of pain/itch blocks to control blocks within a 3 (stimulus type: pain, itch, control) × 2 (congruency: congruent, incongruent) within-subjects RM ANOVA. The primary research question of attentional interference by itch and pain compared with control stimuli was examined with the main effect of stimulus type and corresponding contrasts. The secondary research question that itch and pain draw attention to their location was examined with the stimulus type × congruency interaction effect and its corresponding contrasts. Sensitivity analyses without participants that had very low sensations and people that had contaminating sensations (eg, felt itch during pain stimulus) were done. Details of these analyses and their results are described in the Supplementary Material Methods S1 (Supplemental Digital Content 1, http://links.lww.com/ITX/A7).

Time course of attentional interference and AB

In order to meet the assumptions of normality, analyses on the time segments of the SAT data were conducted after log10-transforming RTs. To examine the time course of attention over the different stimulus types, each 35 seconds SAT block was divided into 7 equal and consecutive segments of 5s of which the mean RTs per segment for correct incongruent and correct congruent trials of each stimulus type were calculated using MATLAB (Mathworks, 2011). A 2 (congruency: congruent, incongruent) × 3 (stimulus type: itch, pain, control) × 7 (time segment: 1–7) RM ANOVA was performed, with all factors as within-subject factors. The interaction effect of congruency × segment number was of interest, as this shows whether and when attention allocation toward the stimulus location occur, that is AB. Planned contrasts were specified to compare RTs in the first segment with the RTs of all subsequent segments. In addition, post hoc tests with a Sidak correction[43] further explored possible significant changes of attention between segments. Also, the interaction of stimulus type × segment number, as well as the 3-way interaction between stimulus type × congruency × segment number was explored to investigate possible differences in interference between stimuli types over time and differences in AB between stimulus types over time.

AB and attentional inhibition

For the dot-probe task, a 3 (trial type: itch, pain, negative) × 2 (congruent vs. incongruent) RM ANOVA was performed with both factors as within-subject factors. Post hoc tests with a Sidak correction[43] were specified to explore significant main effects. Data of the Flanker task was analysed by conducting a RM ANOVA with congruency (congruent vs. incongruent) as within-subjects factor and RT as outcome variable.

AB and interference indices and associations with other measurements

AB indices for itch and pain were calculated using the formula $RT_{incongruent} - RT_{congruent}$ for the itch and pain blocks of the

Table 2

Median (25%; 75% percentile) numeric rating scale (NRS) score for pain, itch, and intensity ratings per stimulus during baseline and during the somatosensory attention task (SAT) (n = 50).

	NRS_{pain}	NRS_{itch}	$NRS_{intensity}$	Significant Comparisons
Baseline				
Pain*	*2.9 (1.8; 4.6)*	0.0 (0.0; 0.5)	3.8 (1.9; 5,1)	Painful > itchy
Itch*	0.0 (0.0; 0.8)	*1.5 (0.9; 2.5)*	1.0 (0.3; 2.0)	Itchy > painful
Control*	0.0 (0.0; 0.0)	0.0 (0.0; 0.4)	*2.8 (1.7; 3.5)*	Intense > painful, intense > itchy
SAT				
Pain*	*2.0 (1.3; 3.9)*	0.0 (0.0; 0.0)	2.2 (1.2; 3.5)	Painful > itchy
Itch*†	0.0 (0.0; 0.0)	*1.0 (0.5; 1.7)*	0.5 (0.1; 1.1)	Itchy > painful; itchy > intense
Control*	0.0 (0.0; 0.0)	0.0 (0.0; 0.2)	*1.8 (1.3; 2,4)*	Intense > painful, intense > itchy

The NRS of interest per stimulus type is italicized.
*Friedman test showed significant difference between NRS_{pain}, NRS_{itch}, and $NRS_{intensity}$, $P < 0.001$.
†n = 49 due to a missing itch block for 1 participant.

SAT separately. A higher index is indicative of a stronger AB towards pain or itch, respectively. For the Flanker and dot-probe task, a congruency index was calculated by the same formula: higher indices on the dot-probe task indicating more AB and higher indices on the Flanker task indicating less attentional inhibition. In addition, post hoc analyses were done with an interference index for itch and pain, calculated by $RT_{pain\ or\ itch} - RT_{control}$, with a higher index suggesting more interference. All indices were subsequently correlated with data from self-report questionnaires to explore associations between individual characteristics and AB, as well as interference for somatosensory itch and pain. In addition, associations between the 3 behavioral tasks were explored by correlating the itch and pain indices of the SAT and the congruency indices of the dot-probe task and the Flanker task.

