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Exploring the role of interoception in anxious traits and symptoms

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Introduction: Interoception, the ability to sense internal bodily signals, has been increasingly linked to anxiety, yet the mechanisms underlying this relationship remain largely unknown. This study explored the associations between multiple dimensions of interoception and anxiety-related traits and symptoms in a non-clinical adult sample.

Methods: A total of 305 participants completed self-report measures assessing interoceptive beliefs, attention, and perceived interoceptive accuracy, alongside measures of anxiety-related traits and symptoms. A subsample (n = 103) additionally completed laboratory-based heartbeat perception tasks to assess interoceptive accuracy, confidence, and insight via heartbeat counting and detection tasks..

Results: Correlational analyses revealed that anxiety-related traits were significantly associated with self-reported interoceptive difficulties. Novel associations between intolerance of uncertainty and interoception were observed, including negative correlations with interoceptive insight, bodily trust, and increased tendency to worry about discomforting internal sensations. Anxiety symptom severity was linked to self-reported increased attention to bodily signals, reduced bodily trust, and lower perceived accuracy. However, no significant relationships were observed between the heartbeat perception task measures and anxiety-related traits, symptoms, or self-reported interoceptive abilities..

Discussion: Findings support the conceptualisation of interoception as a multidimensional construct, demonstrating interoceptive accuracy and interoceptive beliefs as distinct constructs. Results align with emerging evidence that anxious traits are more closely related to subjective beliefs and interpretations of bodily signal than to behavioural interoceptive accuracy. These findings contribute to theoretical models of anxiety by highlighting interoceptive beliefs and attentional processes, rather than accuracy, as key factors warranting further investigation in clinical contexts.

KEYWORDS
anxiety, anxiety sensitivity, heartbeat perception, interoception, intolerance of uncertainty, trait anxiety

Introduction

Interoception refers to the nervous system's ability to sense, interpret, and regulate signals from within the body (1, 2). It plays a critical role in maintaining homeostasis (3, 4) and has been found to underpin a range of higher-order cognitive functions, including attention, perception, decision-making, memory, and emotion regulation (5, 6). Given its role within these core cognitive and physiological processes, interoception has been increasingly studied as a transdiagnostic mechanism underlying the pathophysiology of various mental health conditions (7).

Suksasilp and Garfinkel (8) proposed a multidimensional framework of interoception that expands on previous dimensional models (9), by incorporating a broader range of dimensions and distinguishing them based on levels of processing. At the lowest level, the framework considers the fundamental strength and nature of afferent bodily signals, followed by their preconscious impact and neural representation. Higher-order conscious dimensions of interoception include interoceptive accuracy, beliefs, insight, attention, and the attribution of interoceptive sensations (8). Interoceptive accuracy is defined as the ability to correctly identify internal body signals, measured by behavioural tests of interoceptive accuracy such as heartbeat perception and detection tasks (10, 11). While cardiac tasks are widely used as a measure of interoceptive accuracy, interoception extends across other bodily systems, including respiratory and gastric domains, which have also been linked to anxiety in lab-based tasks of accuracy (12).

Interoceptive beliefs refers to one's own perceptions and expectations regarding bodily sensations, measured through self-report measures such as questionnaires and confidence ratings. Interoceptive insight is a metacognitive measure which reflects how accurate individuals are at detecting their internal body signals, measured by the relationship between behavioural task performance (e.g., accuracy) and self-report performance (e.g. confidence). Interoceptive attention refers to the degree of focus to interoceptive sensations, typically assessed using self-report questionnaire measures, such as the Body Perception Questionnaire (BPQ; 13). Lastly, the attribution of interoceptive sensations refers to how individuals interpret bodily signals, such as perceiving them as threatening or ambiguous, which can influence emotional and behavioural responses (8).

Interoceptive processes have been increasingly linked to anxiety and may represent a transdiagnostic mechanism across anxiety-related disorders (14). Converging neurophysiological evidence supports this association: studies using heartbeat–evoked potentials (HEPs) show altered cortical processing of cardiac signals in individuals with generalized anxiety disorder (GAD), including reduced condition–dependent modulation and heightened HEP amplitudes related to symptom severity (15), as well as exaggerated HEP responses during adrenergic stimulation (16).

Complementing this neurophysiological work, research has begun to explore this through individual differences in anxious traits and symptom severity across anxiety disorders (17–19). Hierarchical models of anxious traits position trait anxiety as a central higher order dimension which is underpinned by several lower-order dimensions, such as intolerance of uncertainty and anxiety sensitivity (20).

The relationship between trait anxiety and facets of interoception is highly heterogeneous within the literature. Some studies report positive correlations between trait anxiety and cardiac interoceptive accuracy (21–23) whilst others have found a negative relationship (24, 25), or no relationship (26–29). Meta-analyses have similarly found no consistent association between cardiac interoceptive accuracy and trait anxiety (30, 31).

In contrast, the relationship between trait anxiety and interoceptive beliefs has been more consistently reported, with studies using the Multidimensional Assessment of Interoceptive Awareness (MAIA) as a measure of interoceptive beliefs showing negative associations with trait anxiety (28, 32–34). Specifically, Mehling (35) identified that subscales related to regulating attention, not-worrying about, and trusting bodily sensations consistently show the strongest negative associations though some studies report no significant relationships (36). Evidence regarding interoceptive attention is similarly mixed, with some studies identifying heightened bodily awareness as a predictor of trait anxiety (37) and others reporting no relationship (38). Additionally, Harrison et al. (39) found elevated trait anxiety was linked to decreased interoceptive insight in women, but not in men, indicating a potential gender-specific association. Together, these inconsistencies highlight the need for a multidimensional approach to examining interoception in relation to trait anxiety.

Anxiety sensitivity (AS) refers to the fear of anxiety-related bodily sensations and the belief that these sensations are harmful (40). The relationship between AS and interoception has yielded inconsistent findings, with studies reporting positive, negative, and null associations (21, 41–45), likely reflecting methodological variability in interoceptive measurement. Regarding interoceptive beliefs, AS has been negatively associated with the 'Not Worrying', 'Attention Regulation', and 'Trusting' subscales of the MAIA (34, 38), though findings remain mixed (46, 47). Given that AS is inherently centred on the interpretation of bodily sensations, further investigation into its relationship with multiple dimensions of interoception is warranted.

Intolerance of uncertainty (IU) reflects an aversive response to uncertainty and has been identified as a transdiagnostic factor underpinning anxiety (18). Despite recent advances in understanding interoception, the relationship between IU and interoception has not been well defined in literature (48). However, a recent correlation analysis by Bijsterbosch et al. (49) identified a weak positive association between IU and the 'Emotional Awareness' subscale on the MAIA, suggesting lower levels of IU were associated with higher levels of Emotional Awareness. Additionally, IU showed negative associations with 'Not Distracting', 'Not Worrying', and 'Trusting' subscales (49). Beyond these findings, empirical research directly linking IU and interoception is limited, although there is emerging research linking them theoretically; Freeston and Komes (50) provide a theoretical account of how IU may be conceptualised as a "felt sense" or embodied experience of unsafety. Given IU's established role as a transdiagnostic factor in anxiety, empirical investigation into its relationship with multiple dimensions of interoception remains a notable gap in the literature.

Understanding how trait anxiety, anxiety sensitivity and IU interact with different aspects of interoception (as outlined in the

Multidimensional Framework; 8) could clarify transdiagnostic mechanisms through which interoceptive processes contribute to symptom expression and maintenance. Emerging perspectives highlight the transdiagnostic role of interoception across anxiety disorders, including generalised anxiety disorder (GAD) (15), obsessive-compulsive disorder (OCD) (51), panic disorder (52), social anxiety disorder (SAD) (53), post-traumatic stress disorder (PTSD) (54, 55), as well as depression (56). However, these relationships remain unclear and understudied, with existing findings often yielding inconsistent results across anxiety-related disorders.

Given this transdiagnostic relevance, improving our understanding of the role of interoception may offer novel insights into the early identification and treatment of emotional disorders (2, 57). However, much of the existing research has focused on comparing clinical groups with control groups rather than adopting a dimensional approach that examines symptom severity across populations. This limits our understanding of how interoceptive processes contribute to anxiety-related psychopathology along a continuum. Addressing these gaps is particularly pertinent given the rising global rates of anxiety disorders (58).

The present study aimed to explore the relationship between interoceptive dimensions (accuracy, attention, beliefs and insight) and transdiagnostic anxious traits, including trait anxiety, anxiety sensitivity and intolerance of uncertainty, using both self-reported and task-based interoceptive measures. The study additionally examined these associations in relation to anxiety-related symptoms across GAD, OCD, panic disorder, PTSD, and SAD. This was guided by the following research questions:

1. How do anxiety-related traits relate to self-reported interoception?

   Based on prior research, trait anxiety and anxiety sensitivity were expected to be positively associated with interoceptive attention (BPQ). Both were also predicted to show negative associations with interoceptive beliefs, particularly the *Not Worrying*, *Not Distracting*, *Self-Regulation*, and *Trusting* subscales of the MAIA.
2. How do anxiety-related symptoms relate to self-reported interoception?

   Given mixed findings in the literature, associations between anxiety symptoms (GAD, OCD, panic, PTSD, social anxiety, depression) and self-reported interoceptive attention and beliefs were examined exploratorily, without directional predictions.
3. How do anxiety-related traits relate to task-based interoception?

   Due to inconsistent evidence regarding the relationship between anxiety-related traits (trait anxiety, anxiety sensitivity, intolerance of uncertainty) and interoceptive accuracy, confidence, or awareness, these analyses were considered exploratory.
4. How do anxiety-related symptoms relate to task-based interoception?

   Given limited and inconsistent findings regarding symptomatology and task-based interoceptive performance, these associations were also examined without directional predictions.

Methods

The present study comprised of two independent groups: an online sample and a lab-based sample. The online group completed a series of questionnaires remotely, while the lab-based group completed the same questionnaires in-person and additionally completed two heartbeat perception tasks. Ethical approval was granted by the ethics committee of the University of Southampton (ERGO number 89229), and the study was conducted in accordance with the Declaration of Helsinki. All participants provided informed consent prior to participation and were advised that their participation was voluntary and that they could withdraw at any time without penalty. No deception was used in this study. All data were anonymised and stored securely in accordance with data protection guidelines.

