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Sensing the body matters: Profiles of interoceptive sensibility in chronic pain adjustment

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Abstract

Interoception is critical to health regulation and is often disrupted in individuals with chronic pain (ICPs). Interoceptive Sensibility (IS) - the self-reported experience and relationship toward internal states - includes skills such as sensing, interpreting, and using bodily information for self-regulation. Current studies on IS and chronic pain (CP) adjustment are scarce, and how the interplay between different IS skills shapes CP adjustment remains unclear. This cross-sectional study aimed to identify profiles of IS skills among ICPs and examined their associations with pain outcomes and psychological and behavioral risk/protective processes. Individuals with chronic musculoskeletal pain (n = 173; 84.4% women) completed the Multidimensional Assessment of Interoceptive Awareness (MAIA), measures of CP adjustment (depression, anxiety, vitality, pain severity, interference, and physical function), psychological (self-efficacy, catastrophizing, kinesiophobia) and behavioral processes (activity patterns). A cluster analysis identified three IS skills profiles: (1) *High IS skills* (n=68), with the highest levels of attention regulation toward bodily sensations, body trust, listening for insight, and self-regulation; (2) *Low IS skills* (n= 29), who distracted less and worried more about bodily sensations, and presented lower body trust; (3) *Mixed IS skills* (n= 71), despite good body trust, attention regulation, and low worrying, showed lower awareness of body-mind connections. IS skills profiles differed in depression, vitality (fatigue), and psychological/behavioral processes, such as pain-related self-efficacy, catastrophizing, kinesiophobia, and activity pacing. These findings contribute to integrating body-mind connections more explicitly into current theoretical CP models and developing tailored interventions targeting specific IS skills to improve CP adjustment.

Keywords: Chronic pain, interoception, illness adjustment, cluster analysis, fear-avoidance beliefs and behaviors.

Introduction

Interoception - processing internal bodily sensations - is critical to homeostasis, health [50], and emotion regulation [10–12]. Interoceptive sensibility (IS) [14,28] – the self-reported experience of internal states and one's relationship with own bodily sensations – is one of the many features of interoception [28]. This multidimensional construct encompasses several skills [14], such as the ability to focus attention on bodily sensations, noticing their interactions with external factors, using bodily information for insight and self-regulating distress, and trusting the body. The relationship between IS and chronic pain (CP) is poorly investigated, and this study intends to bridge this gap.

Most studies on IS and CP have analyzed the independent effects of IS skills on pain-related outcomes, showing inconsistent results [8,37,48,57]. For example, fewer worries about bodily sensations and higher body trust were associated with lower perceived stress and depression [37]. Better self-regulation of bodily sensations was associated with lower pain disability [57] and intensity [48,57]. In contrast, higher awareness of the links between emotional and bodily states was associated with higher pain intensity and central sensitization symptoms [8]. To our knowledge, no studies have investigated how the interplay between the different IS skills may account for CP outcomes. Such integrated analysis might clarify whether individuals with different IS skills profiles show different CP outcomes, potentially informing the development of tailored IS interventions. Therefore, the first aim of this study was to identify IS skills profiles among individuals with chronic musculoskeletal pain – the most prevalent and burdensome worldwide [6] – and to investigate how these profiles were associated with CP outcomes. Drawing upon theoretical models on body-mind relations in health (e.g., Psychosomatic Competence Model [18]), we expected individuals with a higher IS skills profile to report better CP outcomes, namely, lower pain intensity and interference, better physical function and vitality, and lower affective distress.

Furthermore, we aimed to investigate whether individuals with different IS skills profiles differed in psychological and behavioral processes known to be risk/protective factors in CP. According to the Fear-Avoidance Model (FAM) [59], fear-avoidance beliefs/affect (pain catastrophizing, kinesiophobia) lead to hypervigilance to threat signs and movement/activity avoidance, resulting in increased distress, pain persistence, and disability. Conversely, confronting movement/activity despite pain - often associated with high pain-related self-efficacy [53,55] - leads to recovery [58].

Recent conceptual advances have stressed the role of interoceptive awareness in fear-avoidance psychological and behavioral processes. Some authors emphasized the role of interoceptive sensations as conditioned stimuli in pain-related fear [13,41] and as a trigger to negative emotions and catastrophic worry [49]. Others hypothesized that disruptions in interoceptive awareness hamper some of the self-regulation processes proposed by the FAM [57]. Although evidence for the association between IS and pain-related behaviors, such as activity patterns (e.g., avoidance/pacing/overdoing; [30]) is lacking, some findings support the link between IS and pain-related cognitive and affective processes. For example, according to a recent literature review on body-mind relations in chronic musculoskeletal pain [46], interoceptive-based interventions (psychomotor therapy) might improve individuals' mental health and quality of life by increasing pain-related self-efficacy and decreasing pain catastrophizing. Drawing upon these theoretical models, we expected individuals with higher IS skills to report higher pain-related self-efficacy, lower catastrophizing and kinesiophobia, and more adaptive activity patterns.

Method

Study design and participant recruitment

This is a cross-sectional study using the entire data set of the first assessment wave of a prospective study (still unpublished), the ISENSE-Pain (Interoceptive SENSibility and PAIN), investigating the role of IS on chronic musculoskeletal pain. To participate in this study, individuals had to be over 18 years old, suffer from chronic musculoskeletal pain (i.e., pain originating in the musculoskeletal system, such as in muscles, joints, ligaments, or bones) for more than three months [40], and be able to use a communication device (e.g., computer, tablet, smartphone) with an internet connection. Exclusion criteria included: (1) having experienced recent fractures or surgeries (≤ three months), (2) reporting cancer-related pain, or (3) being pregnant.

Active recruitment was carried out in hospital pain units in the Lisbon area. Potential participants were presented with study information by healthcare professionals and decided if they agreed to be contacted via phone by the research team. Passive recruitment was implemented in patients' associations and the community via study diffusion in internal mailing lists or the distribution of flyers. In this case, those who considered enrolling in the study directly contacted the research team. The first phone contact provided detailed information about the study objectives and procedures. After participants expressed their willingness to enroll in the study, sociodemographic (age, sex, place of birth, marital and cohabitation status, work status, occupation, years of education) and clinical data (pain duration, location/regions, and pattern, i.e., continuous vs. recurrent; current treatments and pain management activities, and if participants were attending a pain consultation) were also collected. Then, a link to an online survey (Qualtrics, Provo, UT) was sent, including self-report measures of IS, pain-related processes (i.e., self-efficacy, pain catastrophizing, kinesiophobia, and activity patterns), and outcomes (i.e., depression, anxiety, pain intensity and interference, physical function, and vitality). Informed consent was obtained via telephone and online immediately before answering the survey. The study was approved by the Ethics Review Board of Iscte (99/2020) and each of the hospitals that participated in the study. Data were collected over a year, ending in March 2022. During this period, contacts with 208 potential participants were made, 19 of which did not participate in the study because: a) they did not have a communication device with an internet connection (n =10); b) they did not meet clinical inclusion criteria (not having pain or reporting other types of pain such as complex regional pain syndrome, neuralgia, headaches; n=5); c) after receiving detailed information they were not interested in participating in the study (n=4). Of the 189 individuals who were sent an online questionnaire, 91.5% (N = 173) completed it.