Results

Manipulation check of somatosensory induction

Descriptive statistics for the NRS ratings and significant differences in ratings per stimulus type during the stimulation-only baseline stimuli and during the SAT can be found in **Table 2**.

Concerning the unpleasantness ratings during the stimulation-only baseline, significant differences appeared, $\chi^2_{(2,\ N=48)} = 38.83$, $P < 0.001$. With pain ($M = 3.6$) and itch ($M = 1.1$) stimuli being significantly more unpleasant than control ($M = 0.6$) stimuli, $Z = -5.41$, $P = 0.006$ and $Z = -2.75$, $P < 0.001$, respectively. Unpleasantness ratings for the 3 stimulus types during the SAT also significantly differed from each other, $\chi^2_{(2,\ N=47)} = 44.73$, $P < 0.001$. Planned comparisons showed that pain ($M = 2.4$) and itch ($M = 0.8$) stimuli were significantly more unpleasant than vibrotactile control ($M = 0.4$) stimuli, $Z = -5.46$, $P < 0.001$ and $Z = -3.13$, $P < 0.001$, respectively.

Low and contaminating sensations

Although, all participants had sufficiently high itch and pain ratings during the step-up procedure, 16 participants reported $NRS_{pain} < 1$ during the pain blocks *and/or* reported $NRS_{itch} < 1$ during the itch blocks of the baseline stimuli. Seven participants reported $NRS_{pain} < 1$ during the pain blocks *and* $NRS_{itch} < 1$ during the itch blocks of the SAT. In addition, 5 participants experienced $NRS_{itch} > 1$ during the pain blocks of the SAT in addition to painful, pointing toward no pure pain sensation in these participants. No participants did report $NRS_{pain} > 1$ during the itch blocks of the SAT. Figure S1 (Supplemental Digital Content 2, http://links.lww.com/ITX/A8) shows itch and pain ratings for each participant for each stimulation type during the SAT, and further details on sensitivity analyses without these participants can be found in the Supplementary Material Results S1 (Supplemental Digital Content 1, http://links.lww.com/ITX/A7).

SAT

The average accuracy score was 94% for all trials of the SAT, ranging from 80% to 100% correct. Analyses without the one outlier in RT on incongruent trials during the pain blocks (n = 47) did not change the results.

Attentional interference

As hypothesized, participants responded slower during the itch and pain blocks compared with the control blocks (**Fig. 2**), indicated by a significant simple contrast for pain versus control stimuli, $F_{1,47} = 6.78$, $P = 0.012$, $\eta_p^2 = 0.126$, and itch versus control stimuli, $F_{(1,47)} = 6.37$, $P = 0.015$, $\eta_p^2 = 0.119$ (main effect of stimulus type, $F_{2,\ 94} = 4.29$, $P = 0.016$, $\eta_p^2 = 0.084$). However, there was no significant difference between itch and pain blocks, $F_{1,47} = 0.437$, $P = 0.512$, $\eta_p^2 = 0.009$.

AB

The hypothesis that participants respond faster if the location of the visual target was congruent with the side of itch and pain stimulation compared to the incongruent location could not be confirmed, as the stimulus type × congruency effect was not significant, $F_{2,94} = 1.50$, $P = 0.229$, $\eta_p^2 = 0.031$. All corresponding contrasts were also not significant ($P > 0.05$). The main effect of