Participants

Recruitment

Participants were recruited using a combination of convenience and voluntary response sampling. Online participants were recruited via social media platforms (e.g., LinkedIn). Lab-based participants were recruited through social media platforms and the University of Southampton's research participation system (SONA). SONA participants received course credit as compensation for their time and effort. Participants not recruited through SONA received no compensation.

Participant inclusion and exclusion criteria

Inclusion criteria required participants to be 18 years of age or older, and to have sufficient fluency in English to complete the questionnaires and tasks, which was self-assessed by the participants. Exclusion criteria included being under 18 years of age, lacking sufficient English fluency, completing less than 85% of the questionnaires and tasks, having a history of traumatic head injury, or currently taking psychotropic medication, as such medications may alter subjective and psychophysiological responses. Current or past mental health diagnoses were not used as explicit exclusion criteria, as the study was designed to reflect a general non-clinical population rather than a screened clinical sample. Participants recruited through the student research panel (SONA) confirmed their eligibility via an initial screening, while those recruited externally confirmed their eligibility through email before participating in the study.

Participant characteristics

Power analysis was conducted using G*Power V3.1.9.2 (59). A-priori power analysis estimated a minimum sample size of

approximately $N = 84$ adult participants for completing heartbeat perception tasks and questionnaires in the lab. The sample size was calculated using a bivariate normal model for correlation analyses (effect size = 0.30, α error probability = 0.05, power (1 - β) = 0.80). For the online questionnaire group, a larger sample size of $N = 193$ was estimated using a smaller effect size ($r = 0.20$) to ensure sufficient power for detecting more subtle relationships. This larger sample size also accounts for potential incomplete questionnaire data. The effect sizes were based on prior studies examining intolerance of uncertainty processes and interoceptive measures (e.g., 60, 61).

A total of 344 participants were recruited to take part across the online and lab-based components of the study. Of the 344 participants recruited, 39 participants did not meet eligibility criteria and were therefore excluded. The final sample consisted of 305 participants, including 202 online participants and 103 lab-based participants (see Figure 1). The mean age of the overall sample was 28 years old ($SD = 13.32$; ranging from 18 to 81) and 74.8% were female. For further demographic characteristics of each group, see Table 1.

Online participant characteristics

A total of 236 participants completed the online questionnaires using a data collection platform, Qualtrics. Thirty-two cases were excluded due to partial completion of the questionnaire, and a further two were excluded due to not reaching the minimum age requirement. Within the final online sample of 202 participants, 96% completed all questionnaires, while 4% of participants completed at least 87% of the 12 questionnaires (i.e., at least 9 questionnaires). The final online sample had a mean age of 31.97 years (SD = 14.87), with 71.3% identifying as female.

Lab participant characteristics

A total of 108 participants were recruited to complete questionnaires and heartbeat perception tasks in the laboratory. Five participants did not attend their scheduled timeslot, resulting in a final lab sample of 103 participants. The final lab sample had a mean age of 21.25 ($SD = 5.28$), with 81.6% identifying as female.

Measures

Participants completed a series of validated self-report measures to assess anxiety-related traits, anxiety-related symptoms, and interoceptive beliefs and attention. Demographic data related to age, sex, ethnicity, nationality, English language fluency and sexual orientation was also collected. The questionnaires outlined below were administered with both online and lab-based participants. No modifications were made to the original scales.

Anxiety trait measures

Intolerance of Uncertainty Scale - 12 (IUS-12; 62). The IUS-12 is a 12 item self-report questionnaire intended to measure

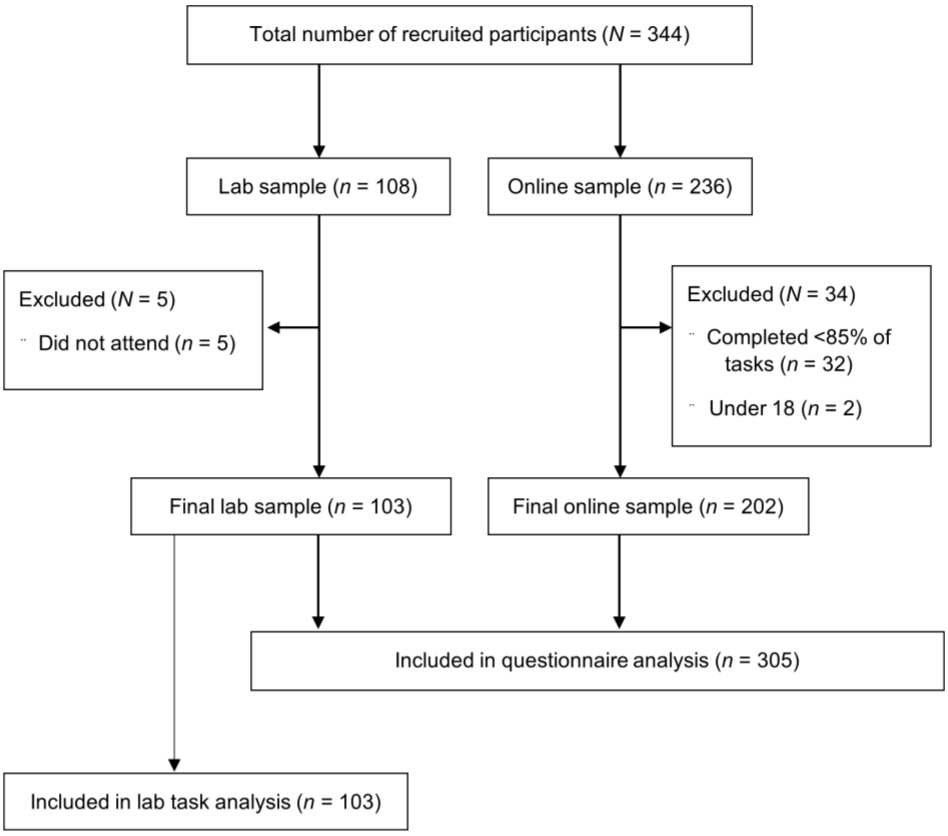


FIGURE 1
Participant flow diagram.

TABLE 1 Participant demographic information by group.

	Lab group (n = 103)	HH Online group (n = 202)
Mean age (*SD*)	21.25 (5.28)	31.97 (14.87)
Gender		
Female	84 (81.6%)	144 (71.3%)
Male	19 (18.4%)	47 (23.3%)
Transgender	0 (0%)	1 (0.5%)
Prefer not to say	0 (0%)	10 (5%)
Ethnicity		
Asian	9 (8.7%)	11 (5.4%)
Black	5 (4.9%)	4 (2%)
Multiethnic	3 (2.9%)	4 (2%)
White	83 (80.6%)	155 (76.7%)
Other	3 (2.9%)	13 (6.5%)
Prefer not to say	0 (0%)	15 (7.4%)
Sexual Orientation		
Asexual	0 (0%)	2 (1%)
Bisexual	16 (15.5%)	21 (10.4%)
Heterosexual	78 (75.7%)	146 (72.3)
Homosexual	7 (6.8%)	9 (4.5%)
Prefer not to say	2 (1.9%)	24 11.9%)

intolerance of uncertainty. Items include questions such as *"Unforeseen events upset me greatly"* and "*The smallest doubt can stop me from acting*" which are rated on a 5-point Likert scale ranging from 1 *(not at all characteristic of me)* to 5 (*entirely characteristic of me)*. Scores range from 12 to 60, with higher scores indicating greater intolerance of uncertainty. The scale has demonstrated excellent internal consistency in prior research (α = .85–.91; 62).

State-Trait Anxiety Inventory – Trait Subscale (STAIT-5; 63**).** The STAIT-5 is self-report questionnaire used to assess an individual's general tendency to experience anxiety. It has five items derived from the trait-anxiety subscale of the original 20-item *Spielberger State-Trait Anxiety Inventory* – Trait Subscale (STAI-T) (64). Participants rate the frequency of anxiety-related feelings (e.g., *"I feel nervous and restless"*) on a 4-point Likert scale ranging from 1 (*Almost never*) to 4 (*Almost always*). Total scores range from 6 to 24, with higher scores indicating greater trait anxiety. The measure has demonstrated excellent internal consistency (α = .91; 63).

Anxiety Sensitivity Index (ASI; 40**).** The ASI is a 16-item self-report questionnaire used to assess the fear of anxiety-related bodily sensations, such as a racing heart or difficulty breathing. Items are rated on a 5-point Likert-type scale ranging from 0 (*very little)* to 4 (*very much*). Total scores range from 0 to 64, where higher scores indicate greater anxiety sensitivity. Sample items include *"When I feel tense, I worry that I might be seriously ill"* and *"It scares me when my heart beats rapidly"*. The ASI has demonstrated good internal consistency and construct validity (65).

Anxiety symptom measures

Patient Health Questionnaire (PHQ-9; 66). The PHQ-9 is a nine-item self-report measure for assessing depressive symptoms. Participants rate how often they have been bothered by symptoms such as *"Feeling down, depressed, or hopeless"* over the past two weeks on a 4-point Likert scale ranging from 0 (*Not at all*) to 3 (*Nearly every day*). Total scores range from 0 to 27, with higher scores indicating greater depressive symptom severity. A cut-off score of 10–14 is suggested for diagnosis of moderate depression. The PHQ-9 has demonstrated excellent internal consistency (α = .89; 66) and strong construct validity (67).

Generalised Anxiety Disorder Questionnaire (GAD-7; 68). The GAD-7 was used to measure symptoms of generalised anxiety. The GAD-7 is a widely used 7-item self-report questionnaire that assesses the frequency of anxiety symptoms over the past two weeks. Participants rate how often they have been bothered by difficulties such as *"Feeling nervous, anxious, or on edge"* on a 4-point Likert scale ranging from 0 (*Not at all*) to 3 (*Nearly every day*). Total scores range from 0 to 21, with higher scores indicating greater severity of anxiety. A cut-off score of 10–14 is suggested for diagnosis of moderate anxiety. The GAD-7 has demonstrated excellent internal consistency (Cronbach's α = .92) and strong construct validity (68).

