The effect of chronic low back pain on tactile suppression during back movements

Running head: Tactile suppression and chronic low back pain

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Abstract

The aim of the present study was to examine whether tactile suppression, the phenomenon whereby tactile perception is suppressed during movement, would occur in the context of back movements. Of particular interest, it was investigated if tactile suppression in the back would be attenuated in those suffering from chronic low back pain. Individuals with chronic low back pain (N = 30) and a matched control group (N = 24) detected tactile stimuli on three possible locations (back, arm, chest) while performing a back or arm movement, or no movement. We hypothesized that the movements would induce tactile suppression, and that this effect would be largest for low-intense stimuli on the moving body part. We further hypothesized that, during back movements, tactile suppression on the back would be less pronounced in the chronic low back pain group than in the control group. The results showed the expected general tactile suppression effects. The hypothesis of back-specific attenuation of tactile suppression in the chronic low back pain group was not supported. However, back-specific tactile suppression in the chronic low back pain group was less pronounced in those who performed the back movements more slowly.

Keywords: Sensory perception; Cognitive processes; Motor processes; Attention; Back pain

1. Introduction

Many functional behaviours such as, for example, standing up from a chair, or lifting a shopping bag, involve back movements. The adequate performance of these goal-directed behaviours requires the brain to selectively filter out the vast majority of potentially distracting tactile inputs that are associated with the execution of such movements (Bays and Wolpert, 2007 and Gallace et al., 2010). As an example of such a filtering mechanism just take the phenomenon of tactile suppression, which refers to the intriguing observation that voluntary movement results in reduced levels of somatosensation (Chapman and Beauchamp, 2006 and Vitello et al., 2010). Tactile suppression has been well documented in studies showing that the execution of a movement attenuates the detection of light, near-threshold tactile stimuli, particularly when delivered to the moving body part (Chapman and Beauchamp, 2006 , Juravle and Spence, 2011 , Juravle et al., 2010 , Juravle et al., 2011 , Juravle et al., 2013 , Post et al., 1994 , Voss et al., 2008 , Wasaka et al., 2003 , Williams and Chapman, 2000, Williams and Chapman, 2002 and Williams et al., 1998). Whereas tactile suppression has typically been demonstrated for those movements involving the fingers or the hands, a recent study also showed that back movements result in an attenuation of the detection of tactile stimuli administered to the back (Van Hulle et al., 2013).

Whereas there has been some debate about the precise mechanisms underlying tactile suppression – most likely a combination of the descending motor command blocking the neural afferent pathway on the one hand, and the sensory feedback resulting from the movement on the other hand – it is commonly agreed that the suppression of tactile perception during a movement task may play an important functional role, namely filtering out task-irrelevant tactile information (Juravle et al., 2011 , Juravle et al., 2013 and Vitello et al., 2010). However, for certain individuals as, for example, chronic low back pain sufferers, tactile input to the back may be more relevant than for others, because they consider it a

signal of potential bodily threat (Crombez et al., 1999 and Peters et al., 2002). Chronic pain patients have been hypothesized to be characterized by heightened attention to bodily sensations signalling potential threat, often referred to as hypervigilance (Chapman, 1986 , Crombez et al., 2005 , Rollman, 2009 and Vlaeyen and Linton, 2000). Hypervigilance has been argued to be a dynamic process that occurs when the fear system is activated, and when the individual's current goal is to escape or avoid pain or bodily threat (Eccleston and Crombez, 1999 , Crombez et al., 2005, Legrain et al., 2009 and Van Damme et al., 2010). Monitoring and avoiding potential bodily threats may be a prominent concern for chronic back pain sufferers when they have to perform a back movement (Crombez et al., 1998). It has been shown that movements repeatedly associated with pain may elicit fear (Meulders et al., 2011 and Meulders and Vlaeyen, 2013). Furthermore, the induction of bodily threat has been shown to result in enhanced attention to the threatened body part (Van Damme et al., 2007 , Van Damme et al., 2009 , Van Damme and Legrain, 2012 and Vanden Bulcke et al., 2013). If a similar threat-induced attentional effect were to occur during the performance of a back movement in those suffering from chronic low back pain, one might hypothesize this to result in less successful tactile suppression in the back region. Moreover, a recent study revealed that tactile suppression during back movements in healthy individuals was significantly reduced when the participants' attention was experimentally manipulated to the stimulated location (Van Hulle et al., 2013).

The aim of the present study was therefore to examine the idea of reduced tactile suppression during back movements in chronic low back pain sufferers. A group of individuals with chronic low back pain and a matched control group had to try and detect the presence (vs. absence) of individually calibrated tactile stimuli on three possible locations on the body (back, arm, or chest) while performing either a back movement, an arm movement, or else no movement at all. In line with previous work (Juravle et al., 2011 , Van Hulle et al.,

2013 and Vitello et al., 2010), we hypothesized that back (arm) movements would result in tactile suppression at the back (arm). Of particular interest, we also hypothesized that tactile suppression in the back during back movements would be less pronounced in the chronic low back pain group than in the control group. Because the experience of bodily threat in the chronic low back pain group was believed to be limited to the back region while performing back movements, no differences with the control group were expected for the control locations (arm, chest) and the control movement (arm).

2. Methods

2.1. Participants

Figure 1 provides a flow chart of the recruitment procedure. Persons with chronic low back pain were recruited through advertisement in local papers. Individuals who granted permission for contact were phoned by the researcher in order to provide more information, check their eligibility, and to make an appointment, if they so desired. During a short telephone interview, they were screened for eligibility using the following criteria: The presence of non-specific chronic low back for six months or more, the absence of other primary pain complaints and neurological conditions, age between 18 and 65 years, and sufficient knowledge of the Dutch language.

