

Generalized hypervigilance in fibromyalgia: normal interoceptive accuracy, but reduced self-regulatory capacity

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Running head: hypervigilance in fibromyalgia

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Abstract

Objective: The factors underlying the aetiology of fibromyalgia (FM) are largely unknown.

According to the generalized hypervigilance hypothesis (GHH), FM patients show excessive attention towards pain stimuli and other sensory events, thereby increasing pain perception and dysfunctional behaviour. We tested this notion by assessing interoceptive accuracy (IA) in FM patients and matched healthy controls. We also tested the hypothesis that FM is characterized by reduced self-regulatory capacity as indexed by heart rate variability (HRV).

Methods: 47 FM patients ($M_{\text{age}} = 45.5$, 39 females) and 45 healthy controls ($M_{\text{age}} = 44.9$, 37 females) completed several self-report scales (Body Vigilance Scale, Depression Anxiety Stress Scales, Pain Catastrophizing Scale). To derive HRV, heart rate was monitored under resting conditions; for the assessment of IA participants performed a heartbeat tracking task in which they were asked to silently count their heartbeats. **Results:** FM patients reported higher body vigilance than healthy controls, but there were no group differences in IA. FM patients had lower HRV compared with healthy controls. HRV did not predict IA. **Conclusion:** In conclusion, our findings do not support the hypothesis of generalized hypervigilance in FM patients. Patients reported a heightened focus on bodily sensations, which was not reflected in IA. It may be that hypervigilance is not a general and stable characteristic but is rather context dependent and modality-specific.

Key words: generalized hypervigilance, fibromyalgia, interoceptive accuracy, heart rate variability

1. Introduction

Fibromyalgia (FM) is characterized by widespread musculoskeletal pain, and is accompanied by fatigue, sleep disorders, memory problems and mood disturbances (1). Despite its prevalence and increasing research, the factors underlying the aetiology of FM remain elusive. One potentially important aetiological factor is generalized hypervigilance, i.e. the excessive attention towards potential threat. The generalized hypervigilance hypothesis (GHH) posits that patients with medically unexplained symptoms, such as FM, focus their attention on potential threat signals, resulting in increased pain sensitivity, and the amplified perception of non-painful sensations in other sensory modalities (2,3). McDermid and colleagues (2) postulated a perceptual style of amplification extending beyond the pain domain. In line with this assumption, subsequent studies aimed to investigate the GHH with innocuous stimuli (e.g. 4, 41). Other studies, however, interpreted the GHH as referring to aversive stimuli only (e.g. 3). The purpose of the current study was to investigate whether generalized hypervigilance also occurs in regard of non-threatening internal bodily signals.

Despite its importance for a better understanding of hypervigilance in FM, research on the perception of internal signals in FM patients, i.e. interoception, is scarce. So far, generalized hypervigilance has been supported by (a) self-report measures, on which FM patients typically show elevated scores for vigilance to pain (4–6) and (b) experimental measures showing decreased pain thresholds and tolerance levels for experimentally induced pain (2,7,8) innocuous (e.g. auditory) stimuli (3,9) and (c) perceptual amplification of non-aversive interoceptive stimulation (10) in FM patients. In line with these findings, FM patients are expected to be hypervigilant towards internal signals and, thus, more accurate in perceiving internal bodily signals.

The accuracy of perceiving internal bodily changes has been conceptualised as a trait (11,12), with the process of accurately detecting and tracking bodily signals relying on actual

bodily changes. The assessment of interoceptive accuracy (IA), therefore, requires the monitoring of physical changes, which can be readily measured. The heartbeat tracking task is a useful assessment paradigm, as heartbeats are easily quantifiable as discrete and determinable stimuli (13–15). Numerous studies have used this paradigm to assess IA in panic patients in order to investigate hypervigilance towards bodily sensations (16–20).

In addition, FM may also be characterized by a deficiency in inhibiting irrelevant information or prioritizing attention towards relevant stimuli or sensations (21). According to the Neurovisceral Integration Model (22,23), insufficient inhibitory control can be physiologically indexed by vagally mediated heart rate variability (HRV). Heart rate reflects the combined result of sympathetic and parasympathetic activity at the sino-atrial node (24). Beat-to-beat variability indexes activity in this reciprocal inhibitory cortico-subcortical neural circuit, and serves as the structural link between psychological processes and health-related physiological processes. As HRV reflects activity that is dynamically organized in response to environmental challenges, it allows for the quantification of behavioural flexibility and adaptability in a changing environment, i.e. self-regulatory capacity. In line with this reasoning, previous research has found lower HRV in FM patients compared to healthy controls (25,26). Porges (1992) defines the ability to rapidly shift and effectively sustain attention in accord with situational demands as one critical component of self-regulation (27). Accordingly, lower HRV has been found to predict hypervigilance and inefficiency of attentional regulation (28).