Obsessive Compulsive Inventory – Revised (OCI-R; 69**).** The OCI-R is an 18-item self-report questionnaire designed to assess distress associated with obsessive-compulsive symptoms. Participants rate how much they have been bothered or distressed by each symptom (e.g., *"I repeatedly check doors, windows, drawers, etc."*) over the past month on a 5-point Likert scale ranging from 0 *(Not at all)* to 4 *(Extremely)*. Total scores range from 0 to 72, with higher scores indicating greater OCD symptom severity. A cut-off score of 21 is suggested for diagnosis-level symptomology. The OCI-R has demonstrated excellent internal consistency (Cronbach's α = .90) and strong test-retest reliability (r = 0.84; 69).

Panic Disorder Severity Scale – Self Report (PDSS-SR; 70**).** The PDDS-SR is a 7-item self-report measure intended to measure the severity of panic disorder. It assesses various dimensions of panic disorder, including the frequency of panic attacks, anticipatory anxiety, agoraphobic avoidance, and functional impairment. Participants rate the severity of each symptom over the past week using a 5-point Likert scale ranging from 0 *(None)* to 4 *(Extreme*), for example *"If you had any panic attacks during the past week, how distressing were they while they were happening?"*. Total scores range from 0 to 28, with higher scores indicating greater severity of panic symptoms. A cut-off score of 8 is suggested for diagnosis-level symptomology. The PDSS has shown good internal consistency (α = 0.92 (70).

Post-traumatic Stress Disorder Checklist for DSM-5 (PCL-5; 71**).** The PCL-5 is a 20 item self-report questionnaire intended to measure the frequency of PTSD symptoms in the past month. Participants rate statements such as *"In the past month, how much were you bothered by having Repeated, disturbing, and unwanted memories of the stressful experience*?" using a 5-point Likert scale ranging grom 0 (*Not at all*) to 4 (*Extremely)*. The total score ranges from 0 to 80, with higher scores indicating more severe PTSD

symptoms. A cut-off score of 31 is suggested for diagnosis-level symptomology. The PCL-5 has demonstrated high internal consistency (α = .94), and test-retest reliability (*r* = .82) (72).

Social Interaction Phobia Scale (SIPS; 73). The SIPS is a 14-item self-report questionnaire intended to measure symptoms of social anxiety symptoms. Participants rate how much they agree with statements such as *"I am nervous mixing with people I don't know well"* on a 5-point Likert scale ranging from 0 (*Not at all*) to 4 (*Extremely*). Total scores range from 0 to 56, with higher scores indicating greater severity of social anxiety symptoms. There is no standard clinical cut-off for the SIPS measure, however, a score of 24 or above is considered clinically significant. The SIPS has demonstrated good internal consistency (73).

Self-report measures of interoception

Multidimensional Assessment of Interoceptive Awareness – Version 2 (MAIA-v2; 74). The MAIA-2 is a 37-item self-report scale intended to assess multiple facets of self-reported interoceptive beliefs. Participants rate statements such as "*I can pay attention to my breath without being distracted by things happening around me*" on a 6-point Likert scale ranging from 0 *(Never)* to 5 (*Always)*, with nine reverse-scored items. The MAIA-2 consists of eight subscales (outlined in Table 2), with mean scores calculated separately for each. Subscale scores range from 0 – 5. Higher scores indicate greater interoceptive awareness. The eight-factor structure has been validated across cultures in clinical (75), and non-clinical samples (76–78).

The MAIA-2 has demonstrated good internal consistency, with Cronbach's α ranging from.64 (Noticing) to.83 (Attention Regulation and Trusting) (74). Test-retest reliability studies have shown moderate to good stability, with intraclass correlation coefficients ranging from.67 to.79 (78).

Body Awareness Subscale of the Body Perception Questionnaire-Short Form (BPQ-SF; 79). The BPQ-SF is a shorter version of the original full scale BPQ developed by Porges (13). The shorter form focuses primarily on the Body Awareness and Autonomic Reactivity subscales. In line with previous research, only the Body Awareness subscale was used in the present study given the focus on subjective awareness of bodily sensations (9, 80). This subscale is a 26 item self-report measure intended to assess an individual's sensitivity to internal bodily sensations (79), relating specifically to the measure of interoceptive attention (8). Participants respond to statements such as *"During most situations, I am aware of how fast I am breathing"* on a 5-point Likert scale, ranging from 1 *(Never)* to 5 (*Always)*. Scores range from 26 – 130, with higher scores representing higher levels of body awareness. The psychometric properties of the BPQ Body Awareness scale demonstrated high internal consistency (α = .92) and high test-retest reliability (79).

Interoceptive Accuracy Scale (IAS; 81). The IAS is a 21-item self-report questionnaire designed to assess an individual's perceived ability to accurately detect internal bodily signals. Participants rate statements such as *"I can accurately perceive when my heart rate changes"* on a 5-point Likert scale, ranging from 1 *(Strongly Disagree)* to 5 *(Strongly Agree*). Scores range from 21 to 105, with higher scores indicating greater self-reported interoceptive accuracy. Internal consistency has been found to be good, with Cronbach's α ranging from.84 to.91 across studies (81).

TABLE 2 MAIA-2 subscales (74).

MAIA subscale	Definition
Noticing	Awareness of bodily sensations
Not Distracting	Tendency not to ignore or distract from sensations of discomfort
Not Worrying	Tendency not to worry about discomforting sensations
Attention Regulation	Ability to sustain and control attention to bodily sensations
Emotional Awareness	Awareness of the connection between bodily sensations and emotions
Self-Regulation	Ability to regulate distress by attending to bodily sensations
Body Listening	Active listening to bodily signals for insight
Trusting	Experience of one's body as safe and trustworthy

MAIA, Multidimensional Assessment of Interoceptive Awareness.

Behavioural measures of interoception

Self-report questionnaires assessing interoception measure an individual's perceived sensitivity to internal bodily signals; however, they do not determine whether this interoceptive belief corresponds to lab-based tasks of interoceptive accuracy (8, 9). Therefore, a smaller sample of participants (*n* = 103) completed heartbeat perception tasks to assess interceptive accuracy. These tasks were combined with a measure of subjective confidence in performing the task to produce an index of interoceptive insight. The relationship between mean task accuracy (interoceptive accuracy) and mean confidence scores (interoceptive beliefs) was analysed to quantify interoceptive insight scores. An overview of the interoceptive dimensions explored and methods of measurement is outlined in Figure 2.

Heartbeat counting task

In the Heartbeat Counting Task (HCT), participants were instructed to estimate their own heartbeats without external verification. At the start of each trial, an auditory cue *("Start")* was played through headphones, prompting participants to silently count their heartbeats without physically checking their pulse. At the end of the trial, a second cue *("Stop")* signalled them to stop counting and report their estimated heartbeat count. There were six trials, with intervals of 25, 30, 35, 40, 45, and 50 seconds, presented in a randomised order.

At the end of each trial, participants rated their confidence of their perceived accuracy. This confidence judgement was made by marking on a continuous visual analogue scale (VAS) that was 10 centimetres long. One end was marked "*Total guess/No heartbeat awareness*" while the other end was labelled "*Complete confidence/ Full perception of heartbeat"*). Confidence ratings on the VAS were measured manually in millimetres using a ruler for each of the six trials and then averaged to produce a single participant confidence

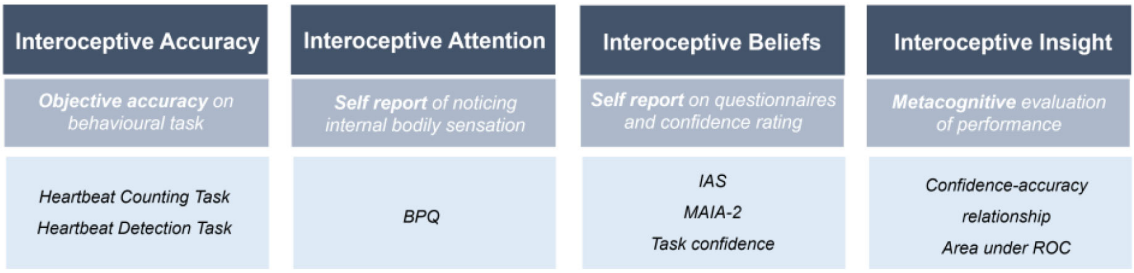


FIGURE 2
Overview of interoception dimensions and methods of measurement. Interoceptive terminology and methods of measurement, as outlined in Suksasilp & Garfinkel's (2022) Multidimensional Model of Interoception. BPQ, Body Perception Questionnaire; IAS, Interoceptive Accuracy Scale; MAIA, Multidimensional Assessment of Interoceptive Awareness; ROC, Receiver Operating Characteristics.

score of their heartbeat counting performance accuracy. Verbatim task instructions are provided in the Supplementary Material.

To measure interoceptive accuracy, a probability accuracy score, 0 to 1, was calculated for each trial, where higher scores indicated greater heartbeat counting accuracy. To provide a symmetric accuracy response between actual number of beats ($n\text{beats}_{\text{real}}$) and reported number of beats ($n\text{beats}_{\text{reported}}$), the absolute difference between these values was calculated using the formula outlined in Figure 3.

When the difference between $n\text{beats}_{\text{real}}$ and $n\text{beats}_{\text{reported}}$ is larger than $n\text{beats}_{\text{real}}$, equation one can produce negative accuracy scores. Not only do these have no interpretable meaning but will cause erroneous mean accuracy values for the whole trial. To prevent this, the absolute difference in values was restricted to a maximum of $n\text{beats}_{\text{real}}$, as given by the formula outlined in Figure 4. After six trials were completed the mean accuracy value was determined for each participant. Interoceptive insight was indexed by calculating within-participant correlations (r) between each participant's accuracy score and their corresponding VAS confidence score (9).

Heartbeat detection task

In the Heartbeat Detection Task (HDT), participants were presented with auditory tones through headphones that were either synchronous or asynchronous with their own heartbeat. In the synchronous condition, auditory tones were delayed by 300 milliseconds to account for the average 250 milliseconds delay between the R-wave and the arrival of the pulse pressure wave at the finger (82). In the asynchronous condition, tones were delayed by an additional 300 milliseconds (i.e., approximately 550 milliseconds after the R-wave), making them perceptually out of sync with the heartbeat (83). The task comprised 20 trials, each lasting 20 seconds. This number of trials was selected to balance statistical power and participant fatigue (84, 85). After each trial, participants were asked to decide whether the auditory tones were synchronous or asynchronous with their own heart. They rated their confidence of their judgement on a 10-centimetre VAS ranging from 0 cm *("Total guess/No heartbeat awareness")* to 10 cm *("Complete confidence/Full perception of heartbeat")*.