The control group was randomly selected from a database of individuals who registered for participation in research from the Health Psychology Resarch Group after advertisement in local papers and via a Facebook page. Individuals who granted permission for contact were phoned by the researcher in order to provide more information, to check the eligibility criteria, and to make an appointment, if they so desired. Individuals were only invited to participate if they fulfilled the following criteria: absence of self-reported chronic pain problems and neurological conditions, aged between 18 and 65 years, and sufficient

knowledge of the Dutch language. Participants from the control group reporting pain of at least medium intensity at the moment of testing were excluded. The chronic low back pain and control groups were matched at the group level for age, sex, and education level on the group level. A total of 63 persons participated in the study: 32 persons with chronic low back pain and 31 controls. They all reported normal tactile perception (absence of nerve damage or injuries) at those locations where the tactile stimuli would be delivered. The study was conducted in accordance with the Declaration of Helsinki. All participants gave informed consent and were free to terminate the experiment at any time. The participants received a financial reward (40 euros) for their participation. The study was approved by the Medical Ethical Committee of Ghent University.

INSERT FIGURE 1

2.2. Apparatus and Materials

The tactile stimuli (200 ms) were presented by means of three resonant-type tactors (C-2 TACTOR, Engineering Acoustics, Inc., Florida) consisting of a housing that was 3.05 cm in diameter and 0.79 cm high, with a skin contactor that was 0.76 cm in diameter. The tactors were attached directly to the skin surface by means of double-sided tape rings and were controlled by a custom-built device at 200 Hz. All of the stimulus characteristics (amplitude and frequency) were controlled by means of a self-developed software program. The tactors were attached to the lower back, the chest (control location at trunk), and the upper arm (control location not at the trunk). In the chronic low back pain group, the tactors were applied to the body side where the participant reported to experience the most low back pain. In the control group, the side of the body where the stimuli were applied was alternated between participants.

Prior to the start of the experiment, the stimulus intensity for each tactor location was individually calibrated, as there is evidence for variation in sensitivity depending on the stimulated body site (Weinstein, 1968). The intensity was determined for each participant by means of an adaptive double random staircase procedure designed to keep detection at a level of 50% at rest (Levitt, 1971). Both staircases started with a randomly chosen stimulation intensity between 0.00017 watts and 0.01377 watts (Power). As such, each staircase started with a different stimulation intensity. The presentation of trials from each of the staircases was randomized. The participants were instructed to respond whether or not they felt the presence of a stimulus by pressing on the corresponding keys (respectively 'f' and 'j' on an AZERTY keyboard). A staircase changed direction after one negative response (i.e., increasing the corresponding location stimulation by one step up) or one positive response (i.e., decreasing the corresponding location stimulation by one step down). Changes in the direction of the staircase are referred to as 'reversals'. A run consists of a sequence of changes in stimulus level in one direction only, thus starting with a reversal. The staircase terminated once the total number of trials (30) had been reached. The first run was excluded from the final threshold calculations which consisted of the average of the mean values of each even run. The participants went through this procedure separately for the tactile stimuli on the back, the arm, and the chest. During the experiment, three different stimulus intensities were used, obtained by multiplying the intensity of detection thresholds by a factor 2 (low), 3 (medium), and 4 (high). Note that the detection threshold intensity itself was not used in the experiment because pilot testing indicated that this intensity could not be perceived at all during the execution of movements.

The set-up of the experiment is depicted in Figure 2. A movement consisted of the relocation of both hands from the start positions to the goal mice either horizontal or diagonal from the start positions. Two warning signals (auditory stimuli; 150 ms, 8399 Hz) and a

starting signal (an auditory stimulus; 200 ms, 9491 Hz), with an inter-stimulus interval (ISI) of 550 ms, indicated when a movement needed to be executed. Participants wore noise-cancelling headphones (PXC 350 Sennheiser) in order to prevent any interference from environmental noise.

INSERT FIGURE 2

2.3. Tactile suppression task

The task was programmed and controlled by the INQUISIT Millisecond software package (Inquisit 3.0, Millisecond Software LLC, Seattle, WA, http://www.millisecond.com). The participants were instructed to detect the presence of tactile stimuli that could be administered on either the back, the arm, or the chest. It was also possible that no stimulus was delivered during these trials (catch trials). After each trial participants indicated whether they felt a tactile stimulus on the back, the arm, the chest, or not at all, by means of a manual response (see Juravle et al., 2011). More specific, they pressed the corresponding response keys (respectively, '1', '2', '3', or '0' on an AZERTY keyboard) with the index finger of their right hand. It was stressed to the particiapants that accuracy, rather than speed, was of importance. Three different tactile stimulus intensities, selected in the pre-experimental phase, were used. An equal number of stimuli with a low, medium, or high intensity were randomly administered within each block. The accuracy (but not the latency) of participants' tactile detection responses was registered by the INQUISIT software.

There were 3 conditions (see Figure 2). The task was performed while executing a back movement (moving both hands from the start positions toward a target mice positioned diagonally from the start position), an arm movement (moving both hands from the start positions toward the target mice, positioned horizontally from the start position), or no

movement at all. Before each block of trials, a picture indicated whether participants needed to perform the arm movement or the back movement, or needed to keep their hands on the start position. The participants had to press the space bar in order to start the first trial. In each trial, the participant heard three auditory signals (200 ms), with an ISI of 550 ms: two warning signals which indicated that they needed to prepare for movement execution, and a start signal, which indicated that they needed to execute the required movement immediately. The participants were instructed to press all of the buttons on the goal mouse as soon as they had completed the movement. When no movement needed to be executed, the trial ended 2900 ms after the start signal. The tactile stimuli were presented at two different timings (500 or 700 ms after the start signal) during the execution phase of the movement in order to reduce expectancy effects. In a no movement block, tactile stimuli were delivered at the same points in time. After each trial, the participants were instructed (on screen) to bring their hand back to the start position, and the next trial was started. In the blocks in which a movement had to be executed, movement latencies (time between start signal and pressing buttons of the goal mice) were registered by the INQUISIT software.