Measures

All variables were assessed with the Portuguese versions of the self-report measures presented below. The Multidimensional Assessment of Interoceptive Awareness (MAIA) was used to assess IS skills and define interoceptive profiles. The psychological and behavioral risk/protective processes were assessed with the Pain Self-Efficacy Questionnaire, the Pain Catastrophizing Scale, the Tampa Scale of Kinesiophobia, and the Patterns of Activity Measure-Pain. CP outcomes were assessed with the Depression Anxiety Stress Scales, the Brief Pain Inventory - short form, and the Medical Outcomes Study-36 – Short Form 36v2.

Noteworthy, some of these instruments were validated with participants with different characteristics from this study sample. For example, the MAIA validation study [34] was conducted with healthy college students instead of adults with chronic pain. As assuming factorial invariance across these samples could be a risk, we analysed the factorial structure of each instrument in our sample before computing the respective scores. This procedure is in line with some authors' suggestions [27], stressing that the construct validity of an instrument should be investigated in every sample to ensure its fit to the specific population under study.

Interoceptive Sensibility

IS was measured with the MAIA [38]. This questionnaire assesses the ability to identify bodily sensations and emotional responses, to be aware of the body-mind relationship, and to report body confidence with 32 items, rated on a 6-point scale from 0 (never) to 5 (always). Originally, MAIA included eight subscales (Noticing, Not-distracting, Not-worrying, Attention regulation, Emotional awareness, Self-regulation, Body listening, and Trusting). This study used the Portuguese version of MAIA [35], which showed good psychometric properties. To analyze the psychometric properties of the MAIA in the present sample, we ran a principal axis factor analysis with orthogonal rotation. The factorability of the data was verified (KMO = .81; Bartlett's $\chi 2$ (435) = 2523.46, $p < .001$). After excluding three items due to low communalities and/or high/ambiguous cross-loadings, eight factors were extracted based on the Kaiser criterion, accounting for 65.0% of the total variance: (1) Not-distracting (4 reversed items; $\alpha = .82$, [31]), i.e., the ability to not ignore or not distract from sensations of pain/discomfort (e.g., *I push feelings of discomfort away by focusing on something else*); (2) Not-worrying I (2 items; $S_B = .81$, [31]), i.e., the ability to not being worried or emotionally distressed by sensations of pain or discomfort (e.g., *I can notice an unpleasant body sensation without worrying about it*); (3) Not-worrying II (2 items; $S_B =.56$, [31]) included two items, from the original Not-worrying dimension, that loaded in a different factor (e.g., *I start to worry that something is wrong if I feel any discomfort*); as this factor presented low reliability it was discarded; (4) Attention regulation (7 items; $\alpha = .84$, [31]), i.e., the ability to perceive and sustain attention towards bodily sensations (e.g., *I can pay attention to my breath without being distracted by things happening around me*); (5) Emotional awareness (5 items; $\alpha = .78$, [31]), i.e., the awareness of the connection between bodily and emotional states (e.g., *I notice how my body changes when I am angry*); (6) Self-regulation (4 items; $\alpha = .86$, [31]), i.e., the capacity to regulate psychological distress by directing attention to bodily sensations (e.g., *I can use my breath to reduce tension*); (7) Body listening (3 items; $\alpha = .83$, [31]), i.e., the ability to listen to the body for insight (e.g., *I listen to my body to inform me about what to do*); and (8) Trusting (3 items; $\alpha = .85$, [31]), i.e., the experience of having a safe and trustworthy body (e.g., *I trust my body sensations*). The final scores of the seven IS skills were calculated by averaging the respective items, and higher scores mean higher IS.

Noteworthy, as in MAIA's original main structure, these factors can be conceptually organized into four overarching types of IS skills, with an increasing degree of complexity [38]: (1) Emotional and attentional response to bodily sensations (Not-Distracting and Not-worrying); (2) Attention regulation by staying focused on bodily sensations when facing numerous sensory stimuli competing for attention (Attention regulation); (3) Awareness of mind-body integration (Emotional awareness, Self-regulation, and Body listening); and (4) Trust in bodily sensations (Trusting).

Pain-related psychological and behavioral processes

Pain-related self-efficacy. The Pain Self-Efficacy Questionnaire (PSEQ) [43]; p.v. [21] assessed individuals' confidence levels regarding their ability to engage in activities or goals despite pain [43]. It includes ten items rated on a 7-point scale, ranging from 0 (not at all confident) to 6 (completely confident) (e.g., *I can still accomplish most of my goals in life, despite the pain*). Both the original and the Portuguese versions identified a unidimensional structure showing good psychometric properties. In our sample, after checking the factorability of the data (KMO = .92; Bartlett's $\chi 2$ (45) = 1123.48, $p < .001$), a principal axis factor analysis was performed. Based on the Kaiser criterion, one factor was extracted. This factor accounted for 60.3% of the total variance and presented an excellent internal reliability (α = .92, [31]). The final score was computed by calculating the average of the ten items; higher scores indicate higher levels of pain-related self-efficacy.

Pain catastrophizing. The Pain Catastrophizing Scale (PCS) [54]; p.v. [1,26], measures pain-related catastrophic thinking, i.e., a maladaptive cognitive-affective response consisting in exaggerating and ruminating about actual or anticipated pain and helplessness regarding pain management [33,51]. This instrument includes 13 items rated on a 5-point scale, ranging from 0 (never) to 4 (always) (e.g., *I can´t stop thinking about how much it hurts*). After establishing the adequacy of the factorial analysis (KMO = .94; Bartlett's $\chi 2$ (78) = 1711.06, $p < .001$) and based on the Kaiser criterion, a principal axis factor analysis identified one factor. This solution accounted for 62.0% of the variance. The factor showed excellent internal reliability (α = .95, [31]). The final score was calculated based on the items' average, and higher results correspond to higher levels of pain catastrophizing.

Kinesiophobia. The Tampa Scale of Kinesiophobia (TSK-13-VP) [42]; p.v. [9], assesses fear of movement, i.e., an excessive and maladaptive fear of activity due to the feeling of being vulnerable to pain or (re)injury [32]. It assesses two dimensions: the fear of suffering from a serious medical condition (henceforth, Somatic focus) and the fear that activity may lead to increased pain or re-injury (henceforth, Fear of activity). The Portuguese version includes 13 items, answered on 4-point scales ranging from 1 (strongly disagree) to 4 (strongly agree). To identify latent factors under the scale and given the adequacy of the data (KMO = .87; Bartlett's χ2 (45) = 606.41, p < .001), a principal axis factor analysis with orthogonal rotation was conducted. After excluding three items due to low communalities and/or ambiguous loadings, two factors were extracted based on the Kaiser criterion, accounting for 57.0% of the total variance: 1) Somatic focus (4 items; α = .75, [31]), e.g., *My body is telling me I have something dangerously wrong*; and 2) Fear of activity (6 items; α = .84, [31]), e.g., *I'm afraid that I might injure myself if I exercise*). The final score of each factor was computed by averaging the respective items, with higher scores indicating higher levels of Somatic focus and Fear of activity.