Confidence ratings on the VAS were measured manually in millimetres for each of the 20 trials and then averaged to produce a single confidence score. Interoceptive accuracy was determined by dividing the number of correct trials divided by the total number of trials, yielding the proportion of correct responses. As data from the HDT was binary, interoceptive insight (metacognitive awareness) was assessed using receiver operating characteristic (ROC) curve analysis (86). The area under the ROC curve quantified the extent to which confidence ratings reflected accuracy across trials (9).

Procedure

Online group procedure

Questionnaire data was collected remotely using the survey platform Qualtrics (87). Participants accessed the survey via an online link distributed through the study advertisement. The advertisement included a brief study description, eligibility criteria, and a direct link to the survey. Within Qualtrics, participants were presented with the Participant Information Sheet, provided informed consent, and completed demographic questions before proceeding to the study measures. Upon completion, participants were provided with a debrief form within Qualtrics outlining the aims of the study and relevant contact and support information. The estimated completion time for all questionnaires was approximately 20 minutes.

Lab group procedure

Upon arrival at the laboratory, participants were provided with information regarding the experimental procedure. Participants

$$\text{Accuracy} = 1 - \frac{|\, n\text{beats}_{\text{real}} - n\text{beats}_{\text{reported}} \,|}{n\text{beats}_{\text{real}}}$$

FIGURE 3
Interoceptive accuracy formula.

$$\begin{array}{lll} |\, n\text{beats}_{\text{real}} - n\text{beats}_{\text{reported}} \,| & < n\text{beats}_{\text{real}} & \text{Accuracy} = 1 - \dfrac{|\, n\text{beats}_{\text{real}} - n\text{beats}_{\text{reported}} \,|}{n\text{beats}_{\text{real}}} \\ & >= n\text{beats}_{\text{real}} & \text{Accuracy} = 0 \end{array}$$

FIGURE 4
Amended interoceptive accuracy formula.

were asked to review and sign an informed consent form to confirm their agreement to participate in the study. Participants were taken to the testing booth where they were asked to complete a series of questionnaires presented on a computer. Next, participants completed the heartbeat counting and heartbeat detection tasks. For these tasks, they were asked to wear headphones, and a reusable soft-sensor pulse oximeter (Nonin Medical XPOD® 3012 LP with USB Connector) was placed on the index finger of their non-dominant hand to measure heartbeats. Tactile sensations from the pulse oximeter were minimised by using a soft, low-pressure sensor designed to minimise pulse-wave feedback (88). The pulse oximeter was connected to a PC and tracked heartbeats in real time during the counting task, allowing for an accurate comparison between actual and perceived counts. The heartbeat counting task was administered first to minimise potential confounds arising from prior exposure to one's own heartbeat during the heartbeat detection task (as illustrated in Figure 5). The lab-based study took approximately 50 minutes to complete. Upon completion, participants were debriefed and provided with a written debrief form outlining the full aims of the study and relevant contact and support information.

Data analysis

All experimental data were inputted and analysed using IBM SPSS version 29.0.2.0 (89). Prior to analysis the data set was examined for missing values, outliers and normality. The data were generally in line with normality assumptions based on skewness and kurtosis values, as well as from visualising histograms. Descriptive statistics and reliability analysis was carried out. Parametric correlational analyses were conducted to examine associations between anxiety trait measures, anxiety symptom measures, self-report interoceptive measures and heartbeat perception task performance. To control for multiple comparisons, false discovery rate (FDR) corrections were applied to correlation analyses using the Benjamini–Hochberg procedure with a false discovery rate set at $q = .05$.

Online and lab questionnaire data were combined ($N = 305$) to explore how subjective interoceptive measures correlate with transdiagnostic anxiety traits (i.e., trait anxiety, AS and IU) and clinical symptom questionnaires (i.e., GAD, OCD, panic disorder, PTSD, and SAD). In a smaller sub-group of participants who completed the heartbeat perception tasks ($n = 103$), task performance was correlated with the corresponding participant's questionnaires to explore whether behavioural measures of interoception are associated with self-reported anxiety traits and symptoms.

Exclusions and missing data

Data were screened for missing responses prior to analysis. All lab participants completed 100% of the questionnaires and heartbeat perception tasks. However, one participant's data were missing for six trials due to a data recording issue in the Heartbeat Detection Task; their score was therefore averaged across the completed 14 trials rather than the full 20.

In the online sample, 236 participants initiated the questionnaire battery. Thirty-two participants (13.6%) were excluded for not meeting the pre-specified 87% completion threshold (i.e., at least 9 out of the 12 questionnaires). A further two participants were excluded for reporting an age below the eligibility criterion of 18 years. This resulted in a final online sample of 202 participants. Among these, all individual questionnaires had 100% item-level

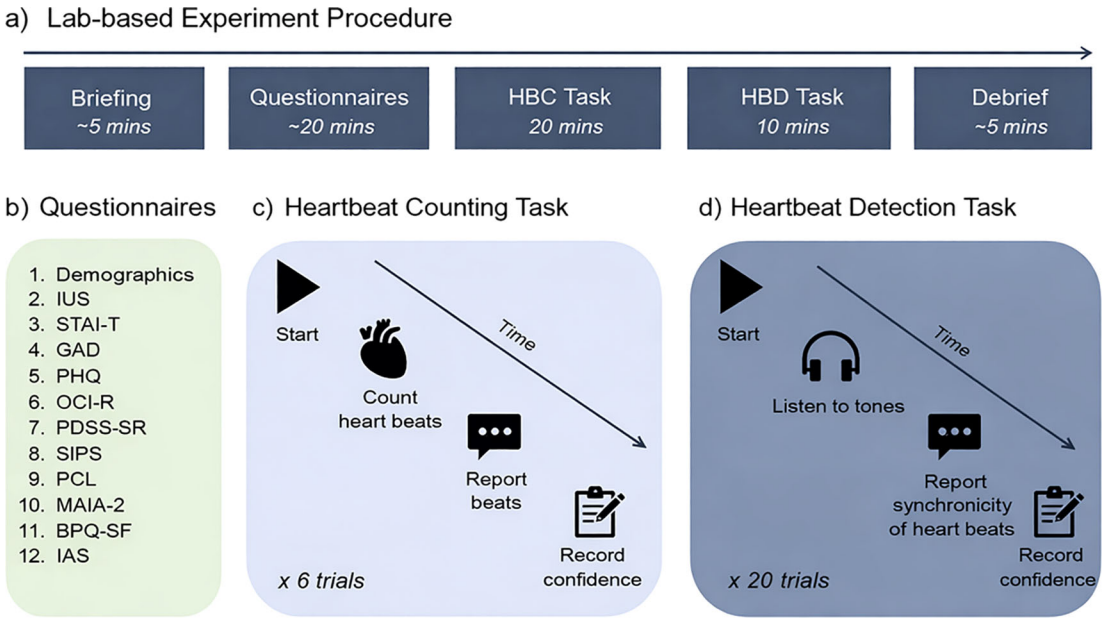


FIGURE 5
Laboratory-based experiment procedure **(a)**, Questionnaires **(b)**, Heartbeat Counting task **(c)**, and Heartbeat Detection Task. ASI, Anxiety Sensitivity Index; BPQ, Body Perception Questionnaire; GAD, Generalised Anxiety Disorder; HBC, Heartbeat Counting Task; HBD, Heartbeat Detection Task; IAS, Interoceptive Accuracy Scale; IUS, Intolerance of Uncertainty Scale; MAIA, Multidimensional Assessment of Interoceptive Awareness; OCI, Obsessive-Compulsive Inventory; PCL, PTSD Checklist; PDSS-SR, Panic Disorder Severity Scale – Short Version; PHQ, Patient Health Questionnaire; SIPS, Social Interaction Phobia Scale; STAI-T, State-Trait Anxiety Inventory – Trait.

completion. However, eight online participants had partial missing data across the full battery: two completed 87%, four completed 92%, and two completed 96% of the total questionnaires. These participants were included in analyses for the measures they completed and excluded from analyses involving the measures they did not complete.

Results

Self-report measure descriptive statistics

Table 3 presents descriptive statistics for the self-report measures in the online sample (n = 202). These measures demonstrated robust psychometric properties, with Cronbach's α values ranging from.75 (*MAIA Not Worrying*) to.96 *(PCL)* for the online group. Most data approximated a normal distribution, although some measures exhibited positive skew. For instance, the PDSS-SR (skewness = 1.66) indicated a floor effect, consistent with the expectation that most participants in a non-clinical sample report low panic symptoms. Similarly, the OCI (skewness = 0.88) reflects lower levels of obsessive-compulsive symptoms within this sample.

Table 4 presents descriptive statistics for the self-report measures in the lab-based sample (n = 103). Internal consistency was similarly robust, with Cronbach's α ranging from.74 *(MAIA Not Worrying)* to.96 (*SIPS*). Distributions for most measures were approximately normal; PDSS and OCI scores were positively skewed (skewness 1.01 and.93 respectively), similar to the online group.

The self-report measures display similar central tendencies and psychometric properties across the online and lab samples. Both groups consistently exhibited strong internal consistency. Overall, these descriptive statistics suggest the self-report instruments are reliable and perform as expected within this sample. Figures 6–8 display violin plots of each anxiety trait measure, symptom measure and interceptive measure, split by group.

Correlational analyses between anxiety-trait and interoception self–report measures

Parametric correlation coefficients were calculated among all scales. Correlations examined the associations between anxiety trait measures and interoception measures (see Table 5). As expected,

TABLE 3 Descriptive statistics of online group questionnaires and subscales.

