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A novel self-report scale of interoception: the three-domain interoceptive sensations questionnaire (THISQ)

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ABSTRACT

Objectives: The self-reported perception of bodily sensations is assumed predictive for health and disease. Existing questionnaires mostly focus on aversive sensations, and associated emotions and cognitions, which potentially confounds associations between interoception and illness. Therefore, we developed the Three-domain Interoceptive Sensations Questionnaire (THISQ), assessing self-reported perception of neutral respiratory, cardiac, and gastroesophageal sensations.

Design: Using cross-sectional surveys, we developed and validated the THISQ.

Main Outcome Measures: In Sample 1 (n = 357), a pool of 28 Dutch items was subjected to exploratory factor analysis. Eighteen items with a primary factor loading >.40 were retained for confirmatory factor analysis in Sample 2 (n = 374) and Sample 3 (n = 484) for the validation of the Dutch and English questionnaire, respectively.

Results: Analyses supported the 3-factor solution: cardiorespiratory activation, cardiorespiratory deactivation, and gastroesophageal sensations. Scales showed acceptable to good internal consistency. Convergent validity was confirmed by significant medium associations between THISQ scores and other self-report measures of interoception. Divergent validity was supported by non-significant or small associations with measures of negative affectivity and symptom-related anxiety.

Conclusion: Our findings suggest that the Dutch and English THISQs are valid and reliable self-report measures of interoception, which could advance our understanding of interoceptive processes in health and disease.

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Interoception is considered to play a prominent role in physical and mental health and disease processes. Interoception is broadly defined as the conscious and unconscious 'processing of internal bodily stimuli by the nervous system', ranging from the mere observation and sensing of internal sensations to specific attention for internal sensations to the interpretation and self-report of the presence or intensity of bodily sensations, and discrimination between these (Khalsa et al., 2018, p. 501). To differentiate between distinct aspects of the umbrella construct of interoception, an empirical model has been introduced distinguishing between three dimensions of interoception: interoceptive accuracy, sensibility, and awareness (Garfinkel et al., 2015). Interoceptive accuracy refers to the extent to which a person's perception of their bodily state is accurate, i.e. matches objective measures of their bodily state, assessed, for example, by the degree to which perceived heart rate matches actual heart rate. Interoceptive sensibility refers to a person's beliefs of their internal state and interoceptive focus as measured by self-reports and questionnaires, assessing, for example, how frequently a person reports to pay attention to their heart pounding. Interoceptive awareness refers to the metacognitive insight into one's interoceptive capabilities, i.e. knowing whether you are interoceptively accurate or not, assessed, for example, by correlations between a person's accuracy in perceiving their heart rate and the confidence with which they estimated their heart rate. Recently, Murphy et al. (2019, 2020) proposed a refinement of this three-dimensional model by introducing a two-by-two factorial model, classifying interoception measures by (1) which interoceptive modality is measured: attention or accuracy, and (2) how interoception is measured: by objective performance measures or subjective, self-reported belief measures. This two-by-two model results in four types of interoceptive measurements: objective measures of interoceptive attention (e.g. whether a person pays attention to their heart rate), subjective measures of interoceptive attention (e.g. whether a person believes and reports to pay attention to their heart rate), objective measures of interoceptive accuracy (e.g. whether a person accurately perceives their heart rate), and subjective measures of interoceptive accuracy (e.g. whether a person believes and reports to accurately perceive their heart rate). In the remainder of the manuscript, we will use the term 'self-reported interoception' to refer to self-report scales or questionnaires of interoception (as defined by Khalsa et al., 2018).

Interoception, in all its dimensions, has been hypothesized to importantly contribute to functions and dysfunctions related to emotion regulation, cognition, symptom perception, and physical and mental health, including mood and anxiety disorders, eating disorders, and substance use disorders (Farb & Logie, 2018; Herbert & Pollatos, 2018; Khalsa et al., 2018; Khalsa & Lapidus, 2016; Tsakiris & Critchley, 2016). Related to different fields of research studying these (dys)functions, a wide range of validated questionnaires with good psychometric qualities exists to assess awareness of, attention to and perception of bodily sensations. These questionnaires include the Body Awareness Questionnaire (BAQ; Shields et al., 1989), the Body Awareness part of the Body Perception Questionnaire (BPQ; Porges, 1993), the Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2012, 2018), the Interoception Sensory Questionnaire (ISQ; Fiene et al., 2018), the Interoceptive Sensitivity and Attention Questionnaire (ISAQ; Bogaerts et al., in press), and the Interoceptive Accuracy Scale (IAS, Murphy et al., 2020). Although these various questionnaires are commonly considered as measures of the

same construct of interoception, all have been developed for different purposes, some not even designed to measure interoception. As a result, these questionnaires inherently measure different conceptualizations of interoception. For example, the BAQ has been developed to assess attention for normal, non-emotional, bodily processes (Shields et al., 1989). In contrast, the ISQ aims to specifically assess confusion about interoceptive states and deviations from normal (Fiene et al., 2018). The MAIA aims to assess self-reports of not only attention and awareness of interoceptive sensations, but also, physiological, cognitive, emotional, social and self-regulation processes related to interoception (Mehling et al., 2012, 2018). The ISAQ has been designed specifically to differentiate between awareness of neutral sensations and attention to negative bodily sensations (Bogaerts et al., in press). In contrast to the majority of questionnaires focusing on self-reported beliefs of attention and awareness of interoceptive sensations, the IAS was recently designed to assess self-reported beliefs of interoceptive accuracy specifically (Murphy et al., 2020).

Although these existing questionnaires are mostly valid measures of the constructs they aim to measure, and have contributed to a large body of interoception research, the variety of aims and foci of these questionnaires imposes important limitations on interoception research, which could potentially explain inconsistent findings in this field of research. For example, although all these questionnaires are commonly used to assess self-reported interoception, interoception scores derived from these questionnaires often show only small to medium correlations (e.g. correlations between ISQ and MAIA scores range from −0.15 to −0.28 (Fiene et al., 2018), correlations between BPQ and IAS scores are below .10 (Murphy et al., 2020) and correlations between MAIA subscales range from −0.01 to 0.52 (Mehling et al., 2012)). In what follows, we will systematically discuss the limitations of the current interoception questionnaires for research on health and disease, and propose a new measure of self-reported interoception: the Three-domain Interoceptive Sensations Questionnaire (THISQ). In response to the described limitations of the existing questionnaires, we will discuss how this new questionnaire, the THISQ, bypasses these limitations to contribute to new insights in interoception research.