<u>Pain-related Activity patterns</u>. The Patterns of Activity Measure-Pain (POAM-P) [5]; p.v. [58] measures three activity patterns, i.e., how people carry out their daily activities when in pain (Avoidance, Pacing, and Overdoing). The Portuguese version includes 28 items assessed on a 5-point scale ranging from 0 (never) to 4 (always). In our sample, the dimensions were identified through a principal axis factor analysis with orthogonal rotation after ensuring the adequacy of the matrix (KMO = .87; Bartlett's χ2 (210) = 1777.56, p < .001). During the process, seven items were excluded due to high/ambiguous cross-loadings or low communalities. The three factors explained 55.4% of the total variance: 1) Avoidance (10 items; α = .87, [31]), i.e., decreasing activity as a result of pain-related experience or its anticipation (e.g., *There are many activities that I avoid because they flare up my pain*); 2) Pacing (8 items; α = .89, [31]), i.e., balancing activity management between movement and rest aiming to achieve individual goals (e.g., *Instead of doing the whole activity I divide it into small parts and do one part at a time*); and 3) Overdoing (3 items; α = .81, [31]), i.e., persistence in activity despite the pain (e.g., *I keep doing what I am doing until my pain is so bad that I have to stop*). The final scores were computed by averaging the respective items; higher scores correspond to higher levels of each activity pattern.

<u>CP outcomes</u>

<u>Depression and anxiety</u>. The Depression Anxiety Stress Scales (DASS-21) [34]; p.v. [47] evaluate three dimensions of affective distress experienced during the previous week (Depression, Anxiety, and Stress). In both original and Portuguese versions, each dimension consists of seven items, answered on 4-point scales ranging from 0 (did not apply to me at all) to 3 (applied to me very

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much, or most of the time). In our study, we only used the Depression and Anxiety subscales and the factorability of the matrix was accepted (KMO = .91; Bartlett's $\chi 2$ (55) = 1144.21, $p < .001$). A principal axis factor analysis with orthogonal rotation was performed, and two factors were identified using the Kaiser criterion. Three items were excluded because of their high or ambiguous cross-loadings, and the two factors accounted for 67.3% of the total variance: 1) Depression (7 items; α = .93, [31]), i.e., the degree of depressive symptoms experienced such as hopelessness, devaluation of life, self-depreciation, anhedonia, dysphoria, lack of interest, and inertia (e.g., *I was unable to become enthusiastic about anything*); 2) and Anxiety (4 items; α = .76, [31]), i.e., the degree of anxious symptoms experienced such as autonomic arousal, skeletal muscle effects, situational anxiety, and subjective experience of anxious affect (e.g., *I was aware of dryness of my mouth*). The final score of each factor was achieved by averaging the items, and higher scores correspond to more depression and anxiety.

<u>Pain intensity and interference</u>. The Brief Pain Inventory – short form (BPI-SF) [7]; p.v. [1] assessed pain intensity and interference. In both the original and Portuguese versions, these dimensions include four and seven items, respectively, assessed with 11-point rating scales ranging from 0 (no pain/interference) to 10 (the greatest pain imaginable/completely interfered). From a principal axis factor analysis with adequacy (KMO = .92; Bartlett's $\chi 2$ (36) = 965.7, $p < .001$), two factors were extracted by Kaiser criterion and with orthogonal rotation. After removing two items due to high and/or ambiguous cross-loadings, the final solution accounted for 73.0% of the total variance. The identified factors were 1) Pain intensity (4 items; α = .81, [31]), i.e., the self-reported magnitude of the current, worst, least, and average pain experience (e.g., *Please rate your pain by indicating the one number that best describes your pain at its worst in the last 24 hours*); and 2) Pain interference (5 items; α = .89, [31]), i.e., the extent to which pain interferes with daily activities such as general activity, walking, work, mood, enjoyment of life, social relations, and sleep (e.g., *Indicate the one number that describes how, during the past 24 hours, pain has interfered with your general activity*). The final scores resulted from averaging the respective items with higher values indicating higher pain severity and interference levels.

<u>Physical function and vitality</u>. The Medical Outcomes Study-36 - Short Form 36v2 (SF-36 v2) [60]; p.v. [19,20]) was used to assess physical function and vitality. Original and Portuguese versions measured physical function with ten items using 4-point scales ranging from 0 (very limited) to 3 (not limited). Vitality in the previous four weeks was assessed by four items rated on 5-point scales

ranging from 1 (always) to 5 (never). After checking the factorability of the data (KMO = .85; Bartlett's $\chi 2$ (91) = 1234.58, $p < .001$), a principal axis factor with orthogonal rotation was performed. Three factors were extracted (Kaiser criterion), which accounted for 63.3% of the total variance: 1) Physical function (10 items; α = .89, [31]), i.e., functional limitations in daily physical activities such as running, climbing stairs, using a vacuum cleaner, bathing, or dressing (e.g., *Does your health now limit you in these activities? If so, how much? Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports*); 2) Vitality Energy (2 items; S_B = .86, [31]), i.e., levels of energy (e.g., *How much of the time during the past 4 weeks did you have a lot of energy?*); 3) and Vitality Fatigue (2 items; S_B = .88, [31]), i.e., levels of fatigue (e.g., *How much of the time during the past 4 weeks did you feel tired?*). As in previous studies [24], the original vitality dimension was split into two factors, detecting energy and fatigue levels separately. The final score of each dimension was computed through an algorithm for converting the respective item ratings into a single score ranging from 0 to 100 [19,20], with higher scores indicating better physical function, higher energy, and lower fatigue.

Data Analysis

Descriptive statistics of the study variables were analyzed. To assess whether the variable distributions tended towards higher or lower scale levels, one-sample t-tests were conducted. Considering the absence of normative standard cut-offs to use as reference and given that most variables were symmetrical, the sample mean was compared to the midpoint of each scale. A bootstrap estimation was performed when a lack of symmetry was found in a few variables (non-distraction, emotional awareness, and depression). The bias obtained was minimal, demonstrating the accuracy of the reported results. Consequently, variable means rated significantly above / below the scale midpoint were considered as reflecting high / low levels of the respective construct being measured. Variables that did not significantly differ from the scale midpoint were interpreted as reflecting moderate levels of the construct being measured. This information was necessary to substantively interpret the meaning of the identified IS profiles.