Questionnaires/ Subscales	*N*	*M*	*SD*	Observed range	Skewness	Kurtosis	α
Trait Measures							
ASI	194*	26.81	13.06	0 – 59	0.28	-0.52	.91
IUS	202	33.20	9.56	13 – 57	0.18	-0.56	.91
STAIT-5	202	12.70	3.98	5 – 20	0.06	-0.99	.86
Interoceptive Measures							
BPQ	202	71.62	23.46	26 – 128	0.20	-0.52	.95
IAS	196*	44.85	13.10	21 – 92	0.46	0.42	.92
MAIA Noticing	202	2.57	1.28	0 – 5	-0.10	-0.67	.84
MAIA Not Distracting	202	2.25	1.13	0 – 5	0.21	-0.57	.87
MAIA Not Worrying	202	2.52	1.00	0 – 4.8	-0.08	-0.19	.75
MAIA Attention Regulation	202	2.36	1.14	0 – 5	0.05	-0.46	.91
MAIA Emotional Awareness	202	3.02	1.31	0 – 5	-0.49	-0.53	.90
MAIA Self-Regulation	202	2.22	1.27	0 – 5	0.19	-0.59	.89
MAIA Body Listening	202	1.91	1.27	0 – 5	0.33	-0.57	.88
MAIA Trusting	202	2.56	1.37	0 – 5	-0.15	-0.80	.88
Symptom Measures							
GAD-7	202	8.46	5.26	0 – 20	0.31	-0.75	.88
OCI	202	18.08	13.62	0 – 56	0.88	0.11	.92
PCL	202	23.14	18.73	0 – 75	0.69	-0.47	.96
PDSS-SR	202	3.96	5.23	0 – 28	1.66	3.01	.94
PHQ-9	202	8.57	6.33	0 – 26	0.62	-0.37	.89
SIPS	202	17.53	13.57	0 – 54	0.63	-0.46	.95

*N is reduced for ASI and IAS measures due to incomplete questionnaire responses. ASI, Anxiety Sensitivity Index; BPQ, Body Perception Questionnaire; GAD, Generalized Anxiety Disorder scale; IAS, Interoceptive Accuracy Scale; IUS, Intolerance of Uncertainty Scale; MAIA, Multidimensional Assessment of Interoceptive Awareness; OCI, Obsessive-Compulsive Inventory; PCL, PTSD Checklist; PDSS, Panic Disorder Severity Scale; PHQ, Patient Health Questionnaire; SIPS, Social Interaction Phobia Scale; STAI-T, State-Trait Anxiety Inventory – Trait. Cronbach's α values represent internal consistency reliability for each group separately.

TABLE 4 Descriptive statistics of lab group questionnaires and subscales.

Questionnaires/ subscales	*N*	*M*	*SD*	Observed range	Skewness	Kurtosis	α
Trait Measures							
ASI	103	29.76	11.73	5 – 62	0.14	0.16	.88
IUS	103	32.29	9.13	14 – 58	0.38	-0.16	.91
STAIT-5	103	12.36	3.49	5 – 20	-0.03	-0.56	.84
Interoceptive Measures							
BPQ	103	72.58	21.16	35 – 130	0.44	-0.13	.94
IAS	103	78.76	11.61	35 – 105	-0.70	1.77	.89
MAIA Noticing	103	2.42	1.15	0 – 5	0.20	-0.73	.83
MAIA Not Distracting	103	2.17	0.94	0 – 4.67	0.08	-0.44	.87
MAIA Not Worrying	103	2.49	0.91	0.40 – 4.80	-0.08	-0.17	.74
MAIA Attention Regulation	103	2.37	0.90	0.43 – 4.43	0.03	-0.50	.85
MAIA Emotional Awareness	103	2.89	1.09	0.40 – 5	-0.17	-0.54	.84
MAIA Self-Regulation	103	2.26	0.95	0 – 4.25	-0.16	-0.18	.78
MAIA Body Listening	103	1.95	1.08	0 – 4.33	-0.04	-0.57	.83
MAIA Trusting	103	2.72	1.29	0 – 5	-0.18	-0.88	.90
Symptom Measures							
GAD-7	103	9.22	5.59	0 – 21	0.26	-0.95	.90
OCI	103	20.63	13.94	0 – 60	0.93	0.54	.92
PCL	103	26.90	17.07	0 – 60	0.05	-1.16	.93
PDSS-SR	103	4.88	4.99	0 – 23	1.02	0.52	.91
PHQ-9	103	9.76	6.48	0 – 26	0.41	-0.73	.88
SIPS	103	21.52	14.84	0 – 56	0.63	-0.34	.96

ASI, Anxiety Sensitivity Index; BPQ, Body Perception Questionnaire; GAD, Generalized Anxiety Disorder scale; IAS, Interoceptive Accuracy Scale; IUS, Intolerance of Uncertainty Scale; MAIA, Multidimensional Assessment of Interoceptive Awareness; OCI, Obsessive-Compulsive Inventory; PCL, PTSD Checklist; PDSS, Panic Disorder Severity Scale; PHQ, Patient Health Questionnaire; SIPS, Social Interaction Phobia Scale; STAI-T, State-Trait Anxiety Inventory – Trait. Cronbach's α values represent internal consistency reliability for each group separately.

there were significant positive relationships between the anxiety trait measures within this sample ($N = 305$). Scatterplots illustrating key associations are provided in Supplementary Materials 3.1, 3.2.

Trait anxiety (STAI-T) showed significant negative correlations with MAIA subscales of 'Not Distracting' ($r = -.27$, $p < .001$), 'Not Worrying' ($r = -.44$, $p < .001$), 'Self-Regulation' ($r = -.24$, $p < .001$), and 'Trusting' ($r = -.26$, $p < .001$). A positive correlation was found between STAI-T and MAIA 'Noticing' ($r = .19$, p <.001). STAI-T scores were also weakly correlated with BPQ scores ($r = .14$, $p < .014$).

Anxiety sensitivity (ASI) exhibited significant negative correlations with MAIA subscales of 'Not Distracting' ($r = -.28$, $p < .001$), 'Not Worrying' ($r = -.60$, $p < .001$), and 'Self-Regulation' ($r = -.19$, $p < .001$), and 'Emotional Awareness' ($r = .14$, $p < .015$). A moderate positive association was also found between ASI and BPQ scores ($r = .32$, $p < .001$). A weaker negative association was found between

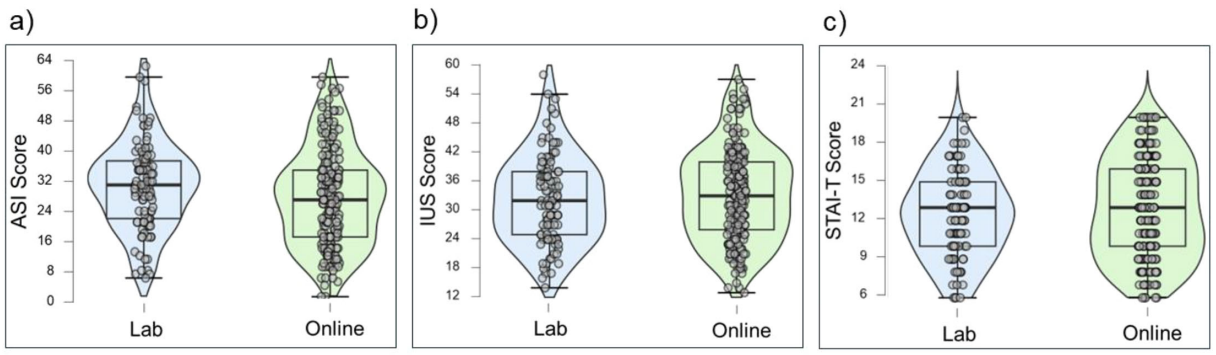


FIGURE 6
Violin plots of trait measures by group: ASI **(a)**, IUS **(b)** and STAI-T **(c)**.

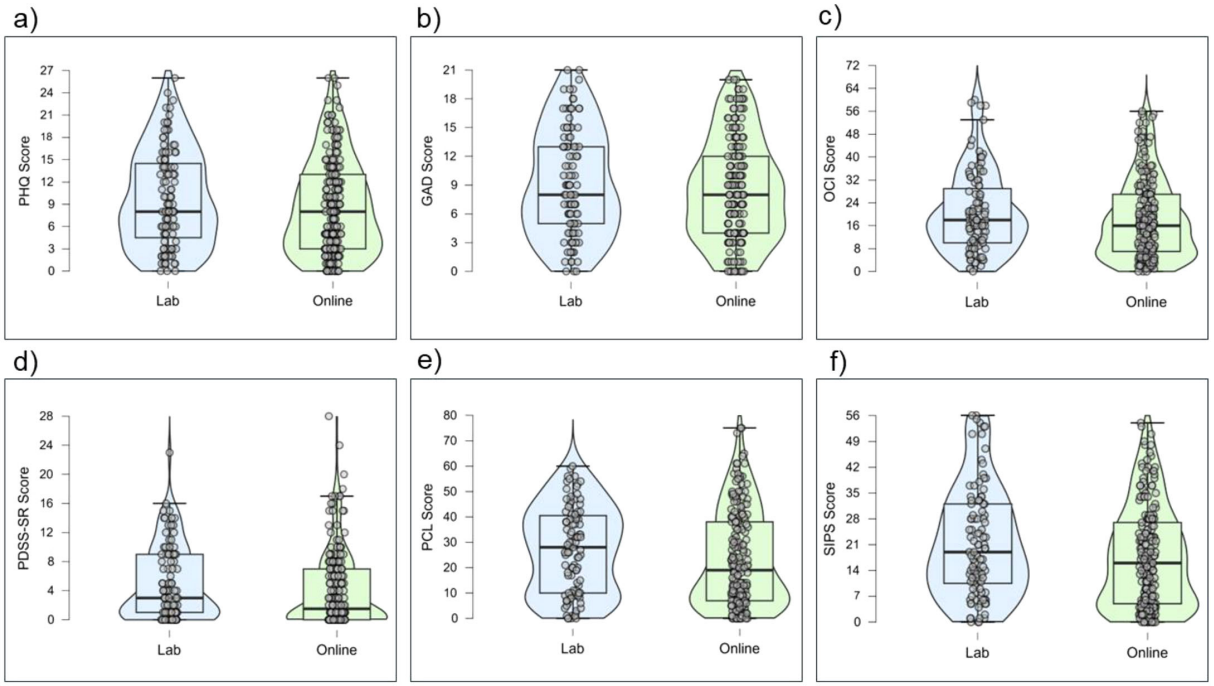


FIGURE 7
Violin plots of symptom measures by group: PHQ **(a)**, GAD **(b)**, OCI **(c)**, PDSS-SR **(d)**, PCL **(e)**, and SIPS **(f)**.