The aims of the current study were threefold: (1) to investigate IA in FM patients, (2) to replicate previous findings on lower HRV in FM patients compared to healthy controls, and (3) to examine the predictive value of self-regulatory capacity for IA. We, therefore, assessed HRV and performance in a heartbeat tracking task (29) in a group of FM patients, compared to age- and sex-matched healthy controls. We hypothesized that 1) FM patients are more

accurate in counting their heartbeats, 2) HRV, as an index of self-regulatory capacity, is reduced in FM patients and 3) HRV is negatively associated with IA.

2. Methods

2.1. Participants and procedure

Participants between the age of 18 and 65 years were recruited in the context of a larger project (see protocol ASEF-I; <http://hdl.handle.net/1854/LU-5686902>) between January 2014 and March 2014. Individuals were eligible to participate if they either were diagnosed with FM and fulfilled the ACR-90 criteria for FM (FM group) or did not report a current pain problem (healthy control group). Additional inclusion criteria were: (1) sufficient knowledge of the Dutch language; (2) absence of neurological conditions. Furthermore, individuals were excluded when they were unable to use both index fingers, reported abnormal sensations in the arms or if their eyesight was not normal or not corrected-to-normal (e.g., by glasses). The latter three criteria were exclusion criteria in regard of a task, which was not part of this study (see ASEF-I). FM patients were recruited via the Multidisciplinary Pain Clinic of Ghent University Hospital. They were informed about the study with a poster in the waiting room of the hospital. Patients who were interested in taking part left their contact details and were screened for eligibility. Individuals of the control group were recruited using advertisements in a local newspaper, flyers and the university website. Individuals who volunteered were contacted and screened for eligibility. Both groups were matched at group level for age, sex and educational level. A total of 98 individuals took part in the study: 49 FM patients and 49 healthy controls.

As the study was part of an extended protocol, we only report the procedure relevant for the current research question. In a first step, participants filled out a set of standardised

questionnaires, including the Body Vigilance Scale (BVS; Schmidt, Lerew, & Trakowski, 1997), the Depression Anxiety Stress Scales (DASS; Lovibond & Lovibond, 1995) and the Pain Catastrophizing Scale (PCS; Sullivan, Bishop, & Pivik, 1995) via an online assessment system (LimeSurvey) at home (if this was not possible, participants received a paper version to fill in). In a second step, i.e., when arriving at the research lab, participants rated their current pain and indicated whether they had consumed coffee within the last two hours (exclusion criterion). The experimenter then checked the ACR-criteria (1) with the patient to confirm the FM diagnosis. Next, heart rate was measured over a period of five minutes. Finally, the participant performed a heartbeat tracking task (29). The study design was approved by the Ethics Review Panel of the University of Luxembourg and the Medical Ethics Committee, University Hospital Ghent. Participants gave written informed consent and received a token of gratitude of 35€ for their participation.

2.2. Self-report data

Pain intensity at the moment of testing was assessed using the item “*how intense is your pain now?*”. Participants answered by using a visual analogue scale from 0 (“*no pain*”) to 100 (“*worst imaginable pain*”).

Depressive mood, anxiety and stress were assessed with the DASS (31). Each of the subscales contain 14 items in which participants are asked to rate the extent to which they have experienced each state (e.g. “I found it difficult to relax”, “I felt sad and depressed”) over the past week using a 4-point Likert scale (0 = *did not apply to me at all* to 3 = *applied to me very much, or most of the time*). Scores may range from 0 to 42. Within the current sample, the scales were found to have excellent internal consistencies ($\alpha = .97$ for depression, $\alpha = .92$ for anxiety and $\alpha = .95$ for stress).