As the first goal of this study was to understand how the interrelationships between the IS skills may allow the definition of different and multivariate profiles in individuals with chronic musculoskeletal pain, a cluster analysis was conducted. If different IS profiles exist, a cluster analysis can aggregate individuals into groups (clusters), thereby maximizing intra-group homogeneity and inter-group heterogeneity [25]. The seven MAIA dimensions were the input variables for clustering, and entered directly into the algorithm, i.e., as quantitative variables. The basis of the algorithm is a proximity matrix, and the distance measure used was the Squared Euclidean distance. From this matrix, the hierarchical clustering algorithm, according to different aggregation methods, analyses the similarity between the individuals and proceeds with the agglomeration. To obtain a more robust extracted solution, two different statistical linkage methods were used: the Ward method (its minimum variance method) and the Complete Method (also known as farthest neighbour clustering). Five participants were excluded from the cluster analysis due to missing data. Afterward, One-way ANOVAs with Tukey's Honest Significant Difference (HSD) for *post hoc* comparisons were used to identify differences between profiles in the seven IS skills. Then, to examine the differences between the IS skills profiles in sociodemographic (age, sex, place of birth, marital and cohabitation status, work status, occupation, years of education) and clinical characteristics (pain duration, regions and pattern, current treatments, pain management activities, and if participants were attending a pain consultation), Chi-square and One-Way ANOVAs with Tukey HSD with Bonferroni correction (p = .05/3 = .017) were conducted for categorical and continuous variables, respectively. Finally, to investigate the differences between IS skills profiles on pain-related processes and outcomes, univariate and multivariate analyses of variance (ANOVA and MANOVA) were conducted. MANOVA were conducted to analyze five sets of dependent variables (regarding outcomes and processes). In line with current guidelines [25], these sets of dependent variables were defined based on their conceptual links and correlations (see results section). First, according to the Fear-Avoidance Model [58], pain catastrophizing and kinesiofobia (both dimensions) were grouped in the same set as fear-avoidance beliefs and affects. Second, the three activity patterns assessed by the POAM-P (avoidance, pacing, overdoing) constituted the activity patterns set. Third, depression and anxiety were considered an expression of affective distress [38]. Fourth, both dimensions of vitality (energy and fatigue) were considered together as representing vitality. Finally, pain intensity and interference were grouped since they express pain severity. Univariate analyses of variance followed by Tukey HSD test were used for physical function and pain-related self-efficacy. The ANOVA and MANOVA were conducted using an unbalanced design. Nevertheless, the recommended minimum cell size (20, [25]) was guaranteed, and all the necessary assumptions (equality of variance and normality) were confirmed. When necessary, in ANOVA, Welch and Brown-Forsythe tests were also performed to confirm the robustness of the results, as they are more reliable than the classic F when variances are unequal [22]. Data management and analysis were performed using the Statistical Package for the Social Sciences, version 28.0 (SPSS, Inc., Chicago, Illinois, USA).

Results

Participants' characteristics

Table 1 presents detailed information about the socio-demographic and clinical characteristics of the participants. One hundred and seventy-three adults with chronic musculoskeletal pain participated in this study. They were mostly women born and living in Portugal and aged between 22 and 86 years old. Most participants were married/in common-law and were living with family members. Their years of formal education ranged between 0 and 26 years. Most participants were working at the time of the study, and about 14% were on sick leave.

As for the clinical characteristics, participants reported an average pain duration of over a decade, ranging from 7 months to 49 years. Most participants reported experiencing generalized continuous pain. Localized pain was mostly reported on low back and hip/lower limbs. Almost half of our sample was attending a specialized pain unit/consultation, and the majority were taking medication for pain relief. About one-fifth reported having psychiatric/psychological support, but only 15.0% were receiving physiotherapy treatments. Almost half of the participants reported performing activities to self-manage their pain (e.g., walking, exercise, Pilates).

Table 1 – Sociodemographic and clinical characteristics of the overall sample and the participants of the three profiles of interoceptive sensibility skills.

			Total sample (n=173)	Mixed interoceptive skills (1) (N=71)	High interoceptive skills (2) (N=68)	Low interoceptive skills (3) (N=29)	Differences between profiles [3]	*p*
Sex	N (%)	Males	27 (15.6%)	14 (19.7%)	9 (13.2%)	3 (10.3%)	χ^2 (2) = 1.82	*n.s.*
		Females	146 (84.4%)	57 (80.3%)	59 (86.8%)	26 (89.7%)		
Age	M (SD)		48.5 (10.9)	47.5 (11.8)	48.7 (10.1)	49.4 (11.1)	*F* (2) = 0.38	*n.s*
Place of birth[1]	N (%)	Portugal	154 (89.0%)	67 (94.4%)	59 (86.8%)	25 (86.2%)	χ^2(2) = 2.73	*n.s.*
		Other*	19 (11.0%)	4 (5.6%)	9 (13.2%)	4 (13.8%)		
Years of education	M (SD)		13.2 (4.6)	13.4 (5.0)	13.4 (4.2)	12.8 (5.0)	*F* (2) = 0.23	*n.s.*
Marital status	N (%)	Single	18 (10.4%)	10 (14.1%)	6 (8.8%)	2 (6.9%)	χ^2 (4) = 1.66	*n.s.*
		Married/common-law	137 (79.2%)	53 (74.7%)	55 (80.9%)	24 (82.8%)		

		Divorced/widower	18 (10.4%)	8 (11.3%)	7 (10.3%)	3 (10.3%)		
Cohabitation status	N (%)	Living alone	12 (6.9%)	6 (8.5%)	4 (5.9%)	2 (6.9%)	χ^2 (2) = 0.35	*n.s.*
		Living with family	161 (93.1%)	65 (91.6%)	64 (94.1%)	27 (93.1%)		
Work-status	N (%)	Working	104 (60.1%)	41 (57.8%)	45 (66.2%)	16 (55.2%)	χ^2(4) = 3.17	*n.s.*
		Sick leave	25 (14.5%)	8 (11.3%)	10 (14.7%)	5 (17.2%)		
		Unemployed or retired	44 (25.4%)	22 (31.0%)	13 (19.1%)	8 (27.6%)		
Occupation[2]	N (%)	Managers and Professionals	67 (38.7%)	32 (45.1%)	24 (35.3%)	11 (37.9%)	χ^2(10) = 16.70	*n.s.*
		Technicians and associate professionals	17 (9.8%)	5 (7.0%)	10 (14.7%)	2 (6.9%)		
		Clerical support	21 (12.1%)	7 (9.9%)	10 (14.7%)	4 (13.8%)		
		Service and sales workers	43 (24.9%)	15 (21.1%)	20 (29.4%)	6 (20.7%)		
		Skilled agricultural, forestry, and fishery workers; Craft and related trades workers; Plant and machine operators and assemblers	10 (5.8%)	6 (8.5%)	1 (1.5%)	0 (.0%)		
		Elementary occupations	15 (8.7%)	6 (8.5%)	3 (4.4%)	6 (20.7%)		
Pain region	N (%)	Localized	97 (56.1%)	43 (60.6%)	33 (48.5%)	16 (55.2%)	χ^2 (2) = 2.03	*n.s.*
		- Head	3 (1.7%)	0 (.0%)	2 (2.9%)	0 (.0%)		
		- Cervical	32 (18.5%)	12 (16.9%)	15 (22.1%)	5 (17.2%)		
		- Shoulder/Upper limbs	26 (15.0%)	13 (18.3%)	7 (10.3%)	5 (17.2%)		
		- Thoracic	12 (6.9%)	7 (9.9%)	3 (4.4%)	2 (6.9%)		
		- Lower back	66 (38.2%)	29 (40.9%)	24 (35.3%)	8 (27.6%)		
		- Abdominal/pelvic	1 (.6%)	0 (.0%)	1 (1.5%)	0 (.0%)		
		- Hip/Lower limbs	44 (25.4%)	20 (28.2%)	10 (14.7%)	10 (34.5%)		
		Generalized	76 (43.9%)	28 (39.4%)	35 (51.5%)	13 (44.8%)		
Pain pattern	N (%)	Continuous	147 (85.0%)	57 (80.3%)	60 (88.2%)	25 (86.2%)	χ^2 (2) = 1.76	*n.s.*
		Recurrent	26 (15.0%)	14 (19.7%)	8 (11.8%)	4 (13.8%)		
Pain duration (years)	M(SD)		12.8 (11.0)	14.8 (11.2)	11.5 (10.9)	11.6 (10.8)	*F* (2) = 1.85	*n.s.*
Physiotherapy	N (%)	Yes	26 (15.0%)	11 (15.5%)	10 (14.7%)	3 (10.3%)	χ^2 (2) = .46	*n.s.*
		No	147 (85.0%)	60 (84.5%)	58 (85.3%)	26 (89.7%)		
Psychological treatments	N (%)	Yes	35 (20.2%)	10 (14.1%)	15 (22.1%)	9 (31.0%)	χ^2 (2) = 3.90.	*n.s.*
		No	138 (79.8%)	61 (85.9%)	53 (77.9%)	20 (69.0%)		
Self-management activities	N (%)	Yes	77 (44.5%)	33 (46.5%)	32 (47.1%)	11 (37.9%)	χ^2 (2) = .76	*n.s.*
		No	96 (55.5%)	38 (53.5%)	36 (53.0%)	18 (62.1%)		
Attending a pain unit	N (%)	Yes	75 (43.4%)	23 (32.4%)	32 (47.1%)	16 (55.2%)	χ^2 (2) = 5.46.	*n.s.*
		No	98 (56.7%)	48 (67.6%)	36 (52.9%)	13 (44.8%)		
Pain medication	N (%)	Yes	159 (91.9%)	67 (94.4%)	61 (89.7%)	26 (89.7%)	χ^2 (2) = 1.17	*n.s.*
		No	14 (8.1%)	4 (5.6%)	7 (10.3%)	3 (10.3%)		