A first limitation is that most of the existing self-report measures of interoception not only measure mere attention to or awareness of interoceptive sensations, but also assess, to more or less extent, cognitions beyond attention, and emotions. Especially the MAIA, consistent with its aims, assesses interoception-related cognitions including worry, trust, and self-regulation. In addition, interoception questionnaires often include assessments of emotional states related to bodily sensations (in the ISQ and MAIA), specific emotions of anger, happiness and joy (in the MAIA), affectionate touch (in the IAS) and jitteriness (in the BPQ). Including assessments of cognitions and emotions when measuring subjective perception of internal sensations could confound the role of self-reported interoception in cognition- and emotion-based pathologies (such as mood and anxiety disorders, eating disorders and substance use disorders), and symptom-related cognitions (e.g. worry, self-regulation) and emotions (e.g. distress and anxiety). For example, emotions assessed by interoception questionnaires in mood disorders, or overlapping content in interoception and emotion questionnaires in anxiety disorders may lead to spurious associations between interoception and disease states. In the same way, this may also distort the well-studied relationship

between interoception and emotion regulation in healthy persons, as shown by highly variable correlations between self-reported interoception (assessed by various questionnaires including more or less emotion content) and alexithymia, a construct reflecting deficits in emotion regulation abilities (e.g. Zamariola et al., 2018). The potential confounds between interoception and emotion (dys)regulation are particularly important given that both subclinical and clinical emotion dysregulation have been specifically associated with dysfunctional affective appraisal of interoceptive sensations, and thus self-reported interoception (Farb & Logie, 2018; Herbert & Pollatos, 2018). For these reasons, the new measure of self-reported interoception we propose, the THISQ, will focus on self-reported perception of neutral internal sensations that are not described as part of an emotional or cognitive state, and that are not inherently associated with strongly valenced emotions, and associated cognitions. For example, we will exclude sensations that are often present in existing interoception questionnaires such as hunger, thirst, discomfort, fatigue, exertion…

Second, most of the existing interoception questionnaires have a strong focus on the assessment of attention or awareness for strongly negatively valenced sensations or symptoms. For example, BAQ items refer to the flu, and MAIA, BPQ, ISAQ, ISQ and IAS items include pain (e.g. physical pain, chest, stomach and gut pain, headaches, muscle and throat soreness), injury and feelings of nausea, dizziness, bloatedness, breathing difficulty and shortness of breath. Although symptoms are inherently interoceptive sensations, recent models show that perception of symptoms may involve different processes than the perception of internal bodily sensations that are not symptoms (Van den Bergh et al., 2017). Consequently, a high number of symptom items in interoception questionnaires may distort an assessment of overall self-reported interoception, its relationship with symptom perception processes, and its role in health and disease. To avoid this, the THISQ will focus on self-reported perception of neutral internal sensations that are not symptoms. Therefore, sensations commonly present in existing questionnaires, such as pain, dyspnea, fatigue, soreness, injury, and bruising, will not be included in the THISQ.

Relatedly, internal bodily sensations that are a consequence of sympathetic activation are more often part of interoception questionnaires than internal sensations deriving from sympathetic deactivation or parasympathetic activation. For example, noticing fast breathing and deeper breaths, heart rate accelerations, tremor, bodily swelling, tension, and arousal are more often inquired on, compared to slow breathing, heart rate decelerations, and bodily calm. Yet, well-established models suggest that, in mental health disorders, and affective disorders specifically, deactivation or inhibition of activation, and the lack thereof, may be a more critical process than activation or reactivity (Friedman, 2007; Thayer & Friedman, 2002; Thayer & Lane, 2000). Therefore, in the development of the THISQ, we will balance items assessing sensations deriving from both sympathetic and parasympathetic activation. This allows a more comprehensive assessment of the associations between self-reported interoception and processes of health and diseases.

Third, all existing interoception questionnaires include items targeting a wide range of bodily systems evoking interoceptive sensations as described by Khalsa et al. (2018) (e.g. cardiovascular, respiratory, gastro-intestinal, hunger and thirst, hormonal, muscle, touch, nociceptive sensations…). This assumes interoception to be a unified construct across domains. However, research shows that correlations between self-reported measures of perception of various bodily domains are low. For example, very low

correlations were found between BAQ scores and subjective pain thresholds and taste perception (Ferentzi et al., 2017). The further exploration of associations and dissociations across interoceptive domains seems important as research suggests that perception of different interoceptive modalities (e.g. respiratory vs. pain, Lapidus et al., 2020) distinctively contribute to increased negative emotional self-reports in eating disorders, and mood and anxiety disorders (Lapidus et al., 2020). Accordingly, the THISQ will include three scales systematically assessing self-reported interoception in three separate domains: the respiratory, cardiac, and gastroesophageal domain. This allows to assess associations and dissociations between different domains of self-reported interoception, and their association with health and diseases processes. We chose these three domains specifically, since interoception in the respiratory, cardiac and gastroesophageal domain is studied in relation to a wide variety of physical and mental health and disease states (e.g. respiratory disease, cardiovascular disease, gastrointestinal disorders, neurological disorders, eating disorders, anxiety disorders, depression, functional syndromes; Aziz & Ruffle, 2018; Farb & Logie, 2018; Herbert & Pollatos, 2018; Khalsa et al., 2018; Yoris et al., 2018).

In summary, a variety of questionnaires used to assess interoception exist. However, these existing questionnaires assess broad interoception-related processes including cognitions, emotion regulation, and symptom perception. Moreover, currently, no questionnaire exists that systematically assesses self-reported interoception across different interoceptive domains. Therefore, this study aimed to develop a novel measure of self-reported perception of internal bodily sensations, the THISQ, which focuses on the perception of neutral sensations resulting from three bodily systems: the respiratory, cardiac, and gastroesophageal system. Self-reported interoception as assessed by the THISQ is defined as the self-reported awareness or observation of these sensations, assessed by the rate at which persons notice or feel (changes in) these internal bodily sensations. By assessing the 'noticing' and 'feeling' of sensations, we excluded interoceptive features such as discrimination, accuracy and attention, to avoid specific emotional or cognitive interpretations of sensations (similar to the BAQ and BPQ). To assess perception of sensations at varying levels of activation and deactivation of the respiratory and cardiac system without referring to emotions, symptoms or negative valence in general, respiratory and cardiac sensations were contextualized by different levels of physical activity. The current study documents the development of the THISQ and its items, as well as its validation in two languages: Dutch and English.