2.4. Self-report measures

Experienced pain and disability were assessed by means of the Graded Chronic Pain Scale (Von Korff et al., 1992). This questionnaire consists of several items measuring pain intensity (pain right now, worst and average pain during the past 6 months) and disability (interference with daily activities, social activities, and work activities) that need to be rated on an 11-point numerical rating scale ranging from 0 to 10. Total intensity and disability scores vary from 0 to 100. The participants also registered the total number of disability days during the past 6 months. Note that this instrument provides information regarding all pain sensations experienced by the participants, and does not differentiate between back pain and

other kinds of pain. The participants were classified in grades, ranging from 0 (pain free) to 4 (high disability-severely limiting). This questionnaire has been shown to be valid and reliable for several pain problems (Von Korff et al., 1992).

The Pain Catastrophizing Scale (PCS; Sullivan et al., 1995) is a 13-item scale used to assess catastrophic thoughts about pain in both non-clinical and clinical populations. Participants are asked to reflect on past painful experiences and to indicate the degree to which they experienced each of the 13 thoughts or feelings during pain (e.g. 'I become afraid that the pain may get worse') on a 5-point scale from 0 (not at all) to 4 (all the time). The Dutch version of the PCS has been shown to be valid and reliable in both healthy populations and chronic pain patients (Van Damme et al., 2002). Cronbach's alpha of the PCS-DV in this study was 0.94.

The Tampa Scale for Kinesiophobia (TSK; Kori et al., 1990) measures fear of movement and (re)injury. It consists of 17 items (e.g., I'm afraid I might injure myself if I exercise) that need to be rated on a 4-point numerical rating scale (0= "strongly disagree" , 3= "strongly agree"). The Dutch version of the TSK has been shown to be valid and reliable in chronic pain patients (Goubert et al., 2004 and Vlaeyen et al., 1995). Cronbachs' α in the current study was 0.74.

The Pain Vigilance and Awareness Questionnaire (PVAQ; McCracken, 1997) contains 16 items rated on a 6-point scale measuring self-reported vigilance for pain sensations (e.g., I focus on sensations of pain [1= "never", 5= "always"]). The Dutch version of the PVAQ has been shown to be valid and reliable in both healthy populations and chronic pain patients (Roelofs et al., 2002 and Roelofs et al., 2003). Cronbach's α of the PVAQ in this study was 0.88.

The Body Vigilance Scale (BVS; Schmidt et al., 1997) is a four-item questionnaire that measures vigilance for bodily symptoms on a 11-point numerical rating scale (e.g., On

average, how much time do you spend each day 'scanning' your body for sensations [0= "no time", 10= "all of the time"]). The last item is an average of the awareness scores of 15 non-specific body symptoms (e.g., Rate how much attention you pay to each of the following … heart palpitations, dizziness, nausea, … sensations [0= "none", 10= "extreme"]). Cronbach's α of the BVS in this study was 0.91.

2.5. Procedure

On arrival, participants gave their informed consent, and were invited to fill in the Graded Chronic Pain Scale and a general questionnaire, inquiring about their age, sex, and education level.

Next, participants received the instructions for the movement-detection task. In a practice phase, the participants first performed six 'movement task only' and four 'detection task only' trials in which they became familiar with the two tasks separately. Thereafter, the participants performed a total of 28 trials in which these two tasks were combined, as was the case in the experimental phase. Before the start of the experimental phase, the participants were asked to rate on an 11-point Likert scale (0 = "not at all", 10 = "very much") the extent to which they feared that the back movement would evoke pain at the back; to what extent they feared that the arm movement would evoke pain at the back; and to what extent they feared that they would experience pain at the back in the no movement condition.

The experiment phase consisted of a total of 330 trials. The trials varied in which movement participants had to perform (back, arm, no), which location was stimulated (back, arm, chest), and the intensity of tactile stimulation (low, medium, high). The trials were grouped in 15 experimental blocks (5 back movement blocks, 5 arm movement blocks, 5 no movement blocks), each consisting of 22 trials (including 4 catch trials). The order of the blocks was counterbalanced across participants. An overview of the number of trials in each

condition is provided in Table 1. The participants were informed that they could take a short break between the blocks, if they so desired. After each block, the participants were asked to complete a number of self-reports assessing to what extent they experienced pain at the back during the preceding block. The participants were asked to rate these items on a 11-point Likert scale ranging from (0= "not at all", 10= "very much"). For each block type (back movement, arm movement, no movement), the mean pain ratings were calculated. After the experiment, the participants were asked to complete the PVAQ, BVS, PCS and TSK.

INSERT TABLE 1

2.6. Data Reduction and Data analysis

Nine participants were excluded from further analyses (see Figure 1): two from the chronic low back pain group (one because of self-reported pain at the upper instead of the lower back at moment of testing, one because of technical failure of the tactor at the arm during the experimental task), and seven from the control group (five because of the presence of back pain, one because of the presence of a medium to high pain elsewhere at the moment of testing, and one because of too fast movement execution, i.e., movement before administration of tactile stimuli). Differences in characteristics between the chronic low back pain and control groups were examined using independent samples *t*-tests and *Chi-square* tests. Fear of back pain and actual back pain during the experiment (averaged over blocks) were analyzed by means of a repeated measures Analysis of Variance (ANOVA) with Movement (back, arm, no) as a within-participant factor and Group (chronic low back pain, control) as a between-participant factor. Significant effects were followed up by independent samples and paired samples *t*-tests.

With regard to the behavioural data, first, a repeated measures ANOVA was performed on the movement latencies, with Movement (back, arm) as a within-participant factor and Group (chronic low back pain, control) as a between-participants factor. Paired samples *t*-tests and independent samples *t*-tests were used for post-hoc testing. Second, a repeated measures ANOVA was performed on the tactile thresholds obtained from the calibration procedure, with Location (back, arm, chest) as a within-participant factor and Group (chronic low back pain, control) as a between-participants factor. Third, the proportion of accurately detected tactile stimuli was analyzed using a repeated measures ANOVA with Movement (back, arm, no), Location (back, arm, chest), and Intensity (low, medium, high) as the within-participant factors, and Group (control, CLBP) as the between-participants factor. In order to specifically test the hypothesis of reduced tactile suppression on the back during the back movement in the chronic low back pain group, indexes of tactile suppression on the back (arm) were calculated by subtracting tactile detection accuracy on the back (arm) during the back (arm) movement blocks from tactile detection accuracy on the back (arm) during the no movement blocks. Group differences were tested by an ANOVA. Finally, for the chronic low back pain group Pearson correlations were calculated between behavioural measures during back movements and self-report measures (fear of back pain during experiment, amount of back pain during experiment, PVAQ, BVS, PCS, TSK).