Note. [1] Other places of birth included Angola, Brazil, Cabo Verde, France, Germany, Mozambique, São Tomé and Príncipe, Spain, and Venezuela. [2] Categories based on the International Standard Classification of Occupations. [3] To examine sociodemographic and clinical differences between profiles, Chi-square was conducted for categorical variables, and One-Way ANOVAs with Tukey HSD with Bonferroni correction (p = .05/3 = .017) were calculated for continuous variables. *n.s.* – non-significant.

1

Analysis of the study variables

Descriptive statistics and one-sample t-tests having as reference the scale midpoint of each variable are presented in Table 2. Overall, most variables showed symmetrical (-3.00 < skewness/SE of skewness < 3.00; [29]) and mesokurtic distributions (-.3.00 < kurtosis/SE of kurtosis < 3.00; [29]), with participants responses covering the entire scale ranges. The exceptions were Not-distracting, Emotional awareness, and Depression, which were particularly skewed, with most participants' responses concentrating on the scale's lower (Not-distracting and Depression) and higher (Emotional awareness) values, respectively. Emotional awareness also presented a leptokurtic distribution.

Most IS skills were, on average, rated significantly above the scale midpoint, except Not-distracting, which was rated below, and Self-regulation, which did not differ substantially from the scale midpoint. These results suggest that, compared with the scale midpoint, participants reported higher levels of Emotional Awareness, Attention Regulation, Body Listening, Not-worrying, and Trusting, and lower levels of Not-distracting skills.

Most ratings regarding pain-related processes did not significantly differ from their respective scale midpoints, namely self-efficacy, kinesiophobia - fear of activity, and activity patterns of pacing and overdoing. However, pain catastrophizing, kinesiophobia - somatic focus, and activity avoidance were rated significantly above the scale midpoint, suggesting high levels of fear-avoidance beliefs and affects, as well as movement avoidance.

Most outcome variables were rated significantly below their respective scale midpoints, namely vitality (both dimensions), physical function, depression, and anxiety. In contrast, pain severity was rated significantly above the scale midpoint (moderate to high pain intensity), and pain interference did not significantly differ from the scale midpoint. Taken together, these results suggest poor pain outcomes regarding vitality, physical function, and pain severity but not affective distress.

Table 2 – Descriptive statistics and one sample t-test for interoceptive sensibility skills and pain-related processes and outcomes

	Variable [Possible Min-Max]	Midpoint	Min - Max	*M*	*SD*	*Kurtosis/SE kurtosis*	*Skewness/SE skewness*	One-sample t-test[1]	*p*
Interoceptive Sensibility	Not-distracting [0 – 5]	2.5	0.00 - 4.75	1.41	1.00	1.27	4.39	*t* (171) = -14.25	.001
	Not-worrying [0 – 5]	2.5	0.00 - 5.00	2.93	1.34	-1.52	-2.62	*t* (171) = 4.21,	.001
	Attention regulation [0 – 5]	2.5	0.00 - 5.00	3.06	1.01	-0.76	-0.70	*t* (171) = 7.20	.001
	Emotional awareness [0 – 5]	2.5	0.40 - 5.00	4.04	.88	5.36	-6.97	*t* (171) = 22.94	.001
	Self-regulation [0 – 5]	2.5	0.00 - 5.00	2.35	1.18	-1.38	-0.49	*t* (171) = -1.62.	*n.s.*
	Body listening [0 – 5]	2.5	0.00 - 5.00	2.97	1.29	-1.39	-2.41	*t* (171) = 4.77	.001
	Trusting [0 – 5]	2.5	0.00 - 5.00	2.78	1.24	-1.99	-0.01	*t* (169) = 2.96	.004
Psychological and Behavioral processes	Pain-related Self-efficacy [0 – 6]	3.0	0.00 - 5.90	3.18	1.35	-1.38	-0.42	*t* (171) = 1.73	*n.s.*
	Catastrophizing [0 – 4]	2.0	0.00 - 4.00	2.16	0.95	-2.03	-0.51	*t* (172) = 2.27	025
	Kinesiophobia Somatic focus [1 – 4]	2.5	1.00 - 4.00	2.61	0.62	-0.05	-0.02	*t* (169) = 2.25	.026
	Kinesiophobia Fear of activity [1 – 4]	2.5	1.00 - 4.00	2.50	0.67	-0.25	-0.18	*t*(172) = -.06	n.s.
	Activity pattern Avoidance [0 – 4]	2.0	0.20 - 4.00	2.34	0.75	-0.43	-0.74	*t* (171) = 5.92	.001
	Activity pattern Pacing [0 – 4]	2.0	0.13 - 4.00	1.97	0.79	-0.50	-0.30	*t* (172) = -.44	n.s.
	Activity pattern Overdoing [0 – 4]	2.0	0.00 - 4.00	2.11	1.06	-1.72	-1.18	*t* (172) = 1.41	n.s.
Outcomes	Pain severity [0 – 10]	5.0	1.00 - 9.75	5.78	1.83	-0.54	-2.72	*t* (172) = 5.62	.001
	Pain interference [0 –10]	5.0	0.00 - 10.00	5.04	2.56	-2.24	-1.10	*t* (166) = .20	n.s.
	Vitality Energy [0 – 100]	50.0	0.00 - 75.00	31.87	18.89	-0.32	1.74	*t* (170) = -12.55	.001
	Vitality Fatigue [0 – 100]	50.0	0.00 - 100.00	30.52	20.69	0.39	2.65	*t* (171) = -12.35	.001
	Physical function [0 – 100]	50.0	0.00 - 100.00	43.67	23.46	-2.35	0.35	*t* (168) = -3.51	.001
	Depression [0 – 3]	1.5	0.00 - 3.00	0.92	0.81	0.18	5.27	*t* (170) = -9.26	.001
	Anxiety [0 – 3]	1.5	0.00 - 3.00	1.12	0.81	-2.04	2.05	*t* (170) = -6.10	.001

Note. Min – Minimum, Max – Maximum. *n.s.* – non-significant.