Method

This study consisted of three phases. For each phase, a different dataset was used (Table 1). Sample 1 (n = 357) was used for questionnaire development in Dutch, Sample 2 (n = 374) for questionnaire validation in Dutch, and Sample 3 (n = 484) for questionnaire validation in English.

Participants

Sample 1. Data were obtained from 357 first-year undergraduate psychology students (84.3% women; mean age = 18.26, SD = 1.33, range = 17–36). Respondents completed

Table 1. Overview of methods and procedures.

Sample	1	2	3
Source	Collective testing of first-year undergraduate psychology students	Prolific Academic	Prolific Academic
Language	Dutch	Dutch	English
N	357	374	484
% female	84.3	39	47.3
Mean age	18.26	28.87	26.99
Range age	17-36	18–73	18–45
Analysis	EFA	CFA, Test-retest reliability	CFA
Measures of convergent validity	BAQ, BPQ, MAIA, ISAQ	BAQ, BPQ, MAIA, ISAQ	BAQ
Measures of divergent validity	PANAS, STAI, ASI, CLQ, TAS-20	TAS-20	ASI

EFA = Exploratory Factor Analysis; CFA = Confirmatory Factor Analysis; BAQ = Body Awareness Questionnaire; BPQ = Body Perception Questionnaire; ISAQ = Interoceptive Sensitivity and Attention Questionnaire; MAIA = Multidimensional Assessment of Interoceptive Awareness; PANAS = Positive and Negative Affect Schedule; STAI = State-Trait Anxiety Inventory; ASI = Anxiety Sensitivity Index; CLQ = Claustrophobia Questionnaire; TAS-20 = Toronto Alexithymia Scale.

the THISQ together with a battery of other questionnaires in return for course credit during the collective session that took place at the start of academic year in 2018.

Sample 2. A total of 399 participants were recruited through the crowdsourcing platform Prolific Academic (www.prolific.co) in 2019. The study was open to respondents with an age of 18 years or older who reported proficient knowledge of Dutch. Participants were paid 3 GBP for completing a 20-minute survey. Respondents who failed to correctly answer at least one of two attention questions (e.g. 'Select the response "Very much"') were excluded from the analyses (n = 25, 6.3%), resulting in a final sample of 374 participants (39.0% women; mean age = 28.87, SD = 9.80, range = 18–73).

Sample 3. A total of 497 participants were recruited through the crowdsourcing platform Prolific Academic (www.prolific.co) in 2019. The study was open to respondents with an age of 18 years or older who reported proficient knowledge of English. Participants were paid 2 GBP for completing a 15-minute survey. Respondents who did not respond correctly to at least one of two attention questions (n = 13, 6.3%) were excluded from the analyses, resulting in a final sample of 484 participants (47.3% women; mean age = 26.99, SD = 7.06, range = 17–45).

Data collection in all samples was approved by the Social and Societal Ethics Committee, KU Leuven, Belgium.

Materials

Cronbach's alphas of all scales and subscales in the three samples are presented in Supplementary Table S3.

Three-domain Interoceptive Sensations Questionnaire (THISQ)**.** We developed an initial pool of 28 items describing the perception of neutral sensations in three bodily domains: the respiratory, cardiac, and gastroesophageal domain. For the purpose of this study, it was crucial that the items were phrased neutrally and did not refer to emotional states or physical symptoms. Items were described as 'noticing' or 'feeling'

sensations, or changes in sensations, to stay as close to 'perception' per se, and to avoid further interpretation of sensations as that might induce a context of valence, emotions or cognitions. For the respiratory and cardiac domains, the items referred to both activation (faster heart rate; deeper or faster breathing) and deactivation (slower heart rate; shallower or slower breathing), at different levels of physical activity (e.g. in response to increased physical activity or recovery from physical activity). Cardiac frequency, and respiratory frequency and depth are basic physiological parameters that lay people are familiar with in daily life (e.g. heart rate monitoring using wearables or slow and deep breathing as part of breathing techniques), and were therefore chosen. The gastroesophageal items comprised of sensations resulting from contractions of and movement in the esophagus, stomach and bowel. For each item, participants were asked to rate on a 5-point Likert scale how often each statement applied to them in their daily life (1 'never', 2 'occasionally', 3 'sometimes', 4 'usually', 5 'always'). The questionnaire was initially developed in Dutch and was subsequently translated to English using forward-backward translation procedure by two native speakers. Items were presented in random order.

Body Awareness Questionnaire (BAQ; Shields et al., 1989; Dutch ad hoc translation). The 18-item measure assessed self-reported attentiveness to non-emotive bodily processes. Participants were asked to respond to statements on a scale from 1 ('not at all true about me') to 7 ('very true about me'). Cronbach's alphas were .82 (Sample 1), .83 (Sample 2), and .84 (Sample 3).

Body Perception Questionnaire (BPQ; Porges, 1993; Dutch translation: Godefroid et al., 2015). The awareness subscale of this questionnaire included a list of bodily sensations, and participants were asked to rate their awareness of each sensation using a 5-point scale ranging from 1 ('never') to 5 ('always'). For this study, the very short form was used including 12 items. Cronbach's alphas were .86 (Sample 1) and .82 (Sample 2).

Interoceptive Sensitivity and Attention Questionnaire (ISAQ; Bogaerts et al., in press; validated in Dutch and English). This questionnaire consists of 17 statements measuring awareness of interoceptive stimuli on the 5-point Likert-type scale ranging from 1 ('strongly disagree') to 5 ('strongly agree'). It has three subscales: Sensitivity to Neutral Bodily Sensations, Attention to Unpleasant Bodily Sensations, and Difficulty Disengaging from Unpleasant Bodily Sensations. Cronbach's alphas ranged between .56 and .72.

Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2012; Dutch translation: Courtois, 2012). This 32-item questionnaire assesses multiple dimensions of interoception on a 6-point scale ranging from 0 ('never') to 5 ('always'). It includes eight subscales: Noticing, Not-Distracting, Not-Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, and Trusting. Cronbach's alphas ranged between .55 and .88.

Positive and Negative Affect Schedule (PANAS; Watson et al., 1988; Dutch validation: Engelen et al., 2006). This questionnaire measures to what extent respondents experience 10 positive and 10 negative emotions in general on a 5-point Likert scale ranging from 1 ('not at all') to 5 ('very much'). Cronbach's alphas in Sample 1 were .86 for positive affect (PA) and .79 for negative affect (NA).

State-Trait Anxiety Inventory–Trait Scale (STAI; Spielberger et al., 1983; Dutch validation: Van der Ploeg et al., 2000). This 20-item questionnaire was used to measure trait

anxiety. It asks respondents to rate how they generally feel in response to statements describing anxiety, on a scale from 1 ('almost never') to 4 ('almost always'). Cronbach's alpha was .92 (Sample 1).

Anxiety Sensitivity Index-3 (ASI; Taylor et al., 2007; Dutch ad hoc translation). This measure assesses the fear of sensations of anxious arousal based on beliefs about their possible negative consequences. Participants rate 18 statements on a 5-item scale ranging from 0 ('very little') to 4 ('very much'). Cronbach's alphas were .87 (Sample 1) and .90 (Sample 3).

Claustrophobia Questionnaire (CLQ; Radomsky et al., 2001; Dutch validation: Van Diest et al., 2010). Fear of suffocations (FoS) was measured using the suffocation scale of the CLQ. Participants rate how fearful they would feel in each of the 14 situations that may induce suffocation fear on a 5-point scale ranging from 0 ('not at all fearful') to 4 ('extremely fearful'). Cronbach's alpha was .83 (Sample 1).

Toronto Alexithymia Scale (TAS; Bagby et al., 1994; Dutch translation: Kooiman et al., 2002). This 20-item questionnaire measures different facets of alexithymia and can be answered on a 5-point Likert scale ranging from 1 ('completely disagree') to 5 ('completely agree'), measuring three subscales: Difficulty Describing Feelings (DDF), Difficulty Identifying Feelings (DIF), and Externally-Oriented Thinking (EOT). Cronbach's alphas for the subscales and total score in the present samples ranged between .61 and .83.

Procedure

All samples completed the THISQ as well as other measures described above to test the construct validity of the THISQ (Table 1). Sample 1 completed all measured described above, Sample 2 completed the BAQ, BPQ, MAIA, ISAQ, and TAS-20, and Sample 3 completed the BAQ and ASI. To examine test-retest reliability, respondents of Sample 2 were invited to complete the THISQ for a second time (n = 286, 76.5% attrition rate, 41.6% women, mean age = 29.35, SD = 9.82, range = 18–66). The second administration occurred on average 26 weeks after the first administration (range 23–29 weeks).

Statistical analysis

Questionnaire development

To explore the factorial structure and to reduce the number of items in the set of 28 items, we performed an exploratory factor analysis (EFA) with an oblique rotation on data from Sample 1. When performing the EFA, a three-factor structure was initially expected, based on the fact that the items for the item pool were selected from three bodily domains (respiratory, cardiac, gastroesophageal). An exploratory factor analysis was conducted with MPlus 8 (Muthén & Muthén, 2017). The model was estimated with a robust mean- and variance-adjusted weighted least squares (WLSMV) procedure and GEOMIN oblique factor rotation. Parallel analysis (Horn, 1965) was conducted to select candidate factors. The final version of the questionnaire included the items with a primary factor loading >.40. We also aimed at achieving a balanced composition of domains (respiratory, cardiac, gastroesophageal) across factors and therefore included the same number of items for each domain, removing items that showed high overlap with other items.

Questionnaire validation in Dutch

Factor structure

Confirmatory Factor Analysis (CFA) was conducted with MPlus 8 (Muthén & Muthén, 2017) on data from Sample 2 to test a 3-factor model of the THISQ resulting from the EFA on Sample 1. WLSMV was used for estimation. The model fit was evaluated with descriptive fit measures, such as the root mean square error of approximation (RMSEA) and the comparative fit index (CFI) as well as modification indices. Following the recommendations of (Hooper et al., 2008; Hu & Bentler, 1999), at least two indices were required to exceed the following cutoff criteria: CFI ≥.90; RMSEA ≤.06; Tucker-Lewis index (TLI) ≥.95; standard root mean square residual (SRMR) ≤.08.

Reliability and validity

Reliability analyses, based on Cronbach's α, for THISQ total scores and subscores of the resulting factors were conducted in STATA 15 (Stata Corp, College Station, TX). Construct validity was examined by means of correlations between THISQ scores and the other relevant self-report measures. To investigate convergent validity, we correlated THISQ scores with other measures of self-reported interoception: the BAQ, BPQ, MAIA, and ISAQ. To study divergent validity, we correlated THISQ scores with self-report measures assessing affective responses in daily life (PANAS, TAS-20) and symptom-related processes (ASI, CLQ, DCS). For those analyses, the data from the two datasets using Dutch language versions (Samples 1 and 2) were merged. Test-retest reliability was evaluated using a Pearson correlation between the THISQ scores at the two time points of administration.

Questionnaire validation in English

Factor structure

CFA was performed on Sample 3 to test a 3-factor model (i.e. the model resulting from the EFA in Sample 1 and tested with CFA in Sample 2) of the English version of the THISQ. The model fit was evaluated as above.

Reliability and validity

Reliability and validity were examined as above. For convergent validity, we correlated THISQ scores with BAQ scores, and for divergent validity, we correlated THISQ scores with ASI scores.

Results

Questionnaire development

Exploratory factor analysis

First, an EFA with an oblique rotation was run for all 28 items on data from Sample 1. Parallel analysis suggested 5 factors. However, the inspection of factors showed that the 5-factor solution consisted of many cross-loadings, and led to less interpretable factors and factors consisting of fewer than 2 items (see Supplementary Table S1 for

Table 2. Factor loadings of the THISQ.