To obtain an objective and standardized measure of the magnitude of the observed effects, namely a standardized difference between two means, effect sizes (Cohen's *d*) for independent samples were calculated (Cohen, 1988). The 95% Confidence Interval (95% CI) was also calculated. Cohen's *d* is an effect size that is not design-dependent and conventional norms are available (Field, 2005). We determined whether Cohen's *d* was small (0.20), medium (0.50), or large (0.80) (Cohen, 1988). For dependent-samples t-tests, we followed the

recommendations by Lakens (2013) and used the Cohen's d repeated measures as calculated by Morris and DeShon (2002).

3. Results

3.1. Self-report data

Table 2 presents an overview of the characteristics and self-report data of both samples. The chronic low back pain group and the control group did not differ in sex, age, and education level, but they did differ in chronic pain grade. The majority of the participants from the chronic low back pain group were classified in Grade 1 (low disability-low intensity) or Grade 2 (low disability-high intensity), whereas the majority of participants from the control group were classified in Grade 0 (no pain). Overall, the chronic low back pain sample in this study seems only to be mildly disabled. Note that 8% of the control group were classified in Grade 3, and 13% in Grade 1, but this was primarily because of headache, whereas no back pain was present in those individuals. The reported "average pain", "most intense pain", and pain intensity at the moment of testing, were all significantly higher in the chronic low back pain group than in the control group. The chronic low back pain group had higher scores than the control group on the PCS, PVAQ, and TSK, although this effect failed to reach significance for the TSK. BVS scores were not different between the groups.

Fear of back pain during the experiment was analyzed by means of a repeated measures ANOVA with Movement (back, arm, no) as a within-participant factor and Group (chronic low back pain, control) as a between-participants factor. There were significant main effects of Movement ($F(2,104) = 10.36$, $p < .001$) and Group ($F(1,52) = 7.11$, $p = .01$), but these were qualified by a significant Movement x Group interaction effect ($F(2,104) = 3.93$, $p = .023$). Post-hoc tests showed that the chronic low back pain group was more fearful than the control group of experiencing low back pain in the back movement condition and in the no

movement condition, but not in the arm movement condition. The amount of back pain experienced during the experiment was analyzed by means of a repeated measures ANOVA with Movement (back, arm, no) as a within-participant factor and Group (chronic low back pain, control) as a between-participants factor. There was a significant mean effect of Group ($F(1,52) = 7.70$, $p = .008$), indicating that the overall amount of back pain reported during the experiment was larger in the chronic low back pain group than in the control group. There was no significant main effect of Movement ($F(2,104) = 1.16$, $p = .316$), and there was no significant Movement x Group interaction effect ($F(2,104) = 0.45$, $p = .637$).

INSERT TABLE 2

3.2. Behavioural data

3.2.1. Movement latencies

A repeated measures ANOVA was performed on the movement latencies, with Movement (back, arm) as a within-participant factor and Group (chronic low back pain, control) as a between-participants factor. The analysis revealed a significant main effect of Movement ($F(1,52) = 177.31$, $p < .001$; $d = 0.71$, 95% CI [0.33, 1.10]), indicating that participants executed the back movement ($M = 1606$ ms, $SD = 320$) more slowly than the arm movement ($M = 1375$ ms, $SD = 322$). There was no significant main effect of Group ($F(1,52) = 0.05$, $p = .824$; $d = 0.06$, 95% CI [-0.47, 0.59]), indicating no overall difference in movement latencies between the chronic low back pain group ($M = 1499$ ms, $SD = 315$) and the control group ($M = 1480$ ms, $SD = 321$). The Movement x Group interaction effect was borderline significant ($F(1,52) = 3.87$, $p = .054$). Although this interaction was only at trend level, a number of follow-up analyses were performed. Paired samples *t*-tests showed that the back movement was performed more slowly than the arm movement in both the chronic low

back pain group ($t(29) = 14.62$, $p < .001$; $d = 0.81$, 95% CI [0.29, 1.32]) and the control group ($t(23) = 6.24$, $p < .001$; $d = 0.58$, 95% CI [0.01, 1.14]). Furthermore, independent samples *t*-tests showed that there was no significant difference between the groups in back movement latency ($t(52) = 0.60$, $p = .551$; $d = 0.16$, 95% CI [-0.37, 0.69]), nor in arm movement latency ($t(52) = 0.16$, $p = .875$; $d = 0.04$, 95% CI [-0.49, 0.57]).

3.2.2. Tactile thresholds

A repeated measures ANOVA was performed on the tactile thresholds obtained from the calibration procedure, with Location (back, arm, chest) as a within-participant factor and Group (chronic low back pain, control) as a between-participants factor. There was a borderline significant main effect of Group ($F(1,52) = 3.39$, $p = .071$; $d = 0.49$, 95% CI [-0.04, 1.03]), indicating that tactile thresholds were lower in the chronic low back pain group ($M = 0.0108$ Watt; $SD = 0.0063$) than in the control group ($M = 0.0140$ Watt; $SD = 0.0065$). There was no significant main effect of Location ($F(2,104) = 1.39$, $p = .253$), nor was there a significant Group x Location interaction effect ($F(2,104) = 0.11$, $p = .892$).

3.2.3. Tactile suppression

Indexes of tactile suppression for both movements were calculated by subtracting tactile detection accuracy during each movement from tactile detection accuracy during the no movement blocks. This was done separately for each stimulus location and each stimulus intensity (see Table 3). One-sample *t*-tests revealed that all tactile suppression indices were positive and significantly different from zero (all $p_s < .001$), confirming the presence of tactile suppression. A repeated measures ANOVA on the tactile suppression indexes was performed with Movement (back, arm), Location (back, arm, chest), and Intensity (low, medium, high) as within-participant factors, and Group (chronic low back pain, control) as a between-participants factor. For the purpose of readability we present this analysis in three steps.