Catastrophic thinking about pain was assessed with the PCS (32). The scale consists of 13 items in which participants indicate the degree to which they experienced catastrophic thoughts or feelings during pain episodes (e.g. “I keep thinking about how much it hurts”, “I can’t seem to keep it out of my mind”) on a 5-point Likert scale (0 = *not at all* to 4 = *all the time*). Scores may range from 0 to 52. This scale showed a good reliability and validity in healthy populations and chronic pain patients (33). Cronbach’s alpha for the current study was .95.

Vigilance for bodily sensations was assessed using the BVS (30). The BVS assesses attentional focus for bodily sensations and consists of four items in which participants indicate on an 11-point Likert scale (0 = *none* to 10 = *extreme*) the degree to which they agree with a particular statement regarding selective attention to bodily sensations. Scores on item 3 (“On average, how much time do you spend each day ‘scanning’ your body for sensations [e.g. sweating, heart palpitation, dizziness]”) are divided by 10. The last item involves having participants rate their attention to 15 bodily sensations (e.g. heart palpitations). Responses to the fourth item are averaged to yield a single score. Summing the four items derives a total score of the BVS with a range from 0 to 40. The questionnaire has adequate internal consistency in clinical and nonclinical populations (30,34). Cronbach’s alpha for the current study was acceptable ($\alpha = .70$).

2.3. Heart rate variability (HRV)

During the baseline period, participants sat in individual cubicles and were instructed to sit quietly and relax. Inter-beat intervals were assessed based on electrocardiographic recordings for 5 minutes at a sampling rate of 1000 Hz using a Polar watch RS800CX (Polar Electro Oy, Kempele, Finland).

2. 4. Perception of bodily sensations

IA was assessed with a heartbeat tracking task based on the paradigm first introduced by Schandry (29). The actual number of heartbeats was recorded with the same Polar watch used for baseline recordings and analysed via Polar ProTrainer software. Participants were asked to silently count all the heartbeats they perceived in their body without taking their pulse or attempting any other manipulation to facilitate the discrimination of their heartbeats. Instructions were given via an E-Prime-based script on a written screen to minimize bias introduced by the experimenter. The task consisted of four intervals of 25, 35, 45 and 55 seconds in randomized order and the duration of these intervals was unknown to participants. The intervals were separated by standard resting periods of 30 seconds. A visual countdown of 3-2-1 followed by a cross on the screen indicated the beginning of the counting period. The period ended with the disappearance of the cross. After the counting period, participants were asked to indicate the number of counted heartbeats. The number of counted heartbeats was compared to the recorded number of heartbeats. Participants started with one training interval of 25 seconds. IA was calculated as the mean score across all the counting intervals (with n = number of valid counting intervals) using the formula $IA_{Schandry} = 1/n \sum [1 - (|HB_{recorded} - HB_{counted}|) / HB_{recorded}]$. Scores vary between 0 and 1 with a maximum score of 1 indicating absolute accuracy. Furthermore, as Brown and colleagues (35) have shown that physical symptom reporting is related to the tendency to report false alarms in a somatosensory signal detection task, we additionally calculated a simple IA score to distinguish over- from underreporting using the formula $IA_{simple} = 1/n \sum (HB_{counted} - HB_{recorded}) / HB_{recorded}$ with a positive score reflecting overreporting and a negative score reflecting underreporting of heart beats.

2.5. Data handling and reduction

To calculate HRV-indices, sequential interbeat intervals were downloaded using the software Polar Pro Trainer 5. All signals were visually inspected for artefacts. HRV analysis was performed using the software ARTiiFACT (36). First, measurement artefacts were identified by applying a distribution-related threshold criterion. Erroneous beats were deleted and substituted by cubic spline interpolation of neighbouring intervals. Time domain measures were directly calculated from RR-interval series. Spectral analysis of the RR-interval series was carried out using Fast Fourier Transformation. Following the recommendations of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996) we defined the high frequency band (HF) as 0.14 to 0.4 Hz and used the following time and frequency HRV parameters for statistical analyses: root mean square of successive differences (RMSSD), percent of difference between adjacent RR intervals that are greater than 50 ms (pNN50) and the absolute power in the HF band (HFabs) (37). We focused on those parameters because they reflect parasympathetic control over heart rate (37). The criterion for outliers in HRV measures was defined as values more than 3 *SD* above the sample mean (cf. 36). After correcting for outliers, HFabs was log transformed to adjust for skewness of the distribution (lnHFabs). Regarding the heartbeat tracking task, for 9 out of 89 participants (5 FM, 4 controls) only three valid intervals were included due to recording problems.