ASI and IAS (r = -.14). However, this effect did not remain significant after correction for multiple comparisons.

Intolerance of uncertainty (IUS) was significantly negatively correlated with several MAIA subscales, including 'Not Distracting' (r = -.22, p <.001), 'Not Worrying' (r = -.39, p <.001), and 'Self-Regulation' (r = -.18, p = .002). A small negative relationship was identified between IU and self-reported interoceptive accuracy (IAS) (r = -.15, p = .009), and no relationship with BPQ.

Correlational analyses between symptom and interoception self–report measures

Table 6 outlines the associations between clinical symptom measures and self-report interoceptive measures. As expected, there were significant positive relationships between all symptom measures in this sample (N = 305) (r = .53 -.77, p's <.001). Higher levels of GAD, PTSD and depression were significantly negatively correlated with the MAIA subscales 'Not Distracting' (see Supplementary 3.3), 'Not Worrying', 'Self-Regulation' and 'Trusting'. Similarly, elevated higher panic and OCD symptoms were also significantly negatively correlated with the MAIA subscales of 'Not Distracting', 'Not Worrying', and 'Trusting'. Social anxiety symptoms were primarily associated with lower scores on MAIA 'Not Worrying' (r -.33; p <.001).

Higher interoceptive attention (BPQ) was positively associated with greater anxiety-related symptoms, particularly social anxiety (r = .28, p <.001), panic (r = .24, p <.001), OCD (r = .23, p <.001), and generalised anxiety (r = .16, p = .005). BPQ scores were also positively correlated with symptom severity of other emotional disorders including PTSD (r = .20, p <.001) and depression (r = .16, p = .005). Interoceptive accuracy (IAS) was significantly negatively correlated with all symptom measures, although the strength of this relationship was weak (r <.22, p 's = .001 -.008).

Heartbeat perception task performance descriptive statistics

Table 7 presents the descriptive statistics for the performance on the heartbeat perception tasks with the lab sample (n = 103). Data was normally distributed for both tasks.

Overall, participants demonstrated overall higher accuracy in the HCT task compared to the HDT task, suggesting heartbeat counting was easier than heartbeat detection. However, overall confidence scores were lower for the heartbeat counting task than the heartbeat detection task. Figure 9 displays violin plots of interoceptive accuracy, confidence and insight metrics for each heartbeat perception task.

Correlational analysis between anxiety trait and heartbeat perception task performance

Correlation analyses were conducted to explore associations between anxiety trait vulnerability factors (i.e., trait anxiety, AS and IU) and heartbeat perception task performance (see Table 8). For the heartbeat counting task, trait anxiety (STAI-T) was negatively associated with Heartbeat Counting (HBC) Confidence (r = -.26). Greater intolerance of uncertainty (IUS) was associated with

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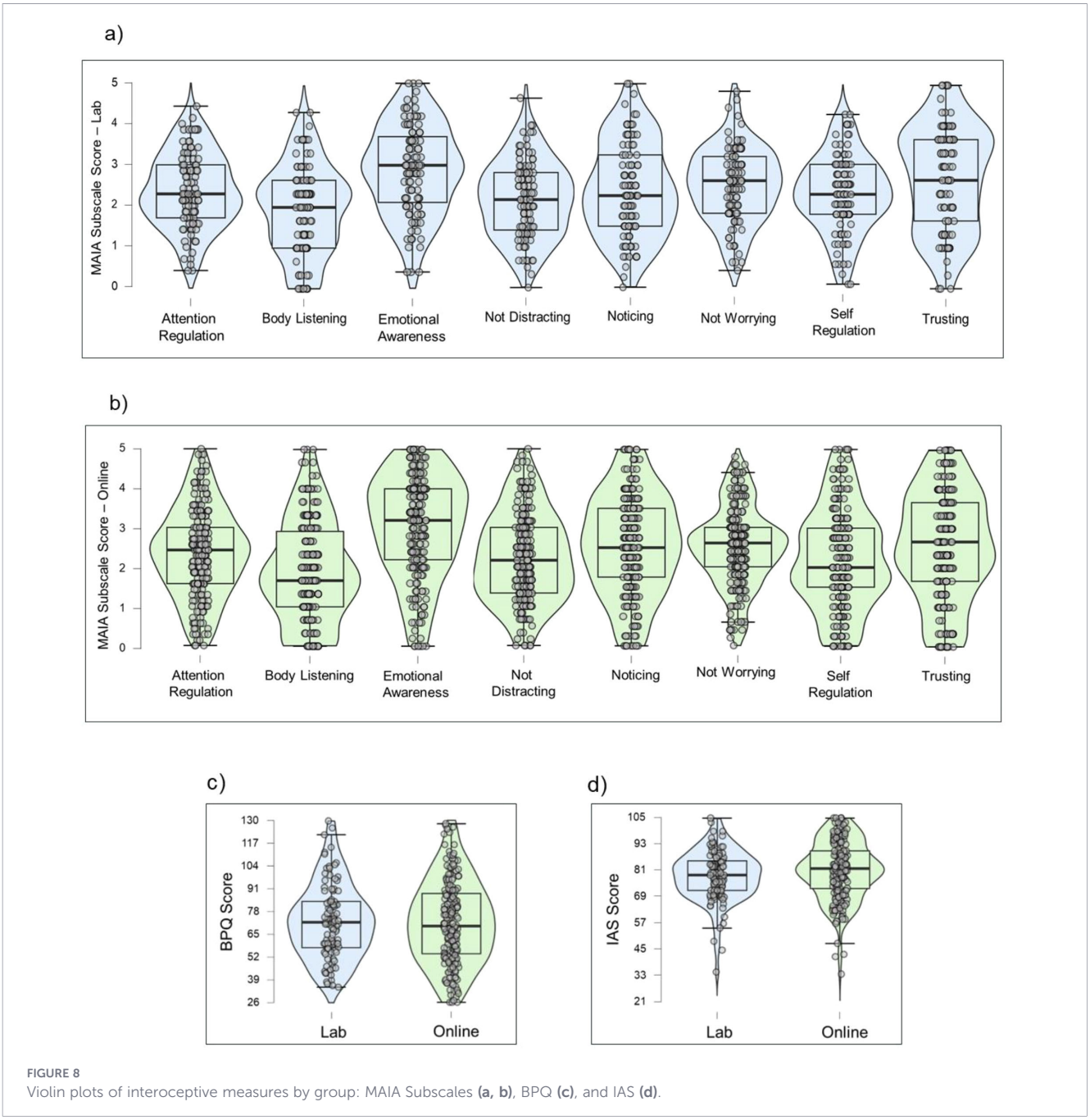


FIGURE 8
Violin plots of interoceptive measures by group: MAIA Subscales **(a, b)**, BPQ **(c)**, and IAS **(d)**.

increased HBC Insight (r = .20). However, both results did not withstand correction for multiple comparisons. No significant associations were found between trait measures and Heartbeat Detection (HBD) performance.

As expected, there were significant positive relationships between the anxiety-trait measures within the lab sample (N = 103). Higher intolerance of uncertainty (IUS) was strongly associated with greater trait anxiety (STAI-T) (r = .65, p <.001) and anxiety sensitivity (ASI) (r = .59, p <.001), consistent with theoretical models that conceptualise intolerance of uncertainty as a transdiagnostic cognitive vulnerability factor for anxiety disorders. Furthermore, trait anxiety (STAI-T) and anxiety sensitivity (ASI) were moderately correlated (r = .46, p <.001).

Correlational analysis between symptom measures and heartbeat perception task performance

Correlation analyses were conducted to explore the relationships between symptom measures and performance on heartbeat perception tasks (see Table 9). No significant relationships emerged between symptom measures and heartbeat perception task metrics

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TABLE 5 Correlation matrix illustrating the relationship between anxiety trait and self-report interoception questionnaires (N = 305).

Questionnaire/subscale	1	2	3	4	5	6	7	8	9	10	11	12	13
1.ASI	–												
2.IUS	.51**	–											
3.STAI-T	.56**	.68**	–										
4.BPQ	.32**	.10	.14*	–									
5.IAS	-.14*†	-.15**	-.15**	.08	–								
6.MAIA Noticing	.26**	.15*	.19**	.36**	.27**	–							
7.MAIA Not Distracting	-.28**	-.22**	-.27**	-.16**	.11*†	-.23**	–						
8.MAIA Not Worrying	-.60**	-.39**	-.44**	-.14*	.18**	-.09	.08	–					
9.MAIA Attention Reg.	-.10	-.10	-.07	.25**	.30**	.46**	-.09	.12*	–				
10.MAIA Emotional Awa.	.14*	.04	.09	.32**	.22**	.58**	-.19**	-.08	.55**	–			
11.MAIA Self-Regulation	-.19**	-.18**	-.24**	.09	.24**	.32**	.04	.15**	.65**	.57**	–		
12.MAIA Body Listening	.04	-.05	-.09	.17**	.25**	.45**	-.01	.01	.53**	.58**	.63**	–	
13.MAIA Trusting	-.16**	-.25**	-.26**	.06	.30**	.25**	.02	.13*	.57**	.51**	.60**	.54**	–

* and ** denote uncorrected significance at p <.05 and p <.01, respectively. † indicates the effect did not remain significant after Benjamini–Hochberg FDR correction (q = .05). ASI, Anxiety Sensitivity Index; BPQ, Body Perception Questionnaire; IAS, Interoceptive Accuracy Scale; IUS, Intolerance of Uncertainty Scale; MAIA, Multidimensional Assessment of Interoceptive Awareness; STAI-T, State Trait Anxiety Inventory – Trait. Correlational Analyses Between Symptom and Interoception Self – Report Measures.

(i.e., interoceptive accuracy, confidence, and insight). As expected, strong positive correlations were observed between symptom questionnaires (r = .50 -.83, p's <.001).

The present study investigates the relationship between multiple facets of interoception, anxious-related traits, and anxiety-related symptoms. Given the heterogeneity of findings in the existing literature, hypotheses regarding these relationships were primarily exploratory, though some directional predictions were made based on prior research.