First, we looked at the hypothesized Movement x Location x Group 3-way interaction effect, which was not significant ($F(2,104) = 0.04$, $p = .962$). Furthermore, we specifically tested the *a priori* hypothesis that during back movements, tactile suppression on the back would be smaller in the chronic low back pain group than in the control group. This hypothesis was not confirmed ($F(1,52) = 0.10$, $p = .922$; $d = 0.03$, 95% CI [-0.50, 0.56]).

Second, we investigated other possibly relevant group effects. There was no significant main effect of Group ($F(1,52) = 1.65$, $p = .205$). The Movement x Location x Intensity x Group 4-way interaction effect was not significant ($F(4,208) = 0.25$, $p = .908$). No other interaction effects involving Group reached statistical significance (all $F_s < 1.15$).

Third, we examined general sensory suppression effects. There were significant main effects of Movement ($F(1,52) = 80.59$, $p < .001$), Location ($F(2,104) = 31.99$, $p < .001$), and Intensity ($F(2,104) = 16.26$, $p < .001$). In order to interpret these effects, post-hoc contrasts were calculated. With regard to Movement, sensory suppression was larger during back movements than during arm movements ($p < .001$). With regard to Location, sensory suppression on the back was less pronounced than on the arm and chest (both $p_s < .001$), while there was no difference between arm and chest. With regard to Intensity, sensory suppression was smaller for high intensity tactile stimuli than for medium and low intensity stimuli (both $p_s < .001$), whereas there was no difference between the low and medium intensity stimuli.

There were also two significant two-way interaction effects (Movement x Location: $F(2,104) = 17.65$, $p < .001$; Movement x Intensity: $F(2,104) = 6.38$, $p = .002$). Regarding the Movement x Location interaction, we tested whether tactile suppression was larger for stimuli at the moving body part than for stimuli at the other locations. Post-hoc contrasts showed that, surprisingly, during back movements sensory suppression was smaller for stimuli on the back as compared to stimuli on the arm ($p = .002$) and on the chest ($p < .001$), whereas there was

no difference between stimuli on the arm and chest. During arm movements tactile suppression was larger for those stimuli presented on the arm as compared to stimuli on the back ($p < .001$), and for stimuli on the chest as compared to the back ($p < .001$), whereas the difference between stimuli on the arm and on the chest failed to reach significance. Regarding the Movement x Intensity interaction, we tested whether the differential effect of back and arm movements depended on stimulus intensity. Post-hoc contrasts, however, showed that for all stimulus intensities, sensory suppression was significantly higher during back movements than during arm movements (all $p_s < .001$).

INSERT TABLE 3

3.2.4. Correlations between behavioural and self-report data

Table 4 presents an overview of the Pearson correlations in the chronic low back pain group. Most of the correlations between behavioural and self-report measures did not reach statistical significance, although there were a number of exceptions. PVAQ scores were significantly positively associated with tactile detection on the back, and higher scores on the BVS were associated with higher tactile thresholds on the back. Furthermore, those who scored higher on the TSK tended to be slower in executing the back movements. Of further interest were a number of significant correlations between the different behavioural measures. Specifically, those who were slower in executing the back movements showed better tactile detection as well as less tactile suppression on the back. Finally, most correlations between self-report measures were as expected. Interestingly, those who scored higher on the TSK reported significantly more fear of back pain during the back movements, and also tended to report more back pain during the back movements.

INSERT TABLE 4

4. Discussion

This study investigated whether chronic back pain sufferers are characterized by reduced tactile suppression on the back when performing back movements. A sample of individuals with chronic low back pain and a matched control group detected tactile stimuli at different locations of the body while performing back movements, arm movements, or no movements. We hypothesized that movements would reduce tactile perception (i.e., tactile suppression), and that this would be especially true for tactile stimuli of lower intensity, and when stimuli were presented on the moving body part. We were particularly interested in the hypothesis that there would be less tactile suppression in the back during the performance of back movements in the chronic low back pain group than in the control group. Whereas the results were, generally, in line with the former hypothesis, the data did not support the latter hypothesis: The chronic low back pain group did not show a back-specific reduction in tactile perception during back movements. These findings are discussed in more detail below.

The general tactile suppression effects were largely in line with the available literature. Tactile detection was less accurate during both movement conditions (back, arm) than in the no movement condition, further adding to the evidence in support of the phenomenon of tactile suppression (Chapman and Beauchamp, 2006; Juravle and Spence, 2011 , Juravle et al., 2010 , Juravle et al., 2011 , Juravle et al., 2013 , Post et al., 1994 , Voss et al., 2008 , Wasaka et al., 2003 , Williams and Chapman, 2000 , Williams and Chapman, 2002 and Williams et al., 1998). The results also revealed that the phenomenon of tactile suppression is not limited to movements of the limbs (most studies used movements of the arms, hands, or fingers), but also emerges during back movements, replicating a previous study (Van Hulle et al., 2013). Furthermore, we found that tactile suppression was less pronounced for tactile

stimuli of a higher intensity, which is in line with the results of other studies (Van Hulle et al., 2013 and Williams and Chapman, 2000). Finally, we found that tactile suppression varies as a function of the distance between the site of the stimulation and the site of movement (Andreatta and Barlow, 2003 , Post et al., 1994 and Williams et al., 1998). As may be expected, tactile suppression on the back was more pronounced during back movements as compared to arm movements, since the back region was not involved in the execution of the arm movement. Sensory suppression of tactile stimuli on the arm was, perhaps surprisingly at first sight, more pronounced during back movements than during arm movements. This may be explained by the fact that during the back movement the arms also moved. It has to be noted that tactile suppression on the chest was quite high during back movements. A possible explanation for this observation is that the back movements, by the active contraction of muscles in the abdomen, may also have activated the chest muscles (Escamilla et al., 2006).