Four participants (1 FM, 3 controls) were excluded from the final analyses due to equipment failure. Furthermore, two participants (1 FM, 1 control) were excluded because of outliers in HRV. Both participants scored more than three *SD* above the sample mean. The final sample, therefore, consisted of 47 FM patients and 45 healthy controls.

2.6. Statistical analyses

Differences in characteristics between the FM and healthy control groups were examined using independent samples t-tests. Pearson correlations were performed between IA, HRV-indices and self-report measures. According to hypothesis one, we expected that FM patients are more accurate in counting their heartbeats than healthy controls. This was tested using an independent samples t-test (2-tailed). Effect size indices for independent samples (Cohen's *d*) and the 95% confidence interval (95% CI) were calculated (39,40). Hypothesis two states that HRV is reduced in FM patients. To test this hypothesis, a multivariate analysis of variance (MANOVA) was conducted in regard of the three related HRV-indices. Finally, we tested the hypothesis of a negative relationship between HRV and IA_{Schandry} using a hierarchical linear regression analysis. In a first step, we entered HRV as predictor. In a next step, we aimed at controlling whether the relationship remains present when controlling for group. For this analysis, we choose HRV-RMSSD because of its robust statistical properties (cf. 35). Critical alpha level for all analyses was set to .05.

3. Results

3.1. Descriptive statistics

Table 1 summarizes sample characteristics and self-report data. There were no significant differences in age, gender or educational level (all *p*'s > .244). All of the FM patients, and 26.7% of the healthy controls reported pain at the moment of testing. Pain intensity at the moment of testing was significantly higher in the FM than in the healthy control group. Pain intensity scores in the FM group ranged between 8 and 84, compared to 0 and 17 in the control group. FM patients had significantly higher scores on all self-report measures as compared to healthy controls (see table 1).

Table 1

Descriptive Statistics by Participant Group

Variable	Group		Difference test
	FM (<i>n</i> = 47)	Control (<i>n</i> = 45)	
Age (<i>M</i> , <i>SD</i>)	45.5 (9.2)	44.9 (12.2)	$t(82)^a = .26, p = .792, d = 0.06$
Gender (<i>n</i> women)	39	37	$\chi^2(1) = .009, p = .924, w = 0.00$
Educational level			$\chi^2(2) = 2.82, p = .244, w = 0.29$
College/University	38.3%	55.6%	
Secondary school	57.4%	42.2%	
Primary school	4.3%	2.2%	
Pain intensity at moment of testing (<i>M</i> , <i>SD</i>)	43.87 (21.5)	1.60 (3.8)	$t(49)^a = 13.28, p < .001, d = 2.73$
DASS – Depression (<i>M</i> , <i>SD</i>)	13.2 (10.6)	5.84 (6.4)	$t(75)^a = 3.95, p < .001, d = 0.84$
DASS – Anxiety (<i>M</i> , <i>SD</i>)	11.34 (7.6)	2.89 (3.6)	$t(66)^a = 6.91, p < .001, d = 1.42$
DASS – Stress (<i>M</i> , <i>SD</i>)	15.26 (7.8)	8.11 (7.4)	$t(90) = 4.51, p < .001, d = 0.94$
PCS (<i>M</i> , <i>SD</i>)	21.62 (10.8)	9.64 (9.6)	$t(90) = 5.61, p < .001, d = 1.17$
BVS (<i>M</i> , <i>SD</i>)	18.41 (6.6)	14.05 (6.4)	$t(90) = 3.21, p = .002, d = 0.67$

Note. FM = fibromyalgia; DASS = Depression Anxiety Stress Scales; PCS = Pain Catastrophizing Scale; BVS = Body Vigilance Scale. ^a = equal variances not assumed.

There were no significant associations between IA and any other measure ($-.081 < r > .142$, ns). Body vigilance was related to higher pain intensity at the moment of testing as well as to higher scores in depression, anxiety, stress and pain catastrophizing. Further, we found a significant negative correlation ($r = -.223, p < .05$) between pain catastrophizing and pNN50. HRV-indices were highly interrelated. Table 2 gives an overview of means and correlations.