Item (item number)	F1	F2	F3
When I make a light physical effort, I notice that my breathing is faster than normal (4).	.78		
When I am moderately physically active I feel that my heart beats fast (17).	.75		
During a moderately intense physical effort, I feel that I breathe fast and deep (5).	.71		
I notice when my heart is racing (18).	.66		
During a light physical effort, I feel my heart beat (16).	.61		
I notice when I pant (6).	.41		
When I relax, I feel that my breathing slows down (3).		.74	
When I come to rest, I feel my heart rate slow down (14).		.74	
When I am relaxed, I notice that my heart rate is slow (13).		.72	
When I feel well-rested, I notice that I breathe slowly (1).		.65	
When I rest after a physical effort, I feel my heart rate decrease (15).		.57	
Before I fall asleep, I feel that my breathing is slow and deep (2).		.50	
I feel when my bowels contract (8).			.84
I notice when bowel contents move through my bowels (9).			.78
I feel when my stomach contracts (7).			.55
When I eat or drink something warm, I feel the heat in my oesaphagus after swallowing (12).			.54
When I swallow food, I feel it move through my oesophagus (10).			.53
When I eat or drink something cold, I feel the cold in my oesaphagus after swallowing (11).			.50

F1 = Cardiorespiratory Activation; F2 = Cardiorespiratory Deactivation; F3 = Gastroesophageal Sensations.

the 5-factor solution). The next best solution was the 3-factor solution resulting in three interpretable factors without cross-loadings and sufficient items per factor: (1) Cardiorespiratory Activation, (2) Cardiorespiratory Deactivation, and (2) Gastroesophageal Sensations. Based on aforementioned criteria, i.e. a primary factor loading >.40 and a balanced composition of domains (respiratory, cardiac, gastric) across factors, a total of 18 factors were retained, with 6 factors per domain. The retained items with factor loadings of the 3-factor solution are listed in Table 2. Factor loadings for all 28 items can be found in Supplementary Table S2.

Questionnaire validation in Dutch

Factor structure

CFA was performed on Sample 2 data to test the model with 3 factors resulting from the EFA analysis above: Cardiorespiratory Activation, Cardiorespiratory Deactivation, and Gastroesophageal Sensations. Items included in the model are presented in Table 2. Standardized factor loadings of the Dutch version of the THISQ are shown in Figure 1. The model fit of this model was acceptable, $\chi^2(132) = 403.10$, $p < .001$, CFI = .92; RMSEA = .07; 90% CI [.07, .08]); TLI = .90; SRMR = .06. Two indices (CFI and SRMR) met the aforementioned requirements.

Reliability and validity

Cronbach's alphas for THISQ total scores were .85 (Sample 1) and .83 (Sample 2), for Cardiorespiratory Activation .76 (Sample 1) and .72 (Sample 2), for Cardiorespiratory Deactivation .84 (Sample 1) and .82 (Sample 2), and for Gastroesophageal Sensations .73 (Sample 1) and .72 (Sample 2).

Table 3. Descriptive statistics and correlations between the factors of Three-Domain Interoceptive Sensations Questionnaire (THISQ) and other self-report measures.

				THISQ			
Measure	Mean	SD	N	THISQ total score	Cardio-respiratory activation	Cardio-respiratory deactivation	Gastro-esophageal sensations
THISQ							
Cardiorespiratory activation	21.42	4.07	731				
Cardiorespiratory deactivation	18.44	5.00	731		.39***		
Gastroesophageal sensations	16.18	4.47	731		.38***	.35***	
THISQ total score	56.04	10.34	731		.75***	.79***	.75***
Convergent validity							
BAQ – Body awareness	3.84	0.86	731	.38***	.22***	.33***	.30***
BPQ – Body perception	39.18	8.39	731	.41***	.33***	.32***	.30***
ISAQ – Sensitivity to neutral bodily sensations	27.73	5.03	731	.47***	.30***	.43***	.35***
ISAQ – Attention to unpleasant bodily sensations	14.66	2.90	731	.23***	.26***	.14***	.15***
ISAQ – Difficulty disengaging from unpleasant bodily sensations	12.37	2.82	731	−.03	.01	−.07	−.01
MAIA – Noticing	3.28	0.82	731	.43***	.32***	.40***	.26***
MAIA – Not-distracting	2.04	0.95	731	−.02	.04	−.04	−.03
MAIA – Not-worrying	3.08	0.98	731	−.06	−.08*	.04	−.11**
MAIA – Attention regulation	2.87	0.84	731	.28***	.11**	.31***	.19***
MAIA – Emotional awareness	3.11	0.98	731	.38***	.23***	.38***	.26***
MAIA – Self-regulation	2.55	1.01	731	.26***	.04	.37***	.16***
MAIA – Body listening	2.36	1.16	731	.31***	.11**	.33***	.25***
MAIA – Trust	3.38	1.14	731	.06	−.04	.13***	.01
Divergent validity							
PANAS – Positive affect	32.87	5.45	348	.02	−.06	.09	.02
PANAS – Negative affect	24.31	7.04	348	.06	.14**	−.05	.07
STAI – Trait anxiety	44.72	10.35	348	.01	.09	−.08	.04
ASI – Anxiety sensitivity	16.56	10.21	348	.13*	.16**	.01	.16**
CLQ – Fear of suffocation	7.54	6.64	348	.07	.10	.01	.07
TAS-20 – Difficulty describing feelings	14.81	4.19	731	.05	.10**	.00	.02
TAS-20 – Difficulty identifying feelings	18.29	5.31	731	.07	.13***	−.05	.09*
TAS-20 – Externally oriented thinking	19.90	4.11	731	−.14***	−.11**	−.09*	−.12**

SD = standard deviation; BAQ = Body Awareness Questionnaire; BPQ = Body Perception Questionnaire; ISAQ = Interoceptive Sensitivity and Attention Questionnaire; MAIA = Multidimensional Assessment of Interoceptive Awareness; PANAS = Positive and Negative Affect Schedule; STAI = State-Trait Anxiety Inventory; ASI = Anxiety Sensitivity Index; CLQ = Claustrophobia Questionnaire; TAS-20 = Toronto Alexithymia Scale.
*$p < .05$; **$p < .01$; ***$p < .001$.