H1. Anxiety-related traits and self-reported interoception

As predicted, anxiety-related traits were significantly associated with self-report measures of interoception. Specifically, trait anxiety was negatively related with MAIA subscales 'Not Worrying', 'Not Distracting', 'Self- Regulation' and 'Trusting' in line with previous research (e.g., 28, 32–34, 36). The strongest relationship was with 'Not Worrying' and 'Trusting', also consistent with literature (32,

TABLE 6 Correlation matrix illustrating the relationship between symptom questionnaires and self-report interoception questionnaire. (N = 305).

Questionnaire/ Subscales	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. GAD	–															
2. OCI	.61**	–														
3. PCL	.74**	.64**	–													
4. PDSS	.60**	.53**	.66**	–												
5. PHQ	.72**	.56**	.77**	.54**	–											
6. SIPS	.53**	.55**	.57**	.51**	.49**	–										
7. BPQ	.16**	.23**	.20**	.24**	.16**	.28**	–									
8. IAS	-.15**	-.21**	-.25**	-.16**	-.22**	-.21**	.08	–								
9. MAIA Noticing	.21**	.21**	.20**	.26**	.14*	.19**	.36**	.27**	–							
10. MAIA Not Distracting	-.25**	-.28**	-.36**	-.25**	-.28**	-.27**	-.16**	.11*	-.23**	–						
11. MAIA Not Worrying	-.38**	-.33**	-.34**	-.28**	-.21**	-.33**	-.14*	.18**	-.09	.08	–					
12. MAIA Attention Reg.	-.09	.05	-.08	-.05	-.13*	-.04	.25**	.30**	.46**	-.09	.12*	–				
13. MAIA Emotional Awa.	.10	.12*†	.10	.15**	-.07	.07	.32**	.22**	.58**	-.19**	-.08	.55**	–			
14. MAIA Self-Regulation	-.20**	-.07	-.17**	-.11	-.27**	-.14*	.09	.24**	.32**	.04	.15**	.65**	.57**	–		
15. MAIA Body Listening	-.06	.05	-.02	.10	-.14*	.03	.17**	.25**	.45**	-.01	.01	.53**	.58**	.63**	–	
16. MAIA Trusting	-.26**	-.15**	-.22**	-.15*	-.29**	-.23**	.06	.30**	.25**	.02	.13*	.57**	.51**	.60**	.54**	–

* and ** denote uncorrected significance at p <.05 and p <.01, respectively. † indicates the effect did not remain significant after Benjamini–Hochberg FDR correction (q = .05). BPQ, Body Perception Questionnaire; GAD, Generalised Anxiety Disorder; IAS, Interoceptive Accuracy Scale; MAIA, Multidimensional Assessment of Interoceptive Awareness; OCI, Obsessive-Compulsive Inventory; PDDS-SR, Panic Disorder Severity Scale – Self Report; PCL, Post-Traumatic Stress Disorder Checklist; SIPS, Social Interaction Phobia Scale.

TABLE 7 Descriptive statistics of heartbeat perception tasks.

Heartbeat Task	*N*	*M*	*SD*	Range	Skewness	Kurtosis
HBC Accuracy	103	0.72	0.17	0.23 – 0.98	-0.65	-0.28
HBC Confidence	103	43.48	19.80	0.17 – 89.83	-0.11	-0.42
HBC Insight	103	0.27	0.49	-0.80 – 0.97	-0.54	-0.75
HBD Accuracy	103	0.49	0.14	0.10 – 0.85	-0.23	0.23
HBD Confidence	103	53.63	16.95	8.65 – 95.05	-0.19	0.00
HBD Insight	103	0.51	0.14	0.11 – 0.87	-0.11	0.49

HBC, Heartbeat Counting; HBD, Heartbeat Detection.

34). This suggests individuals with higher trait anxiety may have difficulty not worrying about discomforting sensations, ignoring and distracting oneself from sensations of discomfit, regulating distress by attending to bodily sensations and trusting their body as a 'safe place'. In contrast to previous findings, MAIA 'Noticing' was positively correlated with trait anxiety, although this relationship is weak. This novel finding may suggest individuals with higher trait anxiety tend to be more attuned to the presence of bodily sensations, but without the accompanying capacity to interpret or regulate them in adaptive ways in a non-clinical sample. These findings align with previous research that suggests higher trait anxiety is associated with greater self-reported sensitivity to internal bodily sensations (27, 37).

BPQ findings were consistent with those from the MAIA 'Noticing' subscale, also showing a positive correlation with trait anxiety. This may reflect the conceptual overlap between the two measures, as both assess subjective awareness of bodily sensations. However, the BPQ has been criticised as a proxy measure for anxiety symptoms, as it primarily captures awareness of aversive, anxiety-related bodily states. In contrast, the MAIA was specifically developed to assess more adaptive, regulatory aspects of interoception, such as mindfulness and coping behaviours (74). This distinction may help explain why some MAIA subscales show negative associations with anxiety, while the BPQ consistently shows positive relationships. These differential relationships highlight a need to distinguish between maladaptive and adaptive forms of interoception (90).

Similarly, AS was positively correlated with the BPQ and MAIA 'Noticing'. Consistent with previous research, it showed the strongest negative correlation with MAIA 'Not-Worrying' (34, 38). This suggests that individuals with higher anxiety sensitivity tend to be more attuned to bodily sensations but are also more likely to interpret these sensations in a distressing way. As expected, individuals with lower AS may be less likely to worry when experiencing

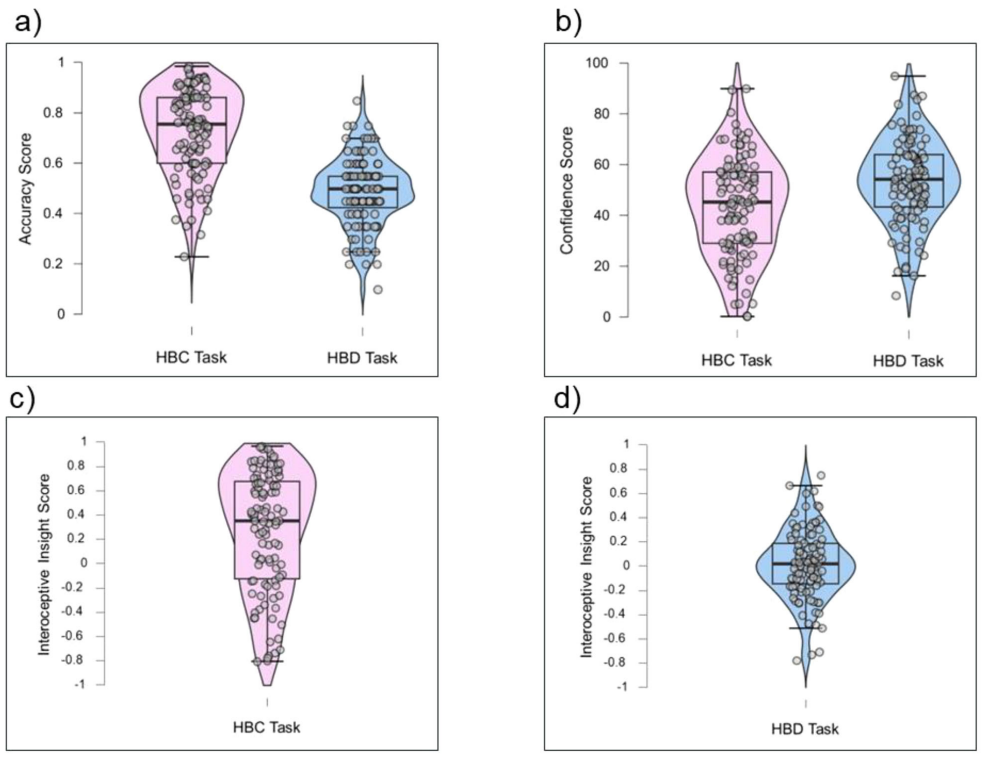


FIGURE 9
Violin plots of heartbeat perception task performance: Accuracy Score **(a)**, Confidence Score **(b)**, Interoceptive Insight Score **(c, d)**. N = 103.

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TABLE 8 Correlation matrix illustrating the relationship between trait questionnaires and heartbeat perception task performance. (N = 103).

Questionnaire/task	1	2	3	4	5	6	7	8	9
1. ASI	–								
2. IUS	.59**	–							
3. STAI-T	.46**	.65**	–						
4. HBC Accuracy	-.02	-.08	-.05	–					
5. HBC Confidence	-.07	-.08	-.26*†	.27**	–				
6. HBC Insight	-.02	.20*†	.17	.13	-.02	–			
7. HBD Accuracy	.12	-.01	-.01	-.02	-.08	.10	–		
8. HBD Confidence	-.18	-.13	-.11	.09	.54**	-.11	-.07	–	
9. HBD Insight	.03	-.05	.12	.03	-.14	.13	.02	-.06	–

* and ** denote uncorrected significance at p <.05 and p <.01, respectively. † indicates the effect did not remain significant after Benjamini–Hochberg FDR correction (q = .05). ASI, Anxiety Sensitivity Index; HBC, Heartbeat Counting; HBD, Heartbeat Detection; IUS, Intolerance of Uncertainty Scale; STAI-T, State-Trait Anxiety Inventory – Trait.

anxiety-related bodily sensations, such as increased heartrate, shortness of breath or chest constrictions.

Given the scarcity of research examining the relationship between IU and interoception, the present study adopted an exploratory approach. Findings revealed that IU was negatively correlated with the MAIA 'Not Distracting' and 'Trusting' subscales, with the strongest negative correlation observed for 'Not Worrying', as reported in existing research (49). These results suggest individuals with higher IU may be less likely to trust their bodily sensations, more prone to worry about them, and more inclined to distract themselves from these signals rather than engage with them adaptively. However, no significant relationship was found between IU and interoceptive attention, as measured by the BPQ, while only a weak positive association emerged with the MAIA Noticing subscale, which also assesses awareness of bodily sensation. This suggests IU may not be related to the extent to which individuals attend to bodily sensations, but rather how individuals may interpret and respond to those sensations. This is further supported by the observed negative association between IU and self-reported interoceptive accuracy, as measured by the IAS. Together, these findings highlight the potential role of higher IU in altered interoceptive processing, characterised by negative beliefs about bodily signals (i.e., interpreting them as threatening), and reduced perceived accuracy in detecting these signals.