Contrary to our hypothesis, we were not able to find a back-specific reduction of tactile suppression during back movements in chronic low back pain sufferers. It was expected that the performance of the back movement would be a threatening situation for the chronic low back pain group, activating the fear system and promoting the goal to escape or avoid pain or bodily threat (Eccleston and Crombez, 1999, Crombez et al., 2005 and Van Damme et al., 2010). Monitoring and avoiding potential bodily threats is believed to increase attention to somatosensory information at the threatened body part (Legrain et al., 2009), and such an effect has already been demonstrated with experimentally induced threat in healthy volunteers (Van Damme et al., 2009 , Van Damme and Legrain, 2012 and Vanden Bulcke et al., 2013). Based upon this reasoning, one would have expected chronic low back pain sufferers to be highly attentive to somatosensory signals presented to their back during the performance of back movements, leading in better detection of tactile stimuli and, consequently, less tactile suppression. It can be speculated as to why such an effect was not

found. First, it should be noted that although the self-report data revealed that in the back movement condition the chronic low back pain group reported being more fearful of pain in the back region than the control group, and also actually experienced more pain, the ratings were still quite low (about 3 on a 0-10 scale). Furthermore, in the chronic low back pain group, fear of back pain was not markedly higher in the back movement condition than in the no movement condition, whereas the amount of actual back pain reported was quite similar across the different movement conditions. It may thus be that the standardized back movement used in this study was not sufficiently threatening for the chronic low back pain group to evoke back-specific effects. In future research, more work will be needed on the development of appropriate back movements, and a more individual approach in which personally relevant movements are selected, may be considered. Second, this sample of chronic low back pain sufferers was recruited from the general population. Although only those persons who fulfilled the inclusion criteria were selected for participation, the sample characteristics nevertheless suggest that our chronic low back pain sample was relatively well-functioning and only mildly disabled. Only 20% of the sample had a chronic pain grade higher than 2, which resembles the low-disability subgroups typically identified in large sample of chronic back pain patients in primary care (Viniol et al., 2013 and Von Korff et al., 1992). Furthermore, scores on pain catastrophizing and fear of pain and movement were relatively low in comparison with chronic low back pain samples obtained in tertiary care (Goubert et al., 2004 and Van Damme et al., 2002). The findings of the present study may thus not be representative of more disabled chronic back pain samples, or patients in tertiary care. Third, it may be that our study was still underpowered to detect the hypothesized difference between the chronic low back pain group and the control group. While this may be partly explained by the relatively small sample sizes, also the selected back movement and recruited back pain sample may have played a role, as mentioned before.

There are a number of issues which require further elaboration. First, the actual intensity of tactile stimuli used in the study (as a result of the calibration procedure) tended to be *lower* in the chronic low back pain group than in the control group. Although this effect was only borderline significant, it may suggest that the chronic low back pain group had a lower tactile threshold. This finding is at odds with a number of other studies showing either no altered tactile thresholds (Moseley, 2008 , Puta et al., 2013 and Wand et al., 2010), or even increased tactile thresholds in the back (Blumenstiel et al., 2011), and a recent demonstration of tactile neglect-like dysfunction in the back (Moseley et al., 2012). The reason for this discrepancy is unclear, although differences in stimulation methods and threshold procedures may play a role, certainly when taking into account the inconsistent effects across somatosensory submodalities reported in some of these studies (Blumenstiel et al., 2011 and Puta et al., 2013). Second, the pattern of correlations found in the chronic low back pain sample, was intriguing. Those who performed back movements more slowly displayed less tactile suppression on the back. Back movement latency showed also positive (albeit non-significant) correlations with general fear of pain and movement, and with fear of back pain during the back movements. Note that we had no experimental control over movement speed, and as such, this could be a confounding factor in some of our findings. Future studies may need to control movement speed, for example by means of a metronome. However, the potential association between movement speed and sensory suppression may generate intriguing research questions in its own right. Perhaps it is the case that alterations in sensorimotor control, muscle recruitment, and movement execution (Hodges and Tucker, 2011 , Karayannis et al., 2013 , Willigenburg et al., 2013 and Wong and Lee, 2004) mediate reductions in tactile suppression, particularly in more disabled or fearful samples. Obviously, further research is recommended in order to investigate these intriguing ideas. Third, we used external stimuli administered to the participants' skin. Although touch, coming from the

external environment but involving the body, is considered to hold aspects from both interoceptive and exteroceptive processing (Haggard et al., 2013), tactile input resulting from external stimulation to the back is not the same as somatosensory input resulting from internal processes within the back. Future research may investigate whether interoceptive sensations, such as muscle contractions in the back, may be considered to be more relevant signals of potential back damage, and thus be more appropriate to detect less successful somatosensory suppression in with chronic low back pain. Fourth, although we matched our groups on age and gender, other criteria such as weight and height could have been included to optimize matching, but this was not possible from a practical point of view.

To conclude, the present study did not provide support for the hypothesis that in persons with chronic low back pain, the performance of back movements triggers hypervigilance for somatosensory information specifically in the region of the back. However, those who performed back movements more slowly displayed less tactile suppression on the back. It was suggested that this effect may be explained – at least to some extent - by fear of back pain during the experiment and overall higher levels of self-reported fear of pain and hypervigilance.

