Hypervigilance for innocuous tactile stimuli in patients with fibromyalgia: An experimental approach.

Running head: Somatosensory hypervigilance in fibromyalgia

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What’s already known about this topic?

- Fibromyalgia is characterized by amplified perception of painful and non-painful sensations
- This perceptual amplification is often believed to result from generalized hypervigilance
- Compelling evidence for this assumption is currently lacking

What does this study add?

- Provides theoretically sound conceptualization and operationalization of hypervigilance
- Experimentally demonstrates that fibromyalgia patients were no more attentive to tactile information than matched controls
- Challenges the view that hypervigilance is a stable feature of fibromyalgia
Abstract

Background

Hypervigilance, that is, excessive attention, is often invoked as a potential explanation for the observation that many individuals with fibromyalgia show a heightened sensitivity to stimulation in various sensory modalities, such as touch and hearing. Compelling evidence for this assumption is, however, lacking. The aim of the present study was to investigate the presence of somatosensory hypervigilance in patients with fibromyalgia.

Methods

Fibromyalgia patients (N = 41) and a matched control group (N = 40) performed a tactile change detection task in which they had to detect whether there was a change between two consecutively presented patterns of tactile stimuli presented to various bodily locations. The task was performed under two conditions: In the unpredictable condition, tactile changes occurred equally often at all possible body locations; In the predictable condition, the majority of tactile changes occurred at one specific body location.

Results

It was hypothesized that the fibromyalgia group would show better tactile change detection in the unpredictable condition and when changes occurred at unexpected locations in the predictable condition. The results did not support this hypothesis. In neither condition was the fibromyalgia group better than the control group in detecting tactile changes.

Conclusions

No evidence was found to support the claim that patients with fibromyalgia display somatosensory hypervigilance. This finding challenges the idea of hypervigilance as a static feature of fibromyalgia, and urges for a more dynamic view in which hypervigilance emerges in situations when bodily threat is experienced.
Introduction

Hypervigilance is a central concept in several theories attempting to explain amplified pain perception, disability, and distress in chronic pain sufferers (Chapman, 1986; Vlaeyen and Linton, 2000; Crombez et al., 2005; Rollman, 2009; Van Damme et al., 2010). Particularly influential is the generalized hypervigilance hypothesis, which states that patients with certain pain syndromes such as fibromyalgia, have a habit of excessively directing their attention towards potential threat signals, resulting in increased pain sensitivity, as well as an amplified perception of non-painful sensations in other sensory modalities (McDermid et al., 1996; Hollins et al., 2009).

These theoretical claims are typically validated by findings in fibromyalgia patients of lowered pain thresholds and tolerance thresholds for experimental pain and auditory stimuli (Lautenbacher et al., 1994; Kosek et al., 1996; McDermid et al., 1996), as well as markedly increased intensity ratings for non-aversive somatosensory and – to a lesser extent – auditory stimuli (Geisser et al., 2003; Hollins et al., 2009). However, one should be cautious when interpreting these findings in terms of hypervigilance. Although amplified perception may be a possible consequence of hypervigilance, the assumed underlying process, i.e., attention, has not been effectively demonstrated. Other explanations such as central sensitization or a generalized state of global nervous system augmentation are equally likely (Geisser et al., 2003; Rollman, 2009; Van Damme et al., 2009a). Furthermore, self-report measures of somatosensory hypervigilance, on which patients with fibromyalgia typically show elevated scores (Peters et al., 2000; Roelofs et al., 2003; Crombez et al., 2004; Tiemann et al., 2012), may have limited value in assessing hypervigilance, as these may reflect the mere presence of pain rather than a perceptual style. Crucial to infering the presence of hypervigilance is the demonstration of heightened attention to pain-relevant information (Crombez et al., 2005; Van Damme et al., 2010).
This study investigated the presence of somatosensory hypervigilance in patients with fibromyalgia. For this purpose, a sample of fibromyalgia patients and a matched control group performed a tactile change detection task (Gallace et al., 2006). The participants were asked to detect whether there was a change between two consecutive spatial patterns of tactile stimuli. As it has been shown that attention improves tactile change detection (Van Hulle et al., 2013b), we hypothesized that, if fibromyalgia patients are hypervigilant for somatosensory information, they would show better tactile change detection than the control group. In order to minimize the potential effects of baseline differences in somatosensory sensitivity on the results (Van Damme et al., 2009a), all tactile stimuli were individually calibrated to match subjectively in terms of their intensity. We also manipulated the predictability of the body location where tactile changes could occur. Because tactile change detection is generally better at attended body locations (Van Hulle et al., 2013b), we hypothesized that the groups would not differ when tactile changes occurred at an expected location, but that the fibromyalgia group would show better tactile change detection than the control group at unexpected locations and when the location of tactile changes could not be predicted.