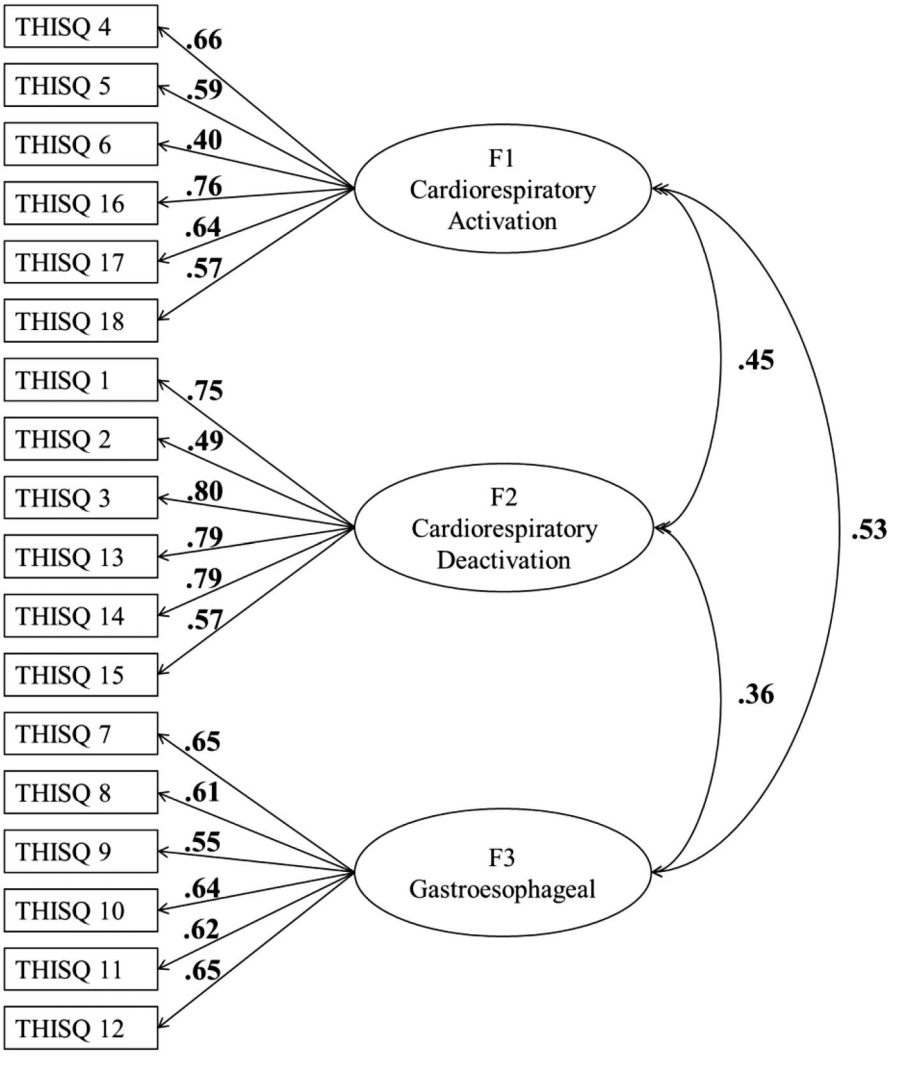

Figure 1. Standardized factor loadings from a three-factor model of the Dutch version of the Three-domain Interoceptive Sensations Questionnaire (THISQ). All loadings are significant at $p < .001$.

Table 3 shows the results of content validity of the THISQ. Concerning convergent validity, THISQ scores were significantly associated with conceptually related measures of self-reported interoception measured with the BAQ, BPQ, ISAQ, and MAIA. The associations with the majority of measures were small to medium (Table 3, e.g. for the THISQ total score, $.23 < rs < .46$, $p < .01$) with exception of the following scales, for which associations with THISQ scores were non-significant or small: the ISAQ subscale Difficulty Disengaging and the MAIA subscales Not Worrying, Not Distracting and Trust (all $rs < .13$). With regard to divergent validity, the THISQ scores showed mostly non-significant or small ($rs < .16$) associations with measures of emotionality, general and breathlessness-related anxiety, and alexithymia (Table 3). The highest associations were found with the Cardiorespiratory Activation subscale (*rs* between −.11 and .16).

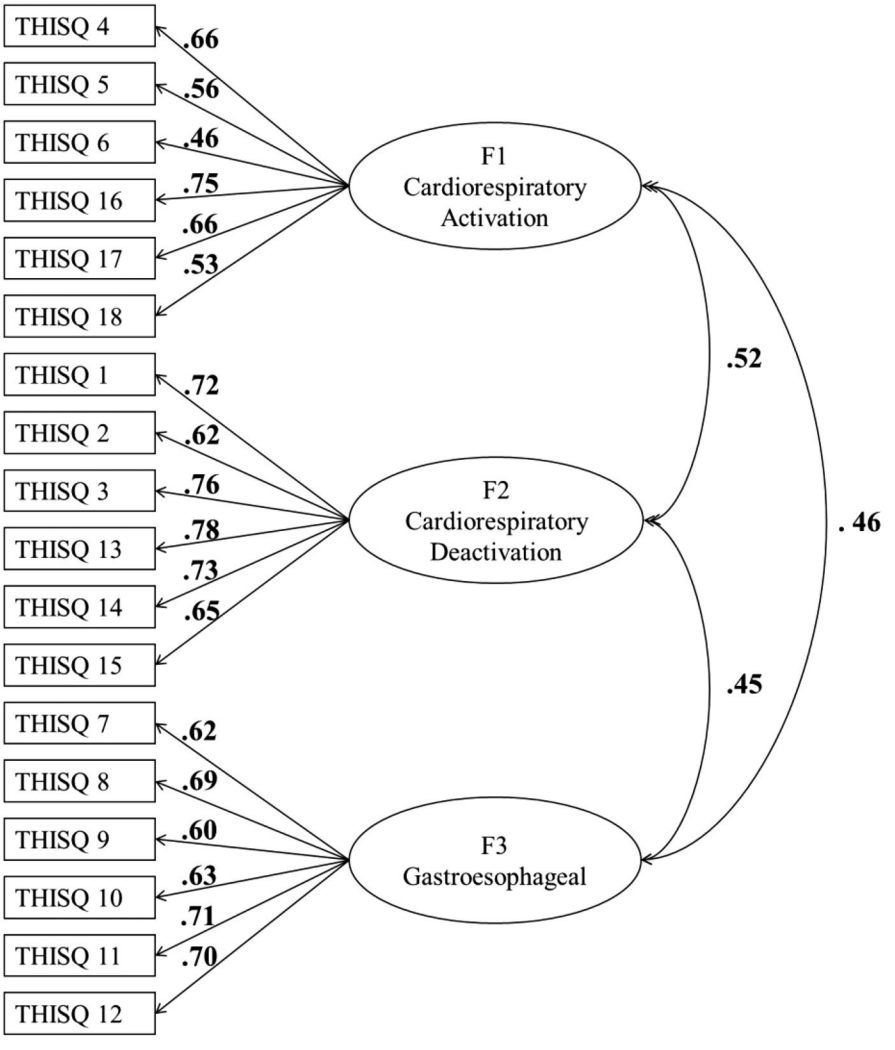

Figure 2. Standardized factor loadings from a three-factor model of the English version of the Three-domain Interoceptive Sensations Questionnaire (THISQ). All loadings are significant at $p < .001$.