[1] The mid-point of each scale was used as a reference for each one-sample t-test. Bootstrap estimations with 5000 samples sustain the parametric results.

Cluster analysis of interoceptive sensibility skills

The cluster analysis was performed with 168 participants and pointed out to three IS skills profiles. Based on the criterion used as a reference – midpoint of the IS scales – the profiles were labeled as: *mixed IS skills* (N = 71; 42.3%), *high IS skills* (N = 68; 40.5%), and *low IS skills* (N = 29; 17.3%).

Figure 1 and Table 3 present the results of the IS skills for each of the identified profiles. Compared to the scale mid-point, all profiles showed lower scores in non-distraction and higher scores in emotional awareness, meaning that they distract a lot from bodily sensations and are highly aware of the connection between bodily and emotional states. The *high IS skills* profile presented the highest levels of IS skills (except for the Not-distracting dimension). This profile characterized a cluster that was able not to worry about bodily sensations, to trust and focus attention on the body, was aware of the body-mind connection, listened to the body for decision-making, and reported good self-regulation skills based on the information provided by own body. In contrast, the *low IS skills* profile included individuals with low to moderate IS skills. Indeed, except for their high emotional awareness, these participants reported low trust and high levels of worry about their bodily sensations, low self-regulation skills, and only a moderate ability to listen to their body for insight and to regulate attention towards bodily sensations. The *mixed IS skills* group included individuals with a few good interoceptive skills, namely, not worrying about bodily sensations, the ability to sustain and control attention to bodily sensations, and a moderate level of trust in the body. However, they also presented low levels of self-regulation focused on their bodies and a low ability to listen to their bodies for insight.

Table 3 shows that the *mixed* and *high IS skills* profiles were similar but significantly different from the *low IS skills* profile in the not-distracting and not-worrying dimensions. This means the former profiles were distracted more and worried less about their bodily sensations (including pain) than the *low IS skills* profile. The *mixed* and *low IS skills* profiles presented significantly lower attention regulation and self-regulation strategies focused on bodily sensations than the *high IS skills* profile. Finally, *high* and *low IS skills* profiles showed higher awareness of the connection between bodily and emotional states, i.e., emotional awareness, than the profile with mixed skills. Body listening and trusting significantly differed across all profiles, with the *high IS skills* profile showing the highest scores in both dimensions and mixed and low interoceptive skills profiles presenting the lowest scores in body listening and trusting, respectively.

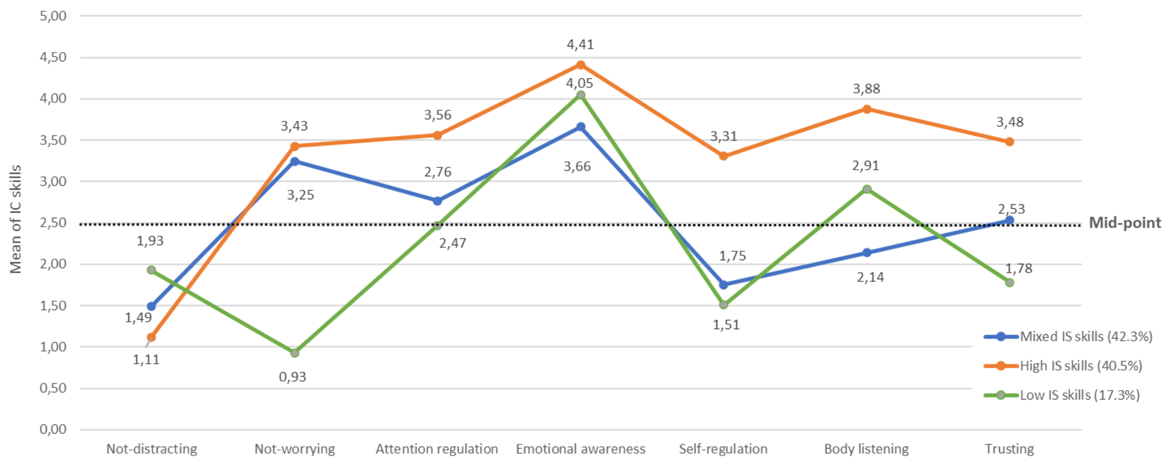

Fig. 1 – Dimensions of interoceptive sensibility across the three clusters.

Table 3 – Means, Standard deviation, and ANOVA results to compare profiles of interoceptive sensibility skills according to MAIA dimensions.

	MAIA Dimensions [Possible Min-Max]	Mixed interoceptive skills (1) (n=71) *M (SD)*	High interoceptive skills (2) (n=68) *M (SD)*	Low interoceptive skills (3) (n=29) *M (SD)*	$F_{(2, 165)}$	*p*
Emotional reaction and attentional response	Not-distracting [0 – 5]	1.49 (.89) [a]	1.11 (.91) [a]	1.93 (1.13) [b]	8.08	<.001
	Not-worrying [0 – 5]	3.25 (1.08) [a]	3.43 (1.04) [a]	.93 (.64) [b]	69.69	<.001
Regulate attention by focusing on bodily sensations	Attention regulation [0 – 5]	2.76 (.95) [a]	3.56 (.87) [b]	2.47 (.86) [a]	20.48	<.001
Awareness of mind-body integration	Emotional awareness [0 – 5]	3.66 (1,08) [a]	4.41 (.52) [b]	4.05 (.62) [b]	14.72	<.001
	Self-regulation [0 – 5]	1.75 (.93) [a]	3.31 (.74) [b]	1.51 (1.02) [a]	70.76	<.001
	Body listening [0 – 5]	2.14 (1.16) [a]	3.88 (.65) [b]	2.91 (1.34) [c]	50.03	<.001
Trusting in bodily sensations	Trusting [0 – 5]	2.53 (1.28) [a]	3.48 (.90) [b]	1.78 (.88) [c]	28.81	<.001

Note. Min – Minimum, Max – Maximum. The superscript letters (a, b, c) identify the significantly different profiles.

Interoceptive sensibility inter-profile comparisons in pain-related processes and outcomes

First, we described and compared the sociodemographic and clinical characteristics of the individuals in the three IS skills profiles (see Table 1). The three profiles did not significantly differ regarding sex, age, place of birth, marital and cohabitation status, years of education, profession, and work status. The three profiles also did not present significant differences in clinical characteristics, namely pain duration, region, and pattern (continuous vs. recurrent pain), use of treatments, and self-management activities.