Method

Participants

A flow chart of the study is available (see Supplementary Methods, Figure S1). Patients with fibromyalgia were recruited through the Multidisciplinary Pain Clinic of Ghent University Hospital. They were informed about the opportunity to participate in a study by means of a poster in the waiting room of the clinic, information given by their physician, and information letters. Those individuals who gave their permission were contacted by the researcher in order to provide more information, check their eligibility, and to make an appointment, if they so desired. The participants were screened for eligibility using the
following criteria: A diagnosis of fibromyalgia according to the criteria of Wolfe et al. (1990),
the absence of neurological conditions, age between 18 and 65 years, and sufficient
knowledge of the Dutch language. The control group was recruited by means of
advertisement in local papers. Individuals who granted permission for contact were contacted
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 for participation when
they fulfilled the following criteria: self-reported absence of chronic pain problems (pain with
a duration of at least 3 months) and neurological conditions, aged between 18 and 65 years,
and a sufficient knowledge of the Dutch language. Control participants reporting pain at the
moment of testing that was higher than 3/10, were excluded from the analyses. The
fibromyalgia and control groups were matched at the group level for age, sex, and education
level on the group level. A total of 83 individuals took part in the study: 41 persons with
fibromyalgia and 42 control persons. All of the participants from both groups were white
Caucasian. The study was approved by the Medical Ethical Committee of the Ghent
University Hospital. 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.

Self-report measures

Before the start of the experiment, the participants completed a number of
questionnaires. The PainDetect (Freynhagen et al., 2006) provided a measure of pain intensity
at the moment of testing, average pain intensity during the last four weeks, and the most
intense pain experienced during the last four weeks. The participants had to rate these items
on an 11-point numerical rating scale from 0 (“none”) to 10 (“maximal”). The Dutch version
of this instrument has been shown to be reliable and valid (Timmerman et al., 2013).
The Pain Disability Index (PDI; Pollard, 1984) is a 7-item inventory designed to measure the degree to which chronic pain interferes with functioning across a range of activities (e.g., social, work, or daily activities) on an 11-point rating scale ranging from 0 (“no disability”) to 10 (“total disability”). The total PDI score thus ranges from 0 to 70. This questionnaire has been shown to be reliable (Cronbach’s α=.86) and valid (Tait et al., 1990). We used the Dutch version (PDI-DLV; Soer et al., 2013). Cronbach’s α in the current study was 0.96.

The Pain Catastrophizing Scale (PCS; Sullivan et al., 1995) is a 13-item scale 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 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, 2003). Cronbach’s α of the PVAQ in this study was 0.83.

The Dutch version of the Body Vigilance Scale (BVS; Schmidt et al., 1997; Peters & Vlaeyen, 1996) is a four-item questionnaire measuring 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 0.92.