Table 2

Means (M), Standard Deviations (SD) and Pearson Correlation Coefficients for All Measures

	<i>M</i>	<i>SD</i>	2	3	4	5	6	7	8	9	10	11
1. IA _{Schandry}	0.56	0.24	.548***	.117	-.005	.024	.110	.051	-.081	.142	.112	.102
2. IA _{simple}	-0.38	0.35		.075	-.054	.068	.003	.003	.080	.054	.040	.018
3. Pain intensity at moment of testing	23.20	26.30			.424***	.590***	.401***	.554***	.299**	-.232*	-.193†	-.147
4. Depression (DASS)	9.59	9.67				.685***	.676***	.639***	.373***	-.114	-.112	-.125
5. Anxiety (DASS)	7.21	7.28					.715***	.642***	.527***	-.099	-.069	-.064
6. Stress (DASS)	11.76	8.36						.575***	.436***	-.071	-.075	-.085
7. Pain Catastrophizing (PCS)	15.76	11.82							.450***	-.182†	-.223*	-.098
8. Body Vigilance (BVS)	16.28	6.83								-.071	-.049	-.021
9. RMSSD	22.60	12.89									.935***	.868***
10. pNN50	6.20	9.37										.876***
11. lnHFabs	4.98	1.24										

Note. IA = interoceptive accuracy; DASS = Depression Anxiety Stress Scales; PCS = Pain Catastrophizing Scale; BVS = Body Vigilance Scale; RMSSD = root mean square of successive differences; pNN50 = percent of difference between adjacent RR intervals that are greater than 50 ms; lnHFabs = log transformed absolute power in the HF band. † $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

3.2. Interoceptive accuracy

IA_{Schandry} did not differ between the FM group ($M = 0.59$; $SD = 0.25$) and the healthy control group [$M = 0.52$; $SD = 0.24$, $t(90) = 1.28$, $p = .205$, $d = 0.29$, 95% CI -0.04 to 0.17]. Similarly, additional analyses using the formula to detect false alarms (IA_{simple}), did not show differences between the FM ($M = -0.33$; $SD = 0.34$) and the healthy control group [$M = -0.42$; $SD = 0.35$, $t(90) = 1.26$, $p = .212$, $d = 0.26$, 95% CI -0.05 to 0.23].

3.3. Heart rate variability

Using Pillai's trace, we found a significant effect for group in all HRV-indices, $V = 0.09$, $F(3,88) = 2.94$, $p = .037$. Follow-up tests revealed lower RMSSD and pNN50 in FM patients compared with healthy controls. Results of separate univariate ANOVAs are summarized in Table 3.

Table 3

Heart Rate Variability Measures by Participant Group

HRV-indices	Group		Difference test (ANOVAs)
	FM ($n = 47$)	Control ($n = 45$)	
	(M , SD)	(M , SD)	
RMSSD	19.36 (10.6)	25.98 (14.3)	$F(1,90) = 6.41$, $p = .013$, $\eta^2 = .07$
pNN50	4.13 (6.9)	8.36 (11.1)	$F(1,90) = 4.88$, $p = .030$, $\eta^2 = .05$
lnHFabs	4.77 (1.2)	5.19 (1.2)	$F(1,90) = 2.58$, $p = .112$, $\eta^2 = .03$

Note. HRV = heart rate variability; FM = fibromyalgia; RMSSD = root mean square of successive differences; pNN50 = percent of difference between adjacent RR intervals that are greater than 50 ms; lnHFabs = log transformed absolute power in the HF band.

3.4. Association between interoceptive accuracy and heart rate variability

We investigated the predictive value of HRV for $IA_{Schandry}$ using a hierarchical regression analysis. The regression analysis indicated that HRV did not explain a significant amount of the variance in $IA_{Schandry}$ when entered as a single predictor [$F(1,90) = 1.86, p = .176, R^2 = .02$], with $\beta = .142$. When controlling for group as a predictor, the regression model was not significant [$F(2,89) = 2.41, p = .096, \Delta R^2 = .03$]. This model is presented in table 4.

Table 4

Hierarchical Regression Model Explaining Interoceptive Accuracy, with Standard Errors and 95% Confidence Intervals Reported in Parentheses

	<i>b</i>	<i>SE B</i>	β	<i>p</i>
Step 1				
HRV (RMSSD)	0.003 (-.001, .007)	0.002	.142	.176
Step 2				
HRV (RMSSD)	0.004 (0.000, 0.008)	0.002	.189	.080
Group	-0.088 (-0.191, 0.015)	0.052	-.182	.092

Note. $R^2 = .020$ for step 1; $\Delta R^2 = .031$ for step 2; RMSSD = root mean of square of successive differences; HRV = heart rate variability.