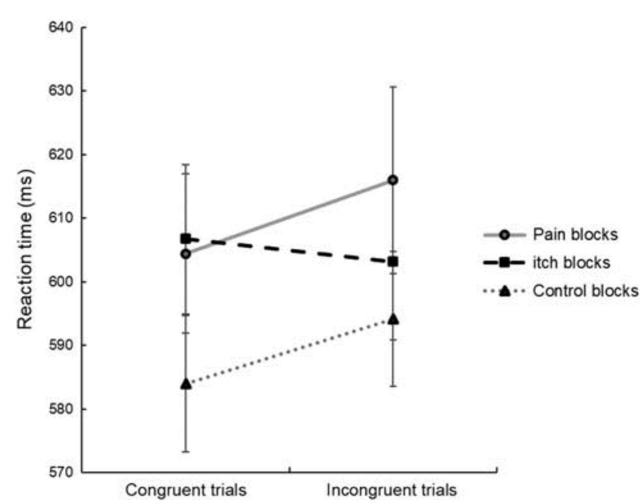

Figure 2. Mean reaction times (ms) of congruent and incongruent trials for the pain, itch, and control blocks in the somatosensory attention task (N = 48). Error bars represent ±1 standard error of the mean.

congruency was not significant either, $F_{1,47} = 2.67$, $P = 0.109$, $\eta_p^2 = 0.054$.

Time course of AB and interference during the SAT

Medians and interquartile ranges of RTs per time segment can be found in Table S1 (Supplemental Digital Content 3, http://links.lww.com/ITX/A9), as well as mean RTs for the time segments per stimulus type in Figure S2 (Supplemental Digital Content 4, http://links.lww.com/ITX/A10). In contrast with the hypothesis, results indicated no shifts in attention allocation toward the location of the somatosensory stimulation, that is no AB; the congruency × segment number effect was not significant, $F_{6,\ 252} = 1.60$, $P = 0.147$, $\eta_p^2 = 0.037$. The main effect of time segment was significant, $F_{6,\ 252} = 22.68$, $P < 0.001$, $\eta_p^2 = 0.351$. Simple contrast analysis revealed that RTs were significantly slower in the first segment than in all subsequent segments ($P < 0.01$), suggesting a larger interference effect in the beginning of stimulation for all stimulus types. In a further exploration of this main effect, post hoc comparisons of RTs in the last time segment with each of the previous time segments showed that RTs were significantly faster in the last segment than in the second and third segments (both $P < 0.001$), whereas RTs in the last segment did not significantly differ from RTs in the fourth, fifth, and sixth segment (all $P > 0.05$). All other main effects and interaction effects appeared to be nonsignificant.

AB toward visual representations of pain- and itch during the dot-probe task

The average accuracy score was 95% (range 83%–100%) for the dot-probe task. Mean reaction times and SDs can be found in **Table 3**. Results showed a significant main effect of trial type, indicating significant differences in RTs between trials with itch, pain, and negative pictures, $F_{2,92} = 9.14$, $P < 0.001$, $\eta_p^2 = 0.16$. Post hoc pairwise comparisons revealed significantly longer RTs for negative trials compared with pain trials ($P = 0.002$) and compared with itch trials ($P = 0.004$) and no significant difference between itch and pain trials ($P = 1.0$). No significant main effect was found for congruency, $F_{1,47} = 0.086$, $P = 0.771$, $\eta_p^2 = 0.002$ and also the congruency × trial type interaction was not significant, $F_{2,94} = 0.938$, $P = 0.395$, $\eta_p^2 = 0.020$.

General attentional inhibition during the Flanker task

The average accuracy score was 96% (range 88%–100%) for the Flanker task. RTs were significantly longer for incongruent (496.55 ms ± 68.57) than for congruent trials (451.48 ms ± 69.72), $F_{1,49} = 240.03$, $P < 0.001$, $\eta_p^2 = 0.83$.

Table 3

Reaction times (RT, in ms) for trials of the dot-probe task per trial type (pain, itch, negative) (n = 47), Mean ± SD.

	RT Congruent Trials	RT Incongruent Trials
Pain trials	631.83 ± 71.59	626.76 ± 80.68
Itch trials	624.27 ± 78.75	633.01 ± 86.47
Negative trials	645.44 ± 88.92	644.21 ± 87.11

Relations between individual characteristics and congruency indices

No significant correlations (all $P > 0.05$) were found between the SAT AB indices for itch and pain and outcomes of the Flanker task, dot-probe task, and self-report questionnaires. For the SAT interference indices, some significant correlations were found, namely between the itch interference index and the pain trials of the dot-probe task, and between the pain interference index and the itch trials of the dot-probe task and disengagement from itch and pain (all $P < 0.05$). Descriptive statistics for the questionnaires can be found in Table S2 (Supplemental Digital Content 5, http://links.lww.com/ITX/A11) and all correlations can be found in Table S3 (Supplemental Digital Content 6, http://links.lww.com/ITX/A12).