**Apparatus and Materials**

Tactile stimuli (200 ms) were presented by means of eight resonant-type tactors (C-2 TACTOR, Engineering Acoustics, Inc.) consisting of a housing of 3.05 cm diameter and 0.79 cm high, with a skin contactor of 0.76 cm diameter. The stimuli were administered on eight different body locations (see Figure 2). These locations included the left upper arm, the right upper arm, the left forearm, the right forearm, the left leg just below the knee, the right leg just below the knee, the left leg just above the ankle, and the right leg just above the ankle. Tactors were attached directly to the skin by means of double-sided tape rings, and were driven by a custom-built device at 200 Hz. The participants wore noise-cancelling headphones (PXC 350 Sennheiser) in order to prevent any interference from environmental noise. Prior to the start of the experiment, the stimulus intensities of each tactor were individually matched, as there is evidence for variation in sensitivity depending on the stimulated body site (Weinstein, 1968). The matching procedure described by Van Hulle et al. (2013b) was used. In short, a reference tactile stimulus ($P = 0.04$ watt) was presented at the right wrist (on a location that was not further used in the tactile change detection task). When participants were not able to perceive this stimulus, the intensity was increased slightly (+0.03 watt or +0.06 watt). Next, tactile stimuli were presented separately at each location to be used in the tactile change detection task, and participants were asked whether the intensity was lower, higher, or equal to the intensity of the reference stimulus. The reference stimulus was repeatedly administered before moving to another tactor location, in order to make sure that they remembered the intensity of the reference stimulus correctly. The intensity of each tactor was varied until it was perceived as being equal to the intensity of the reference stimulus. As such, tactile stimulation at each location was perceived as equally intense (i.e., matched) by
the participant (Van Hulle et al., 2013b). The procedure also minimized potential effects of differences between individuals and groups in tactile sensitivity.

**Tactile Change Detection Task**

The paradigm was programmed and controlled by Inquisit Millisecond software (Inquisit 3.0) on a laptop (HP Compaq nc6120) with a keyboard. The participants were instructed to keep their eyes on a black-colored screen for the duration of the experiment. Each trial started with a white fixation cross that appeared in the centre of the screen for 500 ms. Next, the first stimulus pattern was presented for 200 ms, followed by an empty stimulus interval of 110 ms, after which the second stimulus pattern was presented for 200 ms. Tactile patterns always consisted of three simultaneously presented tactile stimuli. In half of the trials, the second pattern was identical to the first. In the other half of the trials, the two patterns differed, as one of the stimulated locations of the first tactile pattern shifted towards another location in the second tactile pattern. So, one of the three tactors that were active during the first pattern was inactive during the second pattern, and a tactor positioned at another body location became active instead (see Supplementary Methods, Figure S2 for an illustration). The different pattern combinations were randomly presented during the course of the experiment. The participants were instructed to detect whether the first and the second tactile pattern differed, and to respond ‘yes’ or ‘no’ by pressing the corresponding response keys (respectively ‘4’ and ‘6’ on an AZERTY keyboard) with the index and middle finger of their right hand. There was a 3500 ms window in which the participants could respond, and it was stressed that accuracy, rather than speed, was of importance.

**Procedure and predictability manipulation**

The participants were instructed that each trial consisted of the presentation of two consecutive tactile patterns, and that their task was to indicate whether these patterns were identical or not. The tactile change detection task was performed under two conditions.
In the *unpredictable* condition, the participants were told that tactile changes could occur equally often at all body locations. In other words, the participants could not predict at which body location a change would occur. We assumed that this would create divided attention between all potentially stimulated locations.

In the *predictable* condition, the participants were told that the majority of tactile changes would occur at one specific body location. This was either the left or the right forearm, and this location was counterbalanced across blocks (see Supplementary Methods, Figure S2 for an illustration). We assumed that this would create focused attention to the body location where tactile change was expected. This was obtained in the following way. Before each block, a picture was shown indicating on which forearm the tactile change was most likely to occur. In 2/3rd of the change trials, the predicted location was involved in the tactile change (valid change trials), meaning that either a tactile stimulus at that location was present in the second pattern but not in the first, or that a tactile stimulus at that location was present in the first pattern but not in the second pattern. In 1/3 of the change trials, the predicted location was not involved in the tactile change (invalid change trials). The different trial types were presented randomly throughout the course of the experiment.