4. Discussion

The aims of the current study were (1) to assess the accuracy of perceiving interoceptive signals in FM patients using a heartbeat tracking task, (2) to compare HRV between groups, and (3) to investigate the predictive value of HRV for $IA_{Schandry}$. Firstly, FM patients did not differ from healthy controls in IA. Secondly, FM patients showed decreased HRV compared to healthy controls. Thirdly, HRV did not predict $IA_{Schandry}$.

Contrary to our expectations, we did not find altered perception of interoceptive signals in FM patients, as assessed with the heartbeat tracking task, neither using the

traditional formula by Schandry (29), nor the additional formula (IA_{simple}) aiming at the detection of false alarms. Although the small CI indicates robustness of the finding that the accuracy of detecting heart beats does not differ between FM patients and healthy controls, it is opposed to previous results showing increased pain sensitivity and amplified perception of painful and non-painful stimuli in FM patients (2,3,7–9). The present finding, however, is in line with a number of studies, which failed to demonstrate prioritization of external innocuous stimuli in FM patients (4,41). In the study by Van Damme and colleagues (41), participants 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 body locations. Neither in the unpredictable condition nor when changes occurred at unexpected locations in the predictable condition, FM patients showed better tactile change detection than healthy controls. Peters and colleagues (4) used a reaction time paradigm in which participants had to respond as fast as possible to innocuous electrical stimuli which were gradually increasing in strength and administered to one of four different body locations. This task was presented under single and dual (with a second visual reaction time task) task conditions. FM patients did not show superior detection of weak electrical stimuli either under single or dual task conditions.

In regard of the different accounts of the GHH, the current findings do not support the hypothesis that FM patients have a perceptual style of amplification, suggested by McDermid and colleagues (2). Current findings do, however, not rule out the interpretation of Hollins and colleagues (3), which states that generalized hypervigilance only relates to unpleasant stimuli. If, however, only stimuli that are appraised as unpleasant lead to hypervigilance, we might expect that this mechanism is highly contextual and specific. Accordingly, the current results cast doubt on the view of hypervigilance as a general characteristic, which applies to all kinds of signals equally. Rather, hypervigilance may be a dynamic process, which is associated with

specific conditions or modalities, that occurs when the fear system is activated and an individual is concerned about pain (42–45). Hypervigilance would then be expected to only appear in the context of pain or threat, and this has even been shown for healthy individuals who respond with a stronger focus on body parts where pain or bodily threat was anticipated (46–49). Heartbeats are not threatening or aversive for FM patients per se, and the experimental setting did not suggest bodily threat, explaining the current lack of group differences in IA. This may further explain why higher IA has been found in panic pain patients compared to healthy controls (16,17,50), as heartbeats definitely constitute threatening bodily sensations for these patients. Further, the fact that IA and scores on the BVS (30) were not associated, might point to modality-specific hypervigilance. Future studies should investigate hypervigilance in different pain-related and threatening contexts as well as in regard to different modalities in FM patients to better understand the role of interoception on the aetiology of FM.

Interoception entails a complex process with different aspects (51–54). For example, IA can be conceptualized as a function of sensitivity and specificity (52). According to the assumption of a perceptual style of amplification in FM patients (2), one may have expected a superior detection of bodily signals for FM patients. However, it may be reasonable to assume that not only the bodily signal, but also the noise, may be amplified (35), impeding the accuracy of the detection of heart beats. FM patients may then indeed be more sensitive to interoceptive signal change, similarly as to exteroceptive stimuli (2,3,7,8), but not able to reject competing signals as proposed by Pennebaker's competition-of-cues model (55). This model posits that only a limited amount of information can be processed at a given moment in time. In case of FM, persistent pain would then interfere with the processing of other bodily sensations, result in diminished IA and indicate the absence of generalized hypervigilance. In line with this reasoning are findings showing that individuals who report somatosensory

amplification are less accurate in counting their heartbeats (56). Likewise, one recent study reported lower IA in FM patients than in healthy controls, using the same behavioural paradigm for the assessment of IA (57). Several methodological differences between Duschek et al.'s (57) and the current study may, however, explain the diverging results. For example, the instructions for the heartbeat tracking task in the current study were standardized and presented on a screen, whereas in Duschek et al. (57) they were signalled by the experimenter, with the latter representing a potential source of bias. In addition, our findings are based on four compared to only three counting periods used in the study by Duschek and colleagues (57). The number of counting periods may affect the reliability of the task, but further research is necessary to provide specific evidence on this topic. Furthermore, and in contrast to Duschek et al.'s study (57), the current study included balanced sample sizes and groups matched for age, sex and educational level.