Finally, test-retest reliability was calculated for the THISQ total score and subscores (time interval between test and retest: mean 26 weeks, range 23–29 weeks). The correlations between two administrations were large ($rs > .50$): for the total score, $r(284) = .63$, $p < .001$, Cardiorespiratory Activation score, $r(284) = .50$, $p < .001$, Cardiorespiratory Deactivation score, $r(284) = .57$, $p < .001$, and Gastroesophageal Sensations score, $r(284) = .64$, $p < .001$.

Questionnaire validation in English

Factor structure

The factor structure of the English version was investigated with CFA on data from Sample 3 testing a model with three factors: Cardiorespiratory Activation,

Table 4. Descriptive statistics and correlations between the factors of the English version of Three-Domain Interoceptive Sensations Questionnaire (THISQ) and other self-report measures.

				THISQ			
Measure	Mean	SD	N	THISQ total score	Cardio-respiratory activation	Cardio-respiratory deactivation	Gastro-esophageal sensations
THISQ							
Cardiorespiratory activation	21.81	3.88	484				
Cardiorespiratory deactivation	18.66	5.06	484		.41***		
Gastroesophageal sensations	17.00	4.68	484		.38***	.38***	
THISQ total score	57.48	10.53	484		.74***	.80***	.77***
Convergent validity							
BAQ – Body awareness	4.31	0.90	484	.34***	.18***	.35***	.25***
Divergent validity							
ASI – Anxiety sensitivity	28.61	13.82	348	.24***	.25***	.09*	.24***

SD = standard deviation; BAQ = Body Awareness Questionnaire; ASI = Anxiety Sensitivity Index.
*$p < .05$; **$p < .01$; ***$p < .001$.

Cardiorespiratory Deactivation, and Gastroesophageal Sensations. Items included in the model are presented in Table 2. Standardized factor loadings of the English version of the THISQ are shown in Figure 2. The model fit of this model was marginally acceptable, $\chi^2(132) = 622.37$, $p < .001$, CFI = .89; RMSEA = .09; 90% CI [.08, .10]); TLI = .87; SRMR = .06. One of the indices (SRMR) met the aforementioned requirements, whereas CFI approached the required cutoff score.

Reliability and validity

The Cronbach's alpha coefficient value for the English version of the THISQ total score was .84, .71 for Cardiorespiratory Activation, .82 for Cardiorespiratory Deactivation, and .75 for Gastroesophageal Sensations.

Table 4 shows the results of content validity of the English version of the THISQ. Concerning convergent validity, the THISQ scores were significantly associated with BAQ scores, which is a conceptually related measure of self-reported interoception. However, associations were small to medium (Table 4), with the highest associations observed for the Cardiorespiratory Deactivation subscale, $r = .35$, $p < .001$. With regard to divergent validity, the THISQ scores showed small associations ($rs < .25$) with ASI, which is a measure of anxiety related to sensations of anxious arousal. Those associations were higher than in the Dutch sample. It should be noted that this sample had also higher ASI scores compared to the Dutch sample (mean ASI Dutch sample = 16.56, mean ASI English sample = 28.61).

Discussion

The present study aimed to validate a new questionnaire, the Three-Domain Interoceptive Sensations Questionnaire (THISQ), assessing self-reported perception of neutral bodily sensations derived from three specific bodily systems: the cardiac, respiratory, and gastroesophageal system. The final version of the 18-item questionnaire in Dutch and English showed acceptable to good validity and reliability.

The aim of the questionnaire was to assess perception of bodily sensations focusing on the mere awareness and sensing of neutral internal sensations in three interoceptive domains, independent of cognitions and emotions associated with these sensations. In order to do so, we carefully selected neutral internal sensations, excluding negatively valenced sensations, physical symptoms or complaints, pain and discomfort, and sensations that are often perceived as unpleasant, such as hunger, thirst, or fatigue, for example. Measures of convergent validity confirm that THISQ scores correlated moderately with other measures of non-emotional interoceptive attention and awareness, such as the BAQ, Awareness of Bodily Sensations of the ISAQ and the Noticing scale of the MAIA, for example. In contrast, measures of divergent validity confirm that THISQ scores correlated only to a small degree with scales assessing emotional and cognitive processes related to interoception, and not or to a small degree with measures of affect, fear, anxiety, and emotion regulation. Altogether, these results suggest that the THISQ successfully assesses perception of neutral internal sensations. This allows future research to study self-reported interoception beyond symptom perception and emotion regulation processes, and the role of 'mere' interoception in symptom perception and emotion regulation.