In order to become acquainted with the task, the participants first performed a practice phase consisting of 28 trials. In the experimental phase, the participants completed a total of 528 trials, which were divided into six experimental blocks. There were two unpredictable blocks, consisting of 2 x 88 trials (44 ‘same’ trials, 44 ‘different’ trials), two predictable blocks in which attention was directed to the left forearm, consisting of 2 x 88 trials (44 ‘same’ trials, 28 valid ‘different’ trials, and 16 invalid ‘different’ trials), and two predictable blocks in which attention was directed to the right forearm, consisting of 2 x 88 trials (44 ‘same’ trials, 28 valid ‘different’ trials, and 16 invalid ‘different’ trials). The order in which
the blocks were presented was counterbalanced across participants. The participants were informed that they could take a break between these blocks, if they so desired.

**Data reduction and statistical analyses**

Two participants from the control group were excluded from further analyses because of the presence of a medium to high pain intensity at the moment of testing (see Supplementary Methods, Figure S1). Differences in characteristics between the fibromyalgia and control groups were examined using one-way Analysis of Variance (ANOVA) and Chi-square tests.

With regard to the tactile calibration data, a Repeated Measures ANOVA was performed on the mean objective tactor intensities with Location as a within-subject factor and Group as a between-subjects factor. With regard to the behavioural data, tactile change detection was analysed separately for the 2 conditions. In the unpredictable condition, an ANOVA on the mean proportion of accurately detected changes was performed with Group (fibromyalgia, control) as a between-subjects factor. In the predictable condition, a repeated measures ANOVA on the mean proportion of accurately detected changes was performed with Trial Type (valid, invalid) as a within-subject factor, and Group (fibromyalgia, control) as a between-subjects factor.

Finally, Pearson correlations between the behavioural data and self-report measures were calculated. To obtain an objective and standardized measure of the magnitude of the hypothesized 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).
Results

Self-report data

Table 1 presents an overview of the characteristics and self-report data of both samples. There were no significant differences in sex, age, and educational level between the fibromyalgia patients and the control group. All of the participants in the fibromyalgia group and 68% of the participants from the control group reported having experienced pain in the last four weeks. All of the fibromyalgia participants reported pain at the moment of testing, in contrast to 30% of the participants in the control group. Average pain during the last four weeks, most intense pain during the last four weeks, and pain intensity at the moment of testing were all significantly higher in the fibromyalgia group than in the control group. The majority of the fibromyalgia patients (85%) were on pain medication at the time of testing, whereas none of the control participants were. The fibromyalgia group had significantly higher scores on the PCS and the PVAQ, but not on the BVS, as compared to the control group.

INSERT TABLE 1

Tactile change detection task

Tactor intensities. A Repeated Measures ANOVA on the objective intensity of the tactile stimuli yielded a significant main effect of Group \((F(1,79) = 16.91, p < .001, d = 0.86, 95\% CI [0.41, 1.31])\), with a higher intensity in the fibromyalgia group \((M = 0.19\text{ watts}, SD = 0.12)\) than in the control group \((M = 0.11\text{ watts}, SD = 0.05)\). This group difference did not depend on the stimulated body site, as there was no significant Group x Location interaction effect \((F(7,553) = 1.58, p = .163)\). There was, however, a significant main effect of Location \((F(7,553) = 69.75, p < .001)\), indicating that there were differences in tactile intensity between
the stimulated locations. Post-hoc contrasts showed that tactile intensity on all 4 locations on the legs was higher than on all 4 locations on the arms. Furthermore, tactile intensity on both upper arms was higher than on both forearms.

*Unpredictable condition.* An ANOVA revealed that the proportions of accurately detected tactile changes in the fibromyalgia group ($M = 0.60, SD = 0.18$) and the control group ($M = 0.59, SD = 0.17$) were not significantly different ($F(1,79) = 0.07, p = .792; d = 0.06, 95% CI [-0.37, 0.49]$).