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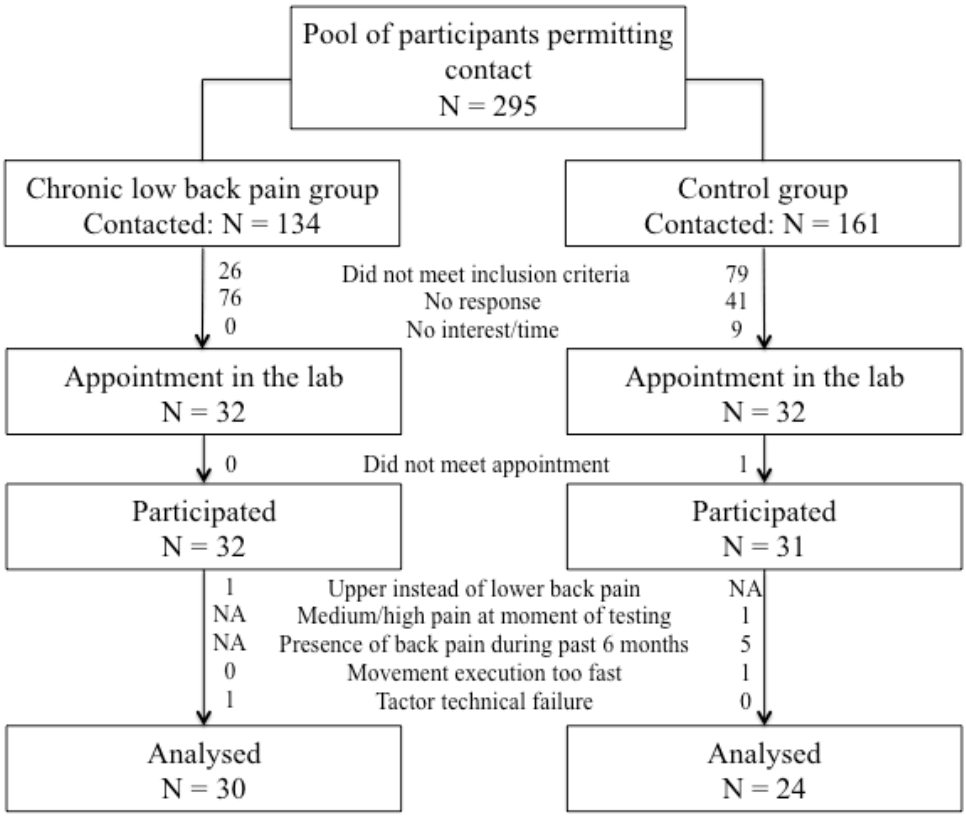
Figure legends

Figure 1. Flow chart of the participant recruitment procedure.

Figure 2. An illustration of the set-up used in the experiment. The participants had to move both hands from the start positions either toward the goal mice horizontal to the start position, which only resulted in an arm movement, or toward the goal mice diagonal from the start position, which resulted in both an arm and back movement.


Pool of participants permitting contact
N = 295
Chronic low back pain group
Contacted: N = 134
Control group
Contacted: N = 161
26
76
0
Did not meet inclusion criteria
No response
No interest/time
79
41
9
Appointment in the lab
N = 32
Appointment in the lab
N = 32
0
Did not meet appointment
1
Participated
N = 32
Participated
N = 31
1
NA
NA
0
1
Upper instead of lower back pain
Medium/high pain at moment of testing
Presence of back pain during past 6 months
Movement execution too fast
Tactor technical failure
NA
1
5
1
0
Analysed
N = 30
Analysed
N = 24

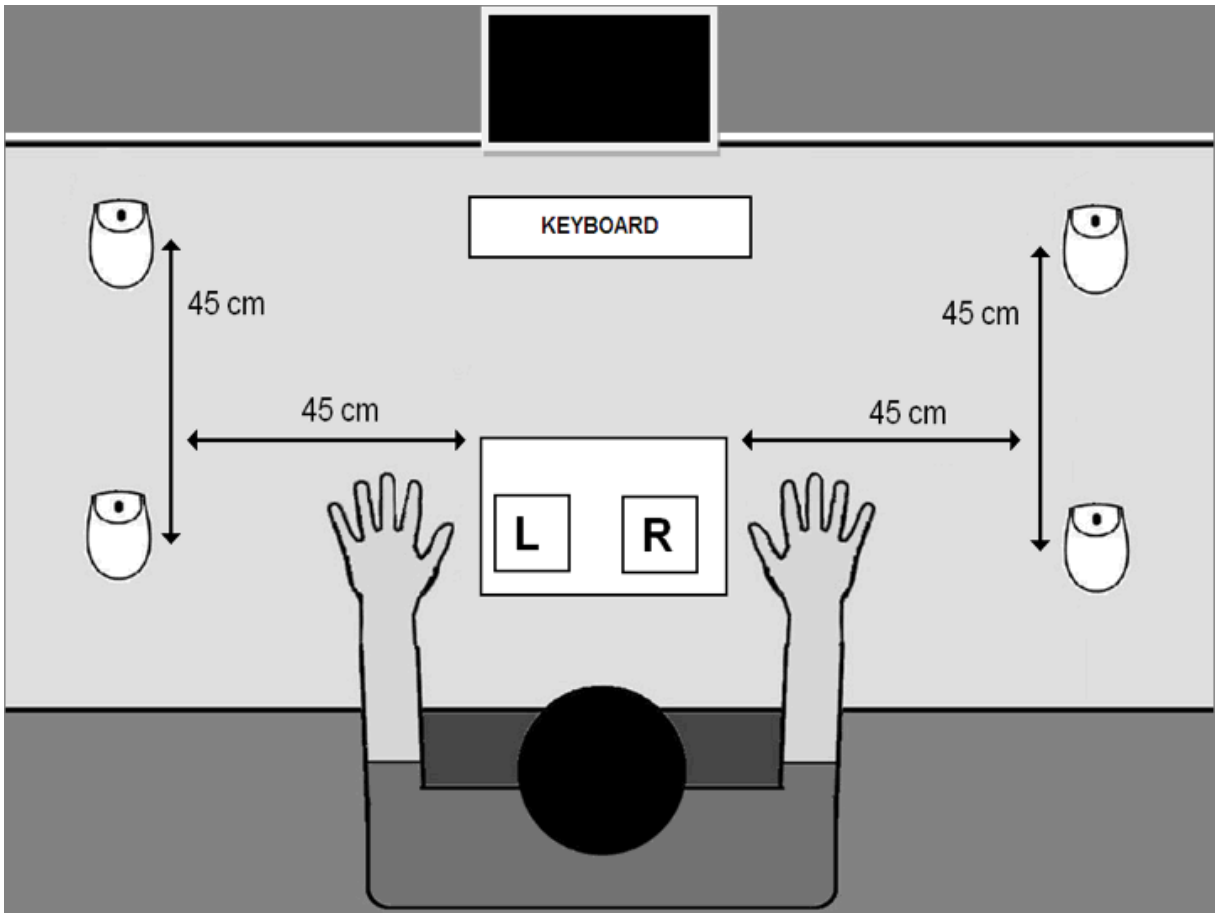

KEYBOARD
45 cm
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Table 1. Overview of the number of trials per trial type