H2. Anxiety-related traits and heartbeat perception tasks

Results from the heartbeat perception tasks found no relationship between cardiac interoceptive accuracy and any of the anxiety-related traits examined. This adds to the body of evidence that suggests interoceptive accuracy does not play a significant role in trait anxiety (28, 30, 31, 85), anxiety sensitivity (42) and provides novel findings for IU. This supports the theoretical model that anxious traits are more closely linked to interceptive beliefs (i.e., how much they believe they notice bodily sensations), rather than behavioural measures of interoceptive accuracy (8, 91).

Notably, IU was at trend positively correlated with interoceptive insight on the HBC task, but not on the HBD task. This discrepancy may be due to inherent differences in task requirements (92). Whilst

TABLE 9 Correlation matrix illustrating the relationship between symptom questionnaires and heartbeat perception task performance. (N = 103).

Questionnaire/Task	1	2	3	4	5	6	7	8	9	10	11	12
1. GAD	–											
2. OCI	.64**	–										
3. PCL	.83**	.56**	–									
4. PDSS-SR	.68**	.54**	.74**	–								
5. PHQ	.73**	.54**	.75**	.58**	–							
6. SIPS	.56**	.50**	.58**	.56**	.58**	–						
7. HBC Accuracy	.09	-.03	.08	.11	.02	-.08	–					
8. HBC Confidence	-.12	-.05	-.10	-.02	-.16	-.02	.27**	–				
9. HBC Insight	-.01	.02	-.02	-.16	-.02	-.12	.13	-.02	–			
10. HBD Accuracy	.01	-.07	.06	-.01	-.04	.08	-.02	-.08	.10	–		
11. HBD Confidence	-.09	-.05	-.01	-.02	-.11	-.04	.09	.54**	-.11	-.07	–	
12. HBD Insight	.01	-.05	.03	.09	.01	-.11	.03	-.14	.13	.02	-.06	–

* and ** denote uncorrected significance at p <no><.05</no> and p <.01, respectively. GAD, Generalised Anxiety Disorder; HBC, Heartbeat Counting; HBD, Heartbeat Detection; OCI, Obsessive-Compulsive Inventory; PDDS-SR, Panic Disorder Severity Scale – Self Report; PCL, Post-Traumatic Stress Disorder Checklist; PHQ, Patient health questionnaire; SIPS, social interaction phobia scale.Discussion.

both tasks are presumed to assume perception of internal sensations, the detection task is a force-choice discrimination task which requires the integration of internal and external stimuli. As such, HBD tasks are often presumed to be more difficult than the HBC task (8, 93).

H3. Anxiety-related symptoms and self-reported interoception

Significant relationships were found between all symptom measures and the IAS and BPQ. BPQ scores were positively correlated with symptom severity, whereas IAS scores were negatively correlated. This suggests that individuals who report poorer interoceptive accuracy tend to experience higher levels of anxiety-related symptoms, with the strongest association observed for PTSD symptoms. Conversely, individuals with greater interoceptive attention tend to report higher symptom severity. These findings suggest that individuals may be highly attuned to their bodily sensations but lack confidence in the accuracy of their perceptions. This aligns with models suggesting that heightened bodily awareness may contribute to increased symptom severity through hypervigilance and misinterpretation of bodily sensations (21, 43).

Supporting this, negative relationships between all symptom measures and the MAIA 'Trusting' subscale suggest that individuals with more severe symptoms may struggle to trust their bodily sensations, particularly those with panic symptoms, where this association was strongest. This pattern is consistent with theories of panic disorder, which emphasise the catastrophic misinterpretation of bodily signals (94–96). Several MAIA subscales were significantly negative associated with symptom measures. For example, PTSD symptoms were most strongly associated with lower scores on the 'Not Distracting' subscale. This is in line with the well-established role of avoidance in PTSD, particularly the avoidance of internal cues that may trigger trauma memories (55). This highlights that individuals with PTSD may actively disengage from bodily sensations in an effort to prevent distressing flashbacks or anxiety, reflecting interoceptive avoidance.

H4. Anxiety-related symptoms and heartbeat perception tasks

No significant correlations were found between symptom measures and metrics derived from the HBC and HBD tasks (i.e., interoceptive accuracy, confidence, and interoceptive insight). These findings are unexpected, and challenge theoretical models that position interoception as central to anxiety disorder symptoms (e.g., 21, 43). This adds to the growing body of research reporting differential associations between interoceptive processes and anxiety symptoms, suggesting that psychopathology may not be characterised by global interoceptive differences (97). These mixed findings may be due to differences in how interoception is conceptualised and methodological variations, underscoring the need for more standardised approaches to studying interoception in psychopathology (2, 98). Moreover, the absence of significant associations may be partly attributable to the non-clinical sample and the reliance on self-reported symptoms. As illustrated in the violin plots (see Figure 7), most symptom scores, apart from GAD, were clustered toward the lower end of the scale, which may have limited the variability needed to detect associations with behavioural interoception.

Discussion

This study applies a multidimensional model of interoception to examine both transdiagnostic anxious traits and symptom dimensions across anxiety-related disorders. Strengths include the combined use of self-report and heartbeat perception tasks, a relatively large sample size, and inclusion of a range of anxiety constructs. By aligning interoceptive measures with a contemporary multidimensional framework, the study helps clarify which interoceptive domains (e.g., accuracy, attention, beliefs) are most relevant to anxiety.

Limitations should also be acknowledged. The present study focuses exclusively on cardiac interoception, therefore results may not generalise to other domains such as respiratory or gastric interoception, which have also shown associations with anxiety when measured (e.g., 12). 39 found performance on inspiratory resistance tasks does not necessarily transfer to cardiac tasks, highlighting that interoceptive abilities may be modality specific. Future research should adopt multimodal approaches to determine whether observed associations are unique to cardiac interoception or reflect broader interoceptive mechanisms.

Secondly, despite widespread use in interoceptive research, the heartbeat perception tasks have been criticised for their validity (99, 100). The HBD task can produce mean accuracies around chance level (50%), as observed in the present study and reported in other studies using comparable (101) or greater numbers of trials (102). This suggests that the task may be particularly challenging for participants. Therefore, the individual difference results here should be interpreted with caution. Consequently, further methodological refinement and technological development are needed to improve the sensitivity, reliability, and validity of heartbeat perception tasks in interoceptive research. Furthermore, it has been argued that HBC performance can be influenced by non-interoceptive factors such as time estimation, knowledge of heart rate and response bias (84, 100, 103). Prior knowledge of heart rate may be particularly relevant given the growing prevalence of heart rate-monitoring wearables, which could potentially confound performance on the HBC task (104). Desmedt et al. (105) demonstrated that modifying task instructions to ask participants not to guess their heartbeats reduced average HCT performance by 50%, suggesting HCT performance may rely on cognitive strategies rather than true interoceptive accuracy. To address these concerns and minimise estimation bias and chance-level responding, future studies should assess participants' baseline knowledge of their heart rate and time estimation abilities, as implemented in some studies (103, 106, 107). This would help clarify the extent to which top-down influences affect task performance and disentangle interoceptive ability from other cognitive factors.

Furthermore, the present study did not observe a significant relationship between HBC and HBD performance (see Supplementary Material), consistent with previous research (108, 109). Meta-analytic evidence suggests performance on the HBC and HBD tasks is only weakly associated, indicating such tasks may capture distinct constructs (92). This raises questions about whether these tasks index a shared interoceptive ability or instead tap into distinct facets of interoception.

Lastly, the sample that was recruited in the current study was intended to reflect a general non-clinical population. However, participants were not excluded based on psychiatric conditions, including personality disorders. In the sample that was recruited, 40-45% met cut-offs for clinically relevant symptoms such as moderate anxiety and depression (see Supplementary Table 2). While there was high reporting of clinically relevant symptoms, it is important to note that anxiety and depression symptoms are relatively common, particularly amongst young people (110). Furthermore, the questionnaires used are for screening purposes only. A diagnostic clinical interview conducted by a trained clinician would be a more appropriate tool to identify diagnosis status. On this basis, in this data set we could not address the impact of mental health status on the result.

In light of the rapidly rising global prevalence of anxiety disorders (58), continued research into interoception as a transdiagnostic factor is warranted. Future studies should extend beyond single measurement paradigms and adopt a systematic, multidimensional assessment of interoception, including exploration of understudied bodily domains beyond the cardiac axis. Such an approach will help to delineate the mechanistic role of interoception in anxiety-related disorders, enhance the development of targeted clinical interventions, and enhance understanding of the real-world relevance and translational potential of interoceptive processes (111).

Conclusion

The present study explored the relationship between interoception and anxiety-related traits and symptoms using a multidimensional framework. By combining self-report and behavioural measures, it aimed to capture distinct facets of interoception to address the gaps in the literature. While some findings aligned with theoretical predictions, highlighting the role of interoceptive beliefs and attention in anxiety, other findings, particularly those involving behavioural task performance, were less consistent. The lack of relationship between heartbeat perception tasks and self-reported experiences highlights ongoing concerns about measurement validity (88, 111). Overall, this research provides novel findings related to anxious-traits and interoception and supports the move towards multidimensional approaches to interoception. Findings highlight the importance of considering both subjective and behavioural measures of interoceptive processes when investigating its role in anxiety-related processes.

Future research should prioritise methodological standardisation, for example by using consistent operationalisations of interoceptive dimensions (accuracy, attention, beliefs, and insight) and using validated behavioural and self-report measures across studies to improve comparability. Including clinically severe and diverse populations, such as those recruited from secondary and tertiary services, would also strengthen generalisability. Finally, clarifying the translational relevance of interoceptive differences could involve examining whether these processes predict treatment response, act as mechanisms of change, or represent novel intervention targets. Such advances may guide the tailoring of treatments to individual interoceptive profiles and enhance therapeutic efficacy.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the University Research Ethics Committee, University of Southampton. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

LS: Writing – original draft, Visualization, Data curation, Formal Analysis, Conceptualization. SR: Formal Analysis, Writing – review & editing. MG: Writing – review & editing, Supervision. GP: Conceptualization, Supervision, Writing – review & editing, Formal Analysis, Methodology. JM: Methodology, Writing – review & editing, Supervision, Project administration, Conceptualization.

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Conflict of interest

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyt.2026.1769315/full#supplementary-material

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