*Predictable condition.* The repeated measures ANOVA on the proportion of accurately detected tactile changes revealed no significant main effect of Trial Type ($F(1,79) = 1.54, p = .219; d = 0.10, 95% CI [-0.33, 0.53]$), indicating that there was no difference in accuracy between the valid ($M = 0.61, SD = 0.19$) and the invalid change trials ($M = 0.63, SD = 0.20$). In addition, there was no significant main effect of Group ($F(1,79) = 0.31, p = .581; d = 0.11, 95% CI [-0.32, 0.54]$), indicating no difference between fibromyalgia patients ($M = 0.61, SD = 0.20$) and healthy controls ($M = 0.63, SD = 0.16$) in the proportion of accurately detected tactile changes. Finally, there was no significant Group x Trial Type interaction effect ($F(1,79) = 0.40, p = .530$). Thus, there was no group effect for either the valid change trials (fibromyalgia group: $M = 0.61, SD = 0.20$; control group: $M = 0.62, SD = 0.17$) or for the invalid change trials fibromyalgia group: $M = 0.61, SD = 0.21$; control group: $M = 0.65, SD = 0.18$).

**Correlations between self-report and behavioural measures in the fibromyalgia group**

Pearson correlations were calculated between self-report measures of hypervigilance and the proportion of accurately detected tactile changes, in both conditions. For the unpredictable condition, there were no significant associations between the proportion of accurately detected changes and the self-report measures, although there was a non-significant
trend for the BVS (PVAQ: \( r = -.06, p = .721 \); BVS: \( r = .28, p = .077 \)). For the predictable condition, no significant associations were found between self-report measures and tactile change detection in valid trials (PVAQ: \( r = -.13, p = .437 \); BVS: \( r = .23, p = .142 \)) as well as invalid trials (PVAQ: \( r = -.07, p = .657 \); BVS: \( r = .17, p = .293 \)).

**Discussion**

The present study examined the idea that patients with fibromyalgia are characterized by somatosensory hypervigilance. Hypervigilance was assessed by means of a tactile change detection task (Gallace et al., 2006), which allowed us to assess attention to tactile information in an environment with multiple attentional demands, and controlling for inter-individual and intra-individual differences in tactile sensitivity (Van Hulle et al., 2013b). It was hypothesized that more tactile changes would be reported in a sample of patients with fibromyalgia than in a matched control group, particularly when those changes occurred at unpredicted body locations.

Our findings did not support this hypothesis. Patients with fibromyalgia were no more accurate than control participants in detecting tactile changes in either of the conditions. In other words, we found no indication of generalized hypervigilance in those patients with fibromyalgia. This finding may seem at odds with studies that have demonstrated amplified perception of non-painful somatosensory stimuli in fibromyalgia patients as compared to healthy controls (Geisser et al., 2003; Hollins et al., 2009). However, in the current study, hypervigilance was operationalized as the prioritization of somatosensory information in an environment with competing demands (Crombez et al., 2005; Van Damme et al., 2009a). Such an operationalization distinguishes the *process* of attention from the possible *consequences* resulting from focused attention, such as perceptual amplification. Hypervigilance is but one of the mechanisms that may account for research findings.
demonstrating hypersensitivity in fibromyalgia patients, and other processes such as central sensitization (Arendt-Nielsen and Henriksson; 2007; Staud et al., 2007), are equally likely explanations. For conceptual clarity, as well as for possible treatment implications, it is recommended not to simply equate hypervigilance with hypersensitivity (Crombez et al., 2005; Van Damme et al., 2009a).

Few studies have examined somatosensory processing in an environment in which there have been competing attentional demands in patients with fibromyalgia. In a study by Peters et al. (2000), fibromyalgia patients and healthy controls were asked to detect weak electrical stimuli of slowly increasing intensity, which could be administered to one of four potential body locations. The task was performed either with or without a simultaneous visual reaction time (RT) task. No differences in detection threshold (time needed to detect an electrical stimulus) between the fibromyalgia group and the control group were found, either in the single or dual task conditions. More recently, Tiemann et al. (2012) had fibromyalgia patients and healthy controls perform a visual RT task of which half of the trials were accompanied by an individually calibrated painful laser stimulus. The administration of pain significantly affected both RTs to, and the neuronal gamma oscillations evoked by, the visual detection task, but the effect was not different between the fibromyalgia group and the controls. Although both of these studies may not allow firm conclusions to be drawn about hypervigilance (electrical stimuli were not individually calibrated in the former study, and the latter study measured task interruption by pain rather than perception of somatosensory information), they are in line with the present study in showing no differences between fibromyalgia patients and healthy controls.