Table 4 describes and compares the IS profiles regarding their scores in relevant pain-related processes and outcomes. Correlations between the dependent variables (along with their conceptual links) guided the MANOVA, which were conducted based on five dimensions: (1) fear-avoidance beliefs and affects – catastrophizing and both kinesiophobia dimensions of somatic focus and fear of activity ($r_{\text{catastrophizing, kinesiophobia somatic focus}} = .53$, $p < .001$; $r_{\text{catastrophizing, kinesiophobia fear of activity}} = .54$, $p < .001$; $r_{\text{kinesiophobia somatic focus, kinesiophobia fear of activity}} = -.60$, $p < .001$), (2) activity patterns – avoidance, pacing, and overdoing ($r_{\text{avoidance, pacing}} = .57$, $p < .001$; $r_{\text{avoidance, overdoing}} = -.39$, $p < .001$; $r_{\text{pacing, overdoing}} = -.35$, $p < .001$), (3) affective distress – depression and anxiety ($r_{\text{depression, anxiety}} = .51$, $p < .001$), (4) vitality – energy and fatigue ($r_{\text{energy, fatigue}} = .36$, $p < .001$), and (5) pain severity – intensity and interference ($r_{\text{Intensity, interference}} = .67$, $p < .001$).

The IS profiles significantly differed in several pain-related processes (Table 4). Pain-related self-efficacy was significantly lower in the *low IS skills* profile than in the other two profiles, which did not differ. The profiles also differed regarding fear-avoidance beliefs and affects [Wilks' Λ = .80, $F(6, 320) = 6.41$, $p < .001$, $\eta_p^2 = .11$]. The *low IS skills* profile showed significantly higher pain catastrophizing than the other two, as well as higher kinesiophobia - fear of activity compared with the *mixed IS skills* profile. The *high IS skills* profile revealed higher kinesiophobia - somatic focus than those with *mixed IS skills* profile. Differences in activity patterns [Wilks' Λ =.88, $F(6, 324) = 3.61$, $p = .002$, $\eta_p^2 = .063$] revealed that *high IS skills* profile presented higher levels of pacing than those with *mixed IS skills* profile. Activity avoidance showed a marginal result with a tendency for higher scores in the *low IS skills* profile compared to the *mixed IS skills* profile. In sum, the *low IS skills* profile presented lower self-efficacy and higher catastrophizing than the *higher* and *mixed IS* profiles and more kinesiophobia - Fear of activity, and a tendency toward more activity avoidance than the latter. The *High IS skills* profile presented more pacing and higher kinesiophobia - somatic focus than the *mixed IS skills* profile.

Concerning the pain-related outcomes results in affective distress [Wilks' Λ = .94, F (4, 324) = 2.78, p = .027, η_p^2 = .03] showed that *low IS skills* profile scored significantly higher in depression than *high IS skills* profile, and marginally higher (p = 0.067), when compared with the *mixed IS skills* profile. As for vitality [Wilks' Λ=.94, F (4, 326) = 2.44, p = .047, η_p^2 = .03], the *mixed IS skills* profile presented higher results in the fatigue dimension than those with low *IS skills* profile. There were no differences in pain intensity and interference [Wilks' Λ=.96, F (4, 316) = 1.69, p = .152, η_p^2 =.02] and physical function across profiles. In a nutshell, the *low IS skills* profile presented worse outcomes, showing higher depression and lower vitality than *high* and *mixed IS skills* profiles, respectively.

Table 4 – Comparisons between IS profiles in pain-related processes and outcomes.

	Variable [Possible Min – Max]	Mixed interoceptive skills (n=71)	High interoceptive skills (n=68)	Low interoceptive skills (n=29)	Univariate tests		
		M(SD)	M(SD)	M(SD)	F	η_p^2	*p*
Psychological and Behavioral processes	Pain-related self-efficacy [0 – 6]	3.22 (1.24) [a]	3.54 (1.31) [a]	2.33 (1.37) [b]	8.98	.098	< .001
	Pain catastrophizing [0 – 4]	1.99 (.88) [a]	1.99 (1.00) [a]	2.88 (.63) [b]	11.48	.124	< .001
	Kinesiophobia Somatic focus [0 – 4]	2.43 (.58) [a]	2.72 (.64) [b]	2.71 (.54) [a, b]	4.82	.056	.009
	Kinesiophobia Fear of activity [0 – 4]	2.37 (.60) [a]	2.47 (.73) [a, b]	2.77 (.63) [b]	3.84	.045	.023
	Activity pattern Avoidance[1] [0 – 4]	2.17 (.74)	2.38 (.69)	2.53 (.81)	2.88	.034	.059
	Activity pattern Pacing [0 – 4]	1.68 (.74) [a]	2.22 (.69) [b]	2.03 (.88) [a, b]	9.05	.099	< .001
	Activity pattern Overdoing [0 – 4]	2.19 (1.01)	2.09 (1.15)	2.13 (1.03)	.15	.002	*n.s.*
Outcomes	Pain intensity [0 – 10]	5.46 (1.68)	5.89 (1.78)	6.17 (2.20)	1.80	.022	*n.s.*
	Pain interference [0 – 10]	4.79 (2.44)	4.90 (2.45)	5.93 (2.90)	2.11	.026	*n.s.*
	Vitality Energy [0 – 100]	32.14 (19.69)	33.64 (17.04)	25.86 (20.58)	1.78	.021	*n.s.*
	Vitality Fatigue [0 – 100]	35.00 (22.68) [a]	28.86 (19.11) [a, b]	23.71 (17.47) [b]	3.52	.041	.032
	Physical function [0 – 100]	44.36 (24.73)	45.52 (21.13)	38.57 (26.49)	0.88	.011	*n.s.*
	Depression[2] [0 – 3]	0.90 (.81) [a, b]	0.80 (.70) [a]	1.30 (1.00) [b]	3.98	.047	.021
	Anxiety [0 – 3]	1.03 (.75)	1.18 (.80)	1.25 (.97)	0.98	.012	*n.s.*

Note. Min – Minimum, Max – Maximum. The superscript letters (a, b, c) identify the significantly different profiles. *n.s.* – non-significant.

[1] Marginally significant in activity avoidance, with the low IS skills profile reporting higher results than the *mixed IS skills* profile (p = .07).

[2] Marginally significant in depression, with the highest levels shown by the *low IS skills* profile, compared with the *mixed IS skills* profile (p = .06).

Discussion (1537 palavras)

Interoception is essential for health regulation, but how the interplay between IS skills shapes CP experiences remains unclear. To our knowledge, this is the first study identifying IS skills profiles among ICPs and providing evidence for their association with CP outcomes and psychological/behavioral processes.

Profiles of IS skills among individuals with chronic musculoskeletal pain

Three IS skills profiles were identified in our sample (adults with musculoskeletal CP). The *high IS skills* profile reported the highest levels of attention regulation toward bodily sensations, body trust, body listening for insight, and self-regulation. In contrast, the l*ow IS skills* profile, albeit with moderate attention regulation skills, reported the lowest levels of body trust and distraction from bodily sensations but the highest worries about the latter. The *mixed IS skills* profile showed good IS skills regarding not worrying, trusting, and being able to regulate attention toward internal sensations but somewhat poor mind-body integration skills (Emotional Awareness, Self-regulation, and Body listening).

Almost half of the participants presented *mixed IS skills* (42.3%), followed by those with *high IS skills* (40.5%), and only around one-fifth (17.3%) presented *low IS skills*. Therefore, not all individuals present IS disruptions to the same extent. This is congruent with a few previous research examining, independently, specific IS skills, which inconsistently showed the presence of IS disruptions among individuals with CP [15,57]. Furthermore, in contrast with previous studies showing that different IS skills (analyzed independently) differ according to sex/gender [23] or age [45], our findings suggest that the integrated IS skills profiles may not differ according to several socio-demographic and clinical characteristics of individuals with (musculoskeletal) CP.