Interestingly, results of the heartbeat tracking task contrasted with self-reported hypervigilance, i.e. the tendency to focus on bodily sensations. Scores on the BVS (30) were significantly higher in FM patients, a result which is in line with previous findings (4,5,58). It is, however, important to note that self-reported body vigilance may be partly affected by the experience of persistent pain. Self-report measures might be biased by non-attentional factors and higher scores might reflect somatic complaints rather than excessive attention (59).

Groups differed in HRV in that FM patients showed lower HRV, specifically in the more robust time domain measures of HRV. These findings are in line with previous research comparing HRV between FM patients and healthy controls (25,26). Chronic pain conditions are accompanied by cognitive, emotional and physiological disturbances (1). The adaptation to these conditions requires the capacity to control one's cognition, emotion and behaviour, i.e. self-regulatory capacity (60,61). The persistent challenge posed by chronic pain may exhaust patients' self-regulatory resources (62), which may be reflected in lower HRV. We

further expected reduced HRV to be related to increased hypervigilance (21), as a link between resting cardiac vagal tone and attentional control has been previously reported (27). Reduced HRV, associated with increased hypervigilance, would then predict more accurate perception of interoceptive signals. We could not confirm this hypothesis. We do, however, find a non-significant trend towards a positive association between HRV and IA with a small effect size. A positive relationship between the perception of internal bodily states and the strength of controlling one's behaviour might indeed be expected based on Damasio's somatic marker hypothesis (63–65). This theory proposes that somatic states mark response options which guide our behaviour. More precisely, internal and external stimuli elicit somatic states which involve physiological modifications and are processed in specific brain structures (e.g. amygdala, ventromedial prefrontal cortex). These patterns of body-related responses to stimuli, i.e. emotions, provide an individual with options to respond to a stimulus and guide his behaviour. Some studies have emphasized the role of feedback of bodily signals in behavioural processes by linking higher IA to increased self-reported self-regulatory capacity or self-regulation of physical load (66,67).

Further research is important to elaborate on body perception in FM patients and investigate hypervigilance with different experimental paradigms and in different contexts. As research regarding the perception of internal bodily sensations is scarce, future studies may aim at expanding this research. One may think of investigating cardiac interoception also by other paradigms, such as the signal discrimination method in which the participant is cued to judge whether a series of external stimuli are presented simultaneously or delayed relative to one's own heart beat (68,69). One may also further investigate the role of the threat value for hypervigilance towards bodily sensations in an experimentally manipulated stress-related context. As such, interoceptive threat may be evoked by hyperventilation due to CO₂ inhalation. Also the direction of any association between the perception of interoceptive

signals and self-regulatory processes remains unclear. Future studies could expand the assessment of self-regulatory capacity by including self-report measures and experimental self-regulation tasks such as an exposure to temptation or an anagram task (62,70).

Some limitations must be pointed out. Firstly, one may argue that IA is not a suitable concept, and, therefore, the heartbeat tracking task not be an appropriate operationalization for investigating generalized hypervigilance. While generalized hypervigilance is supposed to lead to amplified perception of all sensations, it is debatable whether it would imperatively lead to more accurate perception. Secondly, we did not assess body mass index (BMI) which has been related to reduced IA (71), so that we cannot rule out for IA results to have been systematically affected by differences in BMI. Thirdly, the present study used a cross-sectional design, which does not allow for conclusions on cause-effect relationships. Fourthly, pain medication may have affected the results. Finally, in contrast to previous studies investigating generalized hypervigilance in FM, we used heart beats as stimuli which cannot be set at individual threshold levels. Thus, we cannot assure supra-threshold levels of stimulation.

In conclusion, the results suggest that hypervigilance is not a general characteristic of FM patients, but one that is rather context dependent or modality-specific.

Competing interest statement

The authors have no competing interests to report.

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