Do the present findings mean that generalized hypervigilance does not exist, or does not play a role in the perceptual amplification observed in patients with fibromyalgia? We believe that this is not necessarily the most appropriate conclusion. Rather, we argue that
these findings challenge the view of hypervigilance as a *static* characteristic of certain pain syndromes such as fibromyalgia. It may well be that hypervigilance is a *dynamic* process that emerges when the fear system is activated, and when the individual’s current goal is to escape or avoid pain or bodily threat (Crombez et al., 2005; Eccleston and Crombez, 1999; Van Damme et al., 2010; Legrain et al., 2011). Hypervigilance may only emerge in particular situations, when pain is a current concern, i.e., when an individual is worried about pain and its possible consequences (Crombez et al., 2005; Eccleston and Crombez, 2007). It has already been shown in healthy volunteers that attention was more strongly focused on a body part where pain was anticipated or bodily threat was suggested (Van Damme & Legrain, 2012; Van Damme et al., 2007, 2009b; Vanden Bulcke et al., 2013). From that perspective, the lack of findings may be related to the fact that the tactile stimuli were insufficiently threatening, and lacked aversive meaning for fibromyalgia patients. An example of a more naturalistic situation is the performance of a specific movement or activity which a person perceives as potentially painful or harmful. There is thus an urgent need to investigate hypervigilance in such naturalistic situations as, for example, during the execution of pain-relevant movements. A number of experimental paradigms are available that may be well suited to examine this (Meulders et al., 2011; Vangronsveld et al., 2007; Van Hulle et al., 2013a). Another potential explanation for the lack of findings is that fibromyalgia patients have been shown to generally perform worse on a wide range of cognitive tasks (Glass, 2009, 2010), which could have interfered with the measurement of hypervigilance. Moreover, it could be speculated that this cognitive dysfunction may not apply to the somatosensory modality, although this remains to be investigated.

Several issues with regard to the present study require further elaboration. First, as a result of our calibration and matching procedure, the average intensity of tactile stimuli across different body locations, was markedly higher in the fibromyalgia group than in the control
participants. This indicates that a higher intensity was needed for fibromyalgia patients to adequately perceive the tactile stimulation during the matching procedure. This is in line with recent evidence for elevated mechanical thresholds in patients with fibromyalgia (Uceyler et al., 2013), which could result from small-fibre pathology (Oaklander et al., 2013). However, other studies have rather shown amplified somatosensory perception (Geisser et al., 2003, 2008; Hollins et al., 2009). We may speculate that the reduced touch perception in our fibromyalgia group could have been due to the presence of various sensory symptoms such as numbness. As we did not assess such symptoms, we were not able to test this explanation, but it is certainly worthy of further investigation. Note that in the present study, the higher objective intensity of tactile stimuli in the fibromyalgia group did not result in better performance on the tactile change detection task. Second, a number of procedural aspects should be taken into account when interpreting the findings reported here. The task instructions that were given prior to the experiment may also have induced a state of heightened attention (i.e., ‘hypervigilance’) toward the body in the control group, making it more difficult to detect differences between fibromyalgia patients and controls. Furthermore, because the participants did not have to specify what exactly changed between tactile patterns, it is possible that we have overestimated the proportion of correctly detected changes. Future research using this paradigm, though, should consider further refinement of the task. Third, we found that the fibromyalgia group scored higher than the control group on the self-report measures of hypervigilance, although this effect only reached significance for the PVAQ, which assesses attentional style towards pain. This finding is in line with several other studies (Peters et al., 2000; Roelofs et al., 2003; Crombez et al., 2004; Tieman et al., 2012). Yet, it should be borne in mind that the scores on these self-report measures in the fibromyalgia group may be affected, at least to some extent, by the continuous presence of pain and other somatic symptoms, perhaps rather reflecting multiple somatic complaints than an excessive
attentional focus (Van Damme et al., 2009). Interestingly, correlation analyses in the fibromyalgia group showed no significant associations between self-report and behavioural measures of hypervigilance. One may speculate that this provides a further indication that the elevated PVAQ scores in the fibromyalgia group may be inflated by non-attentional factors. Fourth, the fibromyalgia patients were recruited in one tertiary care centre, which may not be an accurate representation of the fibromyalgia population. Obviously, further studies are required in order to examine whether the present findings would generalize to fibromyalgia patients in other settings. Fifth, the majority of the fibromyalgia patients reported to take pain medication. It may well be that this medication had certain effects on task performance.