We developed three separate scales, assessing perception of cardiac, respiratory and gastroesophageal sensations, with both activation and deactivation items for the cardiac and respiratory scales. Although we anticipated a three-factor solution consisting of these three domains, the three-factor solution resulting from the factor analysis revealed a different structure, consisting of Cardiorespiratory Activation, Cardiorespiratory Deactivation and Gastroesophageal Sensations, and medium correlations between these three factors were found (ranging from 0.35 to 0.41). Based on the factor analysis, it is clear that the association between cardiac and respiratory items was larger than between activation and deactivation. This may not be surprising, since a strong cardiorespiratory coupling exists in the autonomic nervous system, both structurally and functionally, while activation versus deactivation of cardiorespiratory activity is regulated via different branches of the autonomic nervous system (Dick et al., 2014; Garcia et al., 2013). This cardiorespiratory coupling implies a consistent joint activation of the cardiac and respiratory system, which may reinforce the shared subjective awareness of cardiac and respiratory sensations. These findings are in part consistent with significant correlations between interoceptive dimensions of related bodily systems (such as gastric and taste perception; Ferentzi et al., 2018). However, no associations were found between cardiac and respiratory interoceptive accuracy (Garfinkel et al., 2016; Van Den Houte et al., 2021). This illustrates that associations or dissociations between interoceptive domains may depend on the interoceptive dimension that is measured (e.g. self-reported interoception vs. interoceptive accuracy). Research systematically investigating associations or dissociations in self-reported interoception between domains and associations or dissociations between interoceptive dimensions within one domain is rather scarce. The THISQ provides an important innovation to further this research. Despite the fact that the factor solution of the THISQ did not result in the three anticipated domains of cardiac, respiratory and gastroesophageal sensations, Supplementary Table S3 shows that the internal consistency of each scale is good and Supplementary Tables S4 and S5 illustrate the correlations between the cardiac, respiratory and gastroesophageal subscales and measures of convergent and divergent validity.

We intentionally created a balance in activation and deactivation items for the cardiac and respiratory scale. The highest correlations between emotion questionnaires and the THISQ, although low, were found for the Cardiorespiratory Activation factor. This is not surprising as emotions (assessed by these specific emotion questionnaires) are related to autonomic arousal, which demonstrates that it is particularly difficult to completely disentangle interoceptive sensations and emotional states. This shows, for example, in common sensations present in the Cardiorespiratory Activation scale (e.g. 'I notice when my heart is racing') and some items of the anxiety questionnaires (e.g. 'I am anxious when my heart beats faster' in the ASI). In addition, since deactivation closely relates to downregulation, it is not unexpected that not Cardiorespiratory Activation, but instead Cardiorespiratory Deactivation correlates moderately with interoception subscales of the MAIA, such as Attention Regulation (e.g. 'I can maintain awareness of my inner bodily sensations even when there is a lot going on around me'), Emotional Awareness (e.g. 'I notice that my body feels different after a peaceful experience'), Self-Regulation (e.g. 'When I feel overwhelmed I can find a calm place inside'), and Body Listening (e.g. 'When I am upset, I take time to explore how my body feels'). Although most interoception questionnaires focus on activation and reactivity of the autonomic nervous system, assessing perception of increases in heart rate and respiration, also deactivation or inhibition of activation is considered to be a critical disease process (Friedman, 2007; Thayer & Friedman, 2002; Thayer & Lane, 2000). Therefore, the two separate scales of Cardiorespiratory Activation vs. Deactivation may allow future research to investigate how these interoceptive dimensions differentially contribute to biological disease processes and subjective symptom perception.

Consistent with other studies (Ferentzi et al., 2018; Murphy et al., 2020), we found a strong test-retest reliability of self-reported interoception. For example, whereas Ferentzi et al. (2018) found a correlation of 0.73 for BAQ scores between two time points over a 2-month period, and Murphy et al. (2020) found correlations of 0.75 and 0.68 for IAS and BPQ, respectively, over a 1-month period, we found a correlation of 0.63 (for the THISQ total score, and $r > 0.50$ for subscores) between two time points over a 6-month period. This suggests temporal stability of self-reported interoception assessed by the THISQ.

Situating the THISQ in current models of interoception, the THISQ items assess the frequency with which persons notice, sense or feel (changes in) internal bodily sensations, and thus focus on the awareness and observation of internal bodily sensations. It does not, however, assess the magnitude, discrimination, accuracy or metacognitive insight of interoception (Khalsa et al., 2018). The THISQ thus partly assesses interoceptive sensibility, the subjective perception of internal bodily sensations (Garfinkel et al., 2015), yet not the tendency to focus on internal bodily sensations (Garfinkel et al., 2015; Khalsa et al., 2018). Positioning the THISQ in the two-by-two factorial model (Murphy et al., 2019), the THISQ assesses self-reported interoception and can thus be categorized in the subjective measurement modality of interoception. However, it does not explicitly assess interoceptive accuracy, nor interoceptive attention. THISQ items are formulated as 'feeling' or 'noticing' sensations in specific contexts, targeting the actual perception of internal sensations, as interoception is defined. The THISQ items are not subjective evaluations of whether one pays attention to these sensations, nor of whether one perceives these sensations accurately.

Despite the merits of this study, some limitations need to be discussed. First, the factor structure fit of the Dutch THISQ is somewhat better than that of the English version. For the Dutch THISQ, two of the fit indices of the confirmatory factor analysis met the formal criteria, whereas for the English THISQ, one index met the formal criteria whereas one other marginally met the criteria. However, indications of reliability and convergent and divergent validity are good. Also, the questionnaires supporting convergent and divergent validity of the English THISQ are too limited to sketch broader associations with interoception related processes. Second, the factor structure of the THISQ emerging from the EFA, and thus the input for the CFAs, is based on a Dutch speaking, young, mostly female, student sample. In addition, the samples of the Dutch and English validation differ in anxiety sensitivity (mean ASI = 16.56, 28.61, respectively). Third, while we aimed to disentangle emotions and cognitions from interoceptive sensations, and our results of divergent validity showed that we were relatively successful in doing so, we cannot exclude potential top-down emotional and cognitive modulation during the interpretation of the items. In addition, intricate relationships exist between autonomic arousal associated with interoceptive sensations and autonomic arousal associated with emotional states, which may contribute to correlations between THISQ items and emotions. Fourth, the THISQ only assesses self-reported interoception of sensations from three bodily systems. Future questionnaires could include sensations deriving from a wider variety of bodily systems. In addition, by excluding symptoms and interoceptive sensations inherently associated with emotions and cognitions, and by limiting perception to the noticing and feeling of sensations, to meet the aims of the new questionnaire, the THISQ only assesses a subset of sensations and features that are considered as interoceptive by the broad definition of interoception (Khalsa et al., 2018).

In conclusion, the THISQ provides an alternative measure of the self-reported sensing of interoceptive sensations resulting from the gastresophageal and cardiorespiratory system, independent of cognitive, emotional and strongly negatively valenced properties of these sensations. Therefore, this questionnaire allows further investigation of new perspectives on the role of interoceptive processes in health and disease.

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Data availability statement

Data are made available here: DOI 10.17605/OSF.IO/FA86S.

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