Discussion

The findings of the current study demonstrate attentional interference with task performance by itch and pain in comparison to a vibrotactile control stimulus in healthy individuals. Participants responded generally slower during itch and pain stimuli than during control stimuli. Contrary to our expectations, attention was not systematically allocated toward the location of the itch and pain stimuli: that is, there was no AB toward somatosensory stimuli. Exploratory analyses of the time course of attention suggest that overall responses were slower during the first 5 seconds after stimulus onset, but that this was also true for vibrotactile stimuli and that attention was not allocated toward the stimulus locations. Our results therefore point toward attentional interference by itch and pain, but could not support an AB toward itch and pain.

The finding that both itch and pain, rather than vibrotactile stimulation, can interfere with a concurrent task replicates the results of one previous study showing interference by tonic itch and pain stimuli on attention[11], although no attentional interference was found for itch alone in another study[17]. Possible explanations for this discrepancy might be a smaller sample size in the latter study[17], as well as lower itch ratings compared with the current study and the earlier study on itch and pain[11]. In any case, the current findings add to the evidence that experimental pain interferes with the execution of a cognitive task, for example[13,44], but also of simulated everyday tasks such as making breakfast, or of actual driving skills[10,15]. These results are in line with the assumption that acute itch and pain disrupt attention to adjust our behavior to protect our body. Our results of higher threat and unpleasantness ratings for the itch and pain stimuli than for vibrotactile control stimuli support the idea that the attentional interference of itch and pain is probably driven by their threatening and aversive nature[20].

The hypothesis that there is an AB toward somatosensory itch and pain could not be supported. In all, our findings replicate previous studies using tonic pain and/or itch stimuli that found interference but no AB[11,17]. In contrast to our results, some studies using phasic pain stimuli did indeed find an AB toward pain[20,22,45]. Phasic pain cannot readily be compared with a tonic stimulus, because such a short stimulus might attract attention primarily during its beginning[46,47]; this is in line with our finding that all somatosensory stimuli interfere with attention during the first 5 seconds of stimulation. Moreover, it has been proposed that for tonic stimuli previous tasks may have failed to capture an

AB because of potential shifts in attention over the time course of such stimuli[11,48]. Despite the stronger focus on attention fluctuations over time than earlier studies[11,17], the current study found no indications for attentional shifts towards the location of these stimuli during a tonic stimulus. It could be speculated though that attention is drawn to the spatial location only in the very beginning of the stimulation, even before a response was required in the current set-up. This would suggest a general orienting response toward itch and pain[49] similar to attention captured with a phasic stimulus. Because the time interval between the stimulus onset and the first target light is too long to capture these responses with the SAT, more specific measures are needed to experimentally investigate different phases in spatial attention allocation toward itch and pain, for instance eye-tracking measures.

With regard to attentional fluctuations during itch and pain, an alternative interpretation for slower reaction times immediately after the onset of the stimulation than later on during stimulation is that our attention is easily distracted by anything that is starting new[46,50,51]. However, slower responses in the first time-segment were not only observed during itch and pain, but also during control stimulation. This suggests that itch and pain have no distinctive quality that govern their interfering effect on attention at the beginning of a sensation. Sustained interference might only be present with an aversive somatosensory stimulus, like itch and pain, which was shown by a significant interference effect of itch and pain in the main analyses. However, as these effects could not be replicated within the current more fine-grained time segment analyses this effects needs replication in the future. Cognitive-motivational models of pain, which can be translated to itch[52], state that pain overrules competing attentional demands, such as daily activities, in order to alarm the individual of potential bodily harm and activate related behavioral strategies, for example, avoidance, which makes sense for itch and pain, and could explain why the interference of a vibrotactile stimulus vanishes after a few seconds[1,3,4,6,53,54].

Explorative findings neither indicated that individual characteristics such as attentional focus on bodily sensations and catastrophizing about itch and pain were associated with AB toward or interference by itch and pain, nor that there is an association with attentional inhibition. However, as there was no significant AB found in this study no firm conclusions can be drawn. Still, these results are in line with several previous studies on attentional interference and AB in healthy participants that did not find associations between AB and for example catastrophizing[7,11,17]. There were some associations between attentional interference indices and the dot-probe task and disengagement; however, these findings are unexpected and difficult to interpret.