In conclusion, we found no indications that patients with fibromyalgia are characterized by somatosensory hypervigilance, at least not in the tactile submodality. We argue for conceptual scrutiny, and for a more dynamic view on hypervigilance, in which hypervigilance is not seen as a stable characteristic of certain pain syndromes such as fibromyalgia, but rather as a transient mechanism that is activated when a person anticipates potential threat to the body and the goal to escape or avoid pain is activated. Future research investigating hypervigilance in more naturalistic situations, such as during movement, would be welcome to test this intriguing idea.

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Author contributions

All authors substantially contributed to the conception and design of the study, discussed the results, commented on the manuscript, and approved the submitted version.
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Table legends

Table 1. Overview of sample characteristics and self-report data (values in brackets are standard deviations)

<table>
<thead>
<tr>
<th></th>
<th>Fibromyalgia</th>
<th>Control</th>
<th>Group difference statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (females/males)</td>
<td>37/4</td>
<td>37/3</td>
<td>$X^2(1) = 0.13, p = .718$</td>
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<tr>
<td>Age</td>
<td>45 (10)</td>
<td>42 (10)</td>
<td>$F(1,79) = 1.69, p = .197$</td>
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<tr>
<td>Education level</td>
<td>2/23/16</td>
<td>1/13/26</td>
<td>$X^2(2) = 5.48, p = .065$</td>
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<tr>
<td>On pain medication</td>
<td>35/6</td>
<td>0/40</td>
<td>$X^2(1) = 60.13, p &lt; .001$</td>
</tr>
<tr>
<td>Pain intensity at the moment of testing</td>
<td>6.61 (1.22)</td>
<td>1.43 (1.63)</td>
<td>$F(1,79) = 455.40, p &lt; .001$</td>
</tr>
<tr>
<td>Average pain intensity during past 4 weeks</td>
<td>6.32 (1.51)</td>
<td>0.50 (0.85)</td>
<td>$F(1,79) = 263.09, p &lt; .001$</td>
</tr>
<tr>
<td>Maximal pain intensity during past 4 weeks</td>
<td>8.49 (1.19)</td>
<td>2.45 (2.62)</td>
<td>$F(1,79) = 179.83, p &lt; .001$</td>
</tr>
<tr>
<td>PCS</td>
<td>24.71 (11.33)</td>
<td>13.05 (8.14)</td>
<td>$F(1,79) = 28.20, p &lt; .001$</td>
</tr>
<tr>
<td>PVAQ</td>
<td>43.20 (8.74)</td>
<td>32.55 (10.54)</td>
<td>$F(1,79) = 24.60, p &lt; .001$</td>
</tr>
<tr>
<td>BVS</td>
<td>17.94 (6.45)</td>
<td>15.50 (5.76)</td>
<td>$F(1,79) = 3.24, p = .076$</td>
</tr>
<tr>
<td>PDI</td>
<td>46.61 (7.08)</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
</tbody>
</table>
Figure 1. Flow chart of the study
Figure S2. The 3 panels illustrate the different trial types in the predictable condition. The filled grey circles represent the tactor locations that were used in the experiment. The white dots represent active tactor locations. The square indicates the body location on which a tactile change is most likely to occur (in this example, the right forearm). Panel A provides an example of a valid change trial in which a tactor of the first pattern becomes inactive in the second pattern, and the tactor at the “predicted” location becomes active instead. Panel B provides an example of a valid change trial in which the tactors at the “predicted” location of the first pattern becomes inactive in the second pattern, and another tactor becomes active instead. Panel C provides an example of an invalid change trial, in which the tactile change does not involve the “predicted” body location.