	Back location			Arm location			Chest location			No
	Low	Mediu m	High	Low	Mediu m	High	Low	Mediu m	High	No
Back	10	10	10	10	10	10	10	10	10	20
Move	10	10	10	10	10	10	10	10	10	20
Arm move	10	10	10	10	10	10	10	10	10	20

Table 2. Overview of sample characteristics and self-report data (values in brackets are standard deviations)

	Chronic low back pain	Control	Group difference statistic
Sex (% females)	57%	50%	$X^2(1) = 0.24$, $p = .625$
Age	40 (12)	41 (12)	$t(52) = 0.21$, $p = .838$
Education level (low/secondary/high)	10/20/70	13/25/62	$X^2(2) = 0.34$, $p = .845$
Graded Pain Grade (% grade 0/1/2/3/4)	0/43/37/13/7	79/13/0/8/0	$X^2(4) = 38.73$, $p < .001$
Average pain intensity during past 6 months	4.27 (1.57)	0.67 (1.55)	$t(52) = 8.42$, $p < .001$
Maximal pain intensity during past 6 months	7.43 (1.48)	1.00 (2.17)	$t(52) = 12.94$, $p < .001$
Pain intensity at the moment of testing	3.52 (2.42)	0.25 (0.90)	$t(52) = 6.28$, $p < .001$
TSK	35.36 (7.18)	32.25 (5.31)	$t(52) = 1.77$, $p = .082$
PCS	17.60 (7.96)	12.96 (6.72)	$t(52) = 2.28$, $p = .027$
PVAQ	39.92 (10.24)	28.57 (12.40)	$t(52) = 3.69$, $p = .001$
BVS	19.28 (5.91)	17.70 (6.37)	$t(52) = 0.94$, $p = .349$
Mean fear of back pain during back movement	3.08 (2.59)	1.33 (1.83)	$t(52) = 2.79$, $p = .007$
Mean fear of back pain during arm movement	1.20 (1.65)	0.88 (1.62)	$t(52) = 0.73$, $p = .472$
Mean fear of back pain during no movement	2.03 (2.47)	0.54 (1.10)	$t(52) = 2.74$, $p = .008$
Mean back pain during back movement	2.66 (2.28)	1.03 (1.84)	$t(52) = 2.85$, $p = .006$
Mean back pain during arm movement	2.34 (2.25)	0.95 (1.70)	$t(52) = 2.51$, $p = .015$
	2.40 (2.19)	0.97 (1.73)	$t(52) = 2.62$, $p = .012$

Mean back pain during no movement

Table 3. Mean tactile suppression indexes (values in brackets are standard deviations)

Movement	Location	Intensity	Back pain group	Control group	Total group
Back movement	Back	Low	0.52 (0.36)	0.48 (0.35)	0.50 (0.35)
		Medium	0.54 (0.34)	0.58 (0.33)	0.56 (0.33)
		High	0.43 (0.34)	0.47 (0.35)	0.45 (0.34)
		Average	*0.50 (0.29)*	*0.51 (0.28)*	*0.50 (0.28)*
	Arm	Low	0.61 (0.32)	0.72 (0.33)	0.66 (0.32)
		Medium	0.61 (0.33)	0.68 (0.36)	0.64 (0.34)
		High	0.51 (0.36)	0.56 (0.37)	0.53 (0.36)
		Average	*0.58 (0.28)*	*0.65 (0.31)*	*0.61 (0.29)*
	Chest	Low	0.60 (0.32)	0.74 (0.26)	0.66 (0.30)
		Medium	0.64 (0.33)	0.75 (0.24)	0.69 (0.29)
		High	0.57 (0.30)	0.62 (0.35)	0.59 (0.32)
		Average	*0.60 (0.28)*	*0.70 (0.24)*	*0.65 (0.27)*
Arm movement	Back	Low	0.25 (0.33)	0.24 (0.27)	0.24 (0.30)
		Medium	0.16 (0.27)	0.24 (0.32)	0.19 (0.29)
		High	0.17 (0.25)	0.23 (0.31)	0.20 (0.28)
		Average	*0.19 (0.23)*	*0.24 (0.26)*	*0.21 (0.24)*
	Arm	Low	0.53 (0.31)	0.67 (0.36)	0.59 (0.34)
		Medium	0.50 (0.34)	0.65 (0.33)	0.56 (0.34)
		High	0.39 (0.31)	0.46 (0.40)	0.42 (0.35)
		Average	*0.47 (0.27)*	*0.59 (0.33)*	*0.53 (0.30)*

Chest	Low	0.46 (0.34)	0.64 (0.30)	0.54 (0.33)
	Medium	0.41 (0.30)	0.52 (0.36)	0.46 (0.33)
	High	0.36 (0.29)	0.44 (0.34)	0.40 (0.31)
	Average	*0.41 (0.26)*	*0.53 (0.29)*	*0.47 (0.28)*

Table 4. Pearson correlations between behavioural and self-report measures during back movements, and questionnaires in the chronic low back pain group

	1	2	3	4	5	6	7	8	9	10
1. Tactile suppression back	-									
2. Tactile accuracy back	.94**	-								
3. Tactile intensity back	-.08	.11	-							
4. Back movement latency	- .49**	.42*	.12	-						
5. Fear of back pain	-.09	-.04	-.14	.30	-					
6. Actual back pain	-.12	.09	-.13	.26	.71**	-				
7. PVAQ	-.29	.37*	.16	.27	.01	.01	-			
8. BVS	-.00	.13	.42*	-.16	-.10	-.12	.11	-		

9. PCS	-.05	.03	-.18	-.06	.21	.13	.61**	-.17	-	
10. TSK	-.28	.21	.06	.35(*)	.40*	.32(*)	.26	-.02	.41*	-