Notably, all profiles presented high distraction levels from bodily sensations. Previous studies have shown similar results among individuals with fibromyalgia [57] and past chronic low back pain, where distraction was associated with pain-ignoring coping [37]. According to recent IS conceptualizations, which consider one's ability to focus on bodily sensations, a vital self-regulation skill [38], these findings suggest poor IS in ICPs. However, self-regulatory dimensions of interoceptive awareness also include the ability to buffer attention towards bodily sensations to manage suffering [18]. This may be particularly valuable for ICPs, who often present an increased attentional bias towards pain-related information to the detriment of other sensations, contributing to pain persistence [4]. Therefore, their ability to distract from (painful) bodily sensations may be adaptive.

Our findings showed high awareness of emotion-body connections across all profiles. CP is often associated with persistent stress, which activates the sympathetic nervous system, facilitating the detection of bodily sensations [52]. Individuals with long pain histories, like most of our participants, have ample opportunities to learn about the reciprocal relationship between stress/emotions and pain, which may account for these findings.

IS skills profiles and chronic musculoskeletal pain outcomes

IS skills profiles only differed in psychological (vs. functional) CP outcomes, namely, depression and vitality (but not anxiety), partially supporting our expectations. These findings align with the well-documented links between IS and psychopathology development [3] and emotion regulation [11]. Specifically, the *low IS skills* group showed significantly higher levels of depressive symptoms than the *high IS skills* group and a similar trend compared with the *mixed IS skills* group. These findings support past research showing that depressive symptoms are frequent among ICPs [56] and are often linked with interoceptive disruptions [44] and poor IS skills (e.g., worrying about bodily sensations, poor self-regulation, and body trust; [37]).

The *low IS skills* group presented lower vitality than the *mixed IS skills* profile. This difference was found for fatigue (not energy), likely due to the high prevalence of fatigue across CP conditions (e.g., fibromyalgia) [16]. These findings support theoretical contentions that interoceptive signaling, related to inflammatory processes, is associated with an adaptative experience of fatigue/vitality as a response to metacognitive beliefs regarding the inefficiency of regulatory systems [50]. The *high IS skills* group did not differ from the other profiles in vitality, which is hard to account for considering current theories and scant empirical evidence.

Contrary to our expectations and previous research showing negative associations between IS and anxiety among healthy individuals and fibromyalgia patients [36,57], this study did not find differences in anxiety levels across profiles. This pattern is likely to derive from the used anxiety measure that included items related to autonomic arousal and muscle effects, leaving out items related to situational anxiety and subjective anxious affect, which may be the main drivers of the previous associations.

IS skills profiles did not differ in pain intensity, interference, and physical function. Previous studies analyzing IS skills independently have shown that while some IS abilities (e.g., not worrying about bodily sensations, self-regulation) are associated with lower pain intensity and disability [8,48,57], others, such as emotional awareness, showed opposite results for pain intensity [8] or did not show significant relations with pain outcomes [37]. This is the first study analyzing how the combination of IS skills influences pain outcomes, which may account for the discrepancies among previous studies and between these and our findings.

IS skills profiles and pain-related psychological and behavioral risk/protective factors

IS skills profiles presented several differences in pain-related psychological/behavioral processes, mostly aligned with our expectations. Regarding psychological processes, the *low IS* group presented the lowest pain-related self-efficacy, the highest pain catastrophizing, and, compared to the mixed IS group, more kinesiophobia (Fear of activity). These findings align with previous studies showing that better IS skills regarding attention regulation, awareness of the body-mind connection, body trust, and worries about internal sensations were associated with less catastrophizing [37,48], being lower worries about the body also linked with less fear-avoidance beliefs in low back patients [37]. These findings also support theoretical models on body-mind connections (Embodied Predictive Interoceptive Coding [2]; Psychosomatic competence model [18]) that hypothesize that individuals' appraisals (e.g., high catastrophizing, low self-efficacy) play a role in incongruences between expected and perceived bodily sensations, in turn activating and reinforcing maladaptive emotions and cognitions. Our results also confirm the interplay between interoceptive skills and the psychological factors considered in the FAM [59], endorsing the inclusion of IS in the model, as previously proposed [57].

Contrary to expectations, the *high IS skills* group reported higher fear that pain signals a potentially serious injury than the *mixed IS skills* group. Although the reason for this is unclear, such fear does not seem to be associated with other maladaptive psychological factors or worse pain outcomes. It is plausible to assume that their higher IS skills may be buffering the potentially negative effects of such fear-related beliefs on pain outcomes [37,48].

Concerning the behavioral processes, profiles did not differ in activity overdoing. However, compared to the *high IS skills* group, the *mixed IS skills* group reported lower levels of activity pacing, which may be accounted for by their lower ability to listen to their bodies for insight or to be aware of body-mind connections. These findings align with evidence showing that increased IS skills are associated with health behavior self-regulation processes [18]. However, no differences were found between the *high* and *low IS skills* groups in activity pacing, perhaps because the POAM-P does not differentiate adaptive (e.g., task contingent) from maladaptive (e.g., pain contingent) pacing [17]. Compared with the *mixed IS skills* profile, the *low IS skills* profile showed a trend toward higher activity avoidance. Their high worries and low levels of trust in bodily sensations may contribute to perceiving body signs as threatening and to a lower ability to regulate their physical capabilities, leading to increased avoidance behaviors [57].

Limitations, implications, and future directions

This study has some limitations, which may inform future research. First, considering its cross-sectional design, conclusions on causal relationships are unwarranted. Prospective studies may uncover such relationships and the pattern of change in IS skills over time. Second, the sample consisted of Portuguese adults (mostly women) with musculoskeletal CP, so generalizations to individuals in other developmental stages, cultures, and/or with other clinical conditions should be considered carefully. Future research should examine whether similar profiles would be found among individuals with other CP conditions and/or other cultural backgrounds, and further explore possible sex/gender differences.

Despite such limitations, this study bears contributions to research and clinical practice. Research-wise, this study stresses the relevance of inter-individual differences in interoception research, widening horizons for investigating IS based on ICPs' profiles, namely regarding IS disruptions and relations with other interoceptive features (e.g., accuracy). Also, it confirms the role of interoception in CP, providing novel data that may help refine theoretical CP models by more explicitly integrating body-mind connections. Our evidence supports the integration of IS in cognitive-behavioral models of CP (e.g., FAM [57]), raising the possibility that IS profiles might be related to other relevant (but less investigated) pain-related psychological constructs (e.g., psychological flexibility, coping) [46]. Likewise, associations with affective (e.g., emotional self-regulation, trauma) and social (e.g., social support, social isolation) processes, as well as with neural pathways [40], should be explored. As for clinical practice, our findings may inform the IS profiling of ICPs based on a parsimonious and cost-effective assessment strategy and may help tailor interventions to individuals' IS needs. For example, individuals with *low* and *mixed IS skills* could be referred to therapies aiming to promote their specific IS deficits, which may be improved through bottom-up (e.g., psychomotor therapy) and/or top-down interventions (e.g., cognitive-behavioral therapy). Future research is required to determine which approach fits best for each IS skills profile.

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Conflicts of interest

The authors claim that there are no conflicts of interest.

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