Several improvements should be noted compared with earlier research that employed the SAT[11,17]. First, an improved control condition with a nonitchy and nonpainful somatosensory sensation was added instead of no stimulation at all. Second, stimulations were grouped in blocks to minimize interactions between evoked sensations. Third, interference by hand movements with sensations was minimized by using foot pedals to measure responses. Fourth, as attentional fluctuations over time were assumed, the order of target lights was semi-randomized and time-analyses were more fine-grained to trace fluctuations within a few seconds.

Several limitations of the current study should be noted as well. First, targeted levels of induced itch and pain during the SAT were not reached in a substantial proportion of participants and a number of participants unintendedly rated pain stimuli as painful *and* itchy. As studies have shown that ratings of painful sensations become lower when a concurrent neutral task distracts someone from the sensation[7], lower ratings during the SAT were expected. In addition, it might be possible that habituation toward the stimuli and the task makes it difficult to repetitively induce a strong sensation, which can be seen in higher ratings during baseline than during the SAT[32] (**Table 2**). However, manipulation checks confirmed that stimuli led to the perception of interest (eg, pain stimulus more painful than itchy) and sensitivity analyses without these participants led to the same results as the overall analyses. Nonetheless, it remains to be determined whether stronger sensations would elicit different effects on interference and AB. Second, the relatively long duration of the current experiment and repetitive nature of the somatosensory attentional tasks, in addition to repetitive step-up and baseline stimulations, may have induced fatigue and lowered participants' motivation to engage in the tasks. Future research should take this potential confounder into account. Moreover, repetitive stimulation might be associated with decreases in evoked itch over time[32,35], but there is also evidence against a decrease in itch[33]. Development of other itch induction methods to evoke prolonged and/or repetitive itch needs investigation. Third, although to our knowledge, this study is the first that used a somatosensory control stimulus, research is needed on different neutral somatosensory stimuli. While we used a vibrotactile, hence mechanical, stimulation here, neutral electrical stimuli need investigation if compared with electrically induced pain or itch. Fourth, a restricted variance in the self-report characteristics in healthy people could explain the lack of significant correlations with attentional indices. Fifth, the sample was rather homogeneous in terms of sex, age, and education which may limit generalizability of the findings to other groups. Lastly, the current methodology was developed to induce a sensation that is a proxy for acute itch and pain. However, the onset of the itch and pain stimuli was highly predictable, which hampers its generalizability to the real world emergence of acute itch and pain which is usually unpredictable. However, this might be the opposite for the emergence of itch and pain in patients with chronic symptoms. In these cases, individuals are already used to the symptoms and might be able to predict their occurrence. In line with predictive coding theory[55,56], this means that unexpected and hence unpredicted symptoms (acute itch and pain) would demand attention to take action, while regular symptoms (chronic itch and pain) are expected and do not need particular attention. Therefore, future studies are recommended to apply a similar design with acute itch and pain in individuals with chronic symptoms to further investigate these hypotheses.

In conclusion, results of the current study show that in healthy individuals, itch and pain interfere with attention. Considering that relatively low levels of induced itch and pain were sufficient to demand attention and slow down task performance in healthy individuals, attentional interference of clinical levels of itch and pain in patients may be even stronger. Moreover, we could speculate that in experimental settings participants are convinced that stimuli will be nonharmful and transient, whereas patients associate itch and pain with bodily threat and are uncertain about its progression. Tonic itch and pain might be more realistic in representing somatic symptoms and this needs further investigation. Furthermore, we found no AB toward the stimulated location. This might imply that regular AB modification trainings based on attention allocation with the SAT cannot be used to train attention away from itch and pain. Still, as itch and pain distract attention away from other tasks, it might warrant further exploration whether focusing attention on a task despite experiencing pain or itch is possible[57], for example, during meditation-based trainings (eg, mindfulness). Altogether, research is needed that examines how attentional interference and AB play a role in symptom perception and symptom maintenance in patients suffering from chronic pain or itch.

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Conflict of interest statement

The authors declare that they have no financial conflict of interest with regard to the content of this report.

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