What Do Measures of Self-Report Interoception Measure?

Insights from A Systematic Review, Latent Factor Analysis, and Network Approach

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Abstract

Recent conceptualizations of interoception suggest several facets to this construct, including "interoceptive sensibility" and "self-report interoceptive scales", both of which are assessed with questionnaires. Although these conceptual efforts have helped move the field forward, uncertainty remains regarding whether current measures converge on their measurement of a common construct. To address this question, we first identified -via a systematic review- the most cited questionnaires of interoceptive sensibility. Then, we examined their correlations, their overall factorial structure, and their network structure in a large community sample (n = 1003). The results indicate that these questionnaires tap onto distinct constructs, with low overall convergence and interrelationships between questionnaire items. This observation mitigates the interpretation and replicability of findings in self-report interoception research. We call for a better match between constructs and measures.

Keywords: Interoception, interoceptive sensibility, exploratory factor analysis, network analysis.

What Do Measures of Self-report Interoception Measure? Combining Latent Factor and Network Approaches

Interoception is the processing of internal bodily states by the nervous system (Khalsa et al., 2017). It is essential for survival as it allows the nervous system to be informed about physiological needs and maintain homeostasis (Craig, 2015). Interoception is thought to play a crucial role in emotional identification (Craig, 2004) and regulation (Füstös et al., 2013) as well as in various other psychological phenomena (e.g., decision-making and body ownership; Tsakiris et al., 2011), therefore potentially explaining associations between interoceptive abilities and mental health (anxiety and depression; e.g., Paulus & Stein, 2010; Pollatos et al., 2008). As a result, interoception is also seen as a relevant candidate for clinical interventions.

At the conscious level, different dimensions of interoception have been proposed. Until 2015, the taxonomy for these dimensions varied a lot between researchers. Based on this observation, Garfinkel and colleagues (2015; 2013) proposed a three-dimensional model of interoception. This model, which has quickly been broadly endorsed by the scientific community (i.e., 388 citations of Garfinkel, 2015, in the Scopus database on January 26, 2021), encompasses three dimensions that can be defined as follows.

Interoceptive accuracy is the capacity to detect accurately and track internal sensations; it is assessed by behavioral performance measures. *Interoceptive sensibility* is the self-reported tendency to focus on internal sensations and the capacity to detect them. *Interoceptive awareness* is the correspondence between objective interoceptive accuracy and self-report; it represents the degree to which interoceptive accuracy is predicted by subjective confidence in one's behavioral performance. With this conceptualization, Garfinkel and colleagues' main goal was to distinguish between objective, subjective, and "metacognitive" interoceptive processes.

Recently, a panel of interoception experts have formulated another taxonomy of interoception comprising eight features (Khalsa et al., 2017). This new proposition includes additional features of interoception and therefore, includes complementary measures (e.g., the perceived intensity of internal signals) that were excluded from the previous conceptualization. Among the eight features, two refer to self-report interoceptive processes. *Interoceptive sensibility* is defined as the self-perceived tendency to focus on interoceptive stimuli. According to Khalsa and colleagues (2017), this construct is well captured by the Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2012, 2018). *Interoceptive self-report scales* are defined as "the ability to reflect upon one's autobiographical experiences of interoceptive states, make judgments about their outcomes, and describe them through verbal or motor responses" (Khalsa et al., 2017). According to these authors, many measures may underly this dimension such as the Visceral Sensitivity Index (VIS; Labus et al., 2007), the Body Awareness Questionnaire (BAQ; Shields et al., 1989), the Body Perception Questionnaire (BPQ; Porges, 1993), and the MAIA (Mehling et al., 2012, 2018).

Although Garfinkel et al. (2015) and Khalsa et al. (2017) should be commended for their conceptual efforts, three important comments are in order here. First, these conceptualizations do not exactly ascribe the same meaning to "interoceptive sensibility". In Khalsa et al. (2017), the self-reported capacity to detect internal signals is removed from the "interceptive sensibility" construct. Hence, it is important to note that the same label relates to different understandings in the two taxonomies, which may prevent good communication between researchers.

Second, there has been a recent tendency to assign an ever-growing number of questionnaires to the “interoceptive sensibility” (as defined by Garfinkel et al., 2015) construct. Specifically, while “interoceptive sensibility” was initially restricted to the self-perceived ability to detect internal signals and the tendency to focus on them, it now additionally covers many other interoceptive-related (but perhaps distinct) features of interoception (e.g., the trust given to internal sensations, tendency to focus on internal sensations, awareness of symptoms, capacity to predict disease from symptoms, emotional awareness). Prominent self-report questionnaires of interoceptive sensibility include the MAIA (Mehling et al., 2012, 2018), the BPQ (Porges, 1993), the BAQ (Shields et al., 1989), or the Eating Disorder Inventory (EDI; Gardner, 1991; Garner et al., 1985).

Third, and directly relevant to the current research, no study has tested yet whether responses to these questionnaires empirically tap onto a common construct. To address this question, we first performed a systematic review to identify the most frequently cited questionnaires of *interoceptive sensibility* or *interoceptive self-report scales*. Second, we ran exploratory factor analysis and network analysis on these questionnaires after completion by a large sample of respondents. The latent factor analysis allowed us to explore the factors underlying these questionnaires and to probe if it is empirically justified to assume one common factor. The network analysis examined interrelationships between the different questionnaires' items and tested whether the distinct questionnaires' items cohere as a unitary network or whether they constitute distinct communities (or subnetworks) of nodes.

Systematic review

Method

This systematic review was conducted with CADIMA and in accordance with PRISMA guidelines (Moher et al., 2009).

Preregistration and data sharing

The systematic review was preregistered at https://osf.io/fzreh/.

Eligibility criteria

We only included articles that identified interoception questionnaire(s) as measure(s) of interoceptive sensibility (Garfinkel et al., 2015; Khalsa et al., 2017) and interoceptive self-report scales (Khalsa et al., 2017). This means that included articles should not necessarily have administered the questionnaire (e.g., they cited a given questionnaire in their introduction), but instead, have merely named (and possibly also administered) it. No other restriction was made.[1]

Search strategy

A systematic literature search (see *Table S1* in Supplementary Materials for the search strategy) was performed by the first author on PubMed, Scopus, PsychINFO, and ScienceDirect from April 2015—the date of publication of Garfinkel et al.'s (2015) study— to September 12, 2020, by restricting to peer-reviewed English papers. The following keywords were entered: ("interoceptive sensibility" or "interoceptive self-report scales") and ("questionnaire" or "inventory" or "scale" or "rating" or "instrument"). The term “interoceptive self-reported scales”, proposed by Khalsa et al. (2017), was never used.

Study selection

Titles, abstracts, and full texts were screened by the first author.

Data collection process

The first author extracted the title, the reference, the questionnaire(s) identified as measure(s) of interoceptive sensibility or interoceptive self-report scales, and the endorsed definition (Garfinkel et al.’s one vs Khalsa et al.’s one)[2]. The outcome of interest was the frequency with which each questionnaire had been cited in the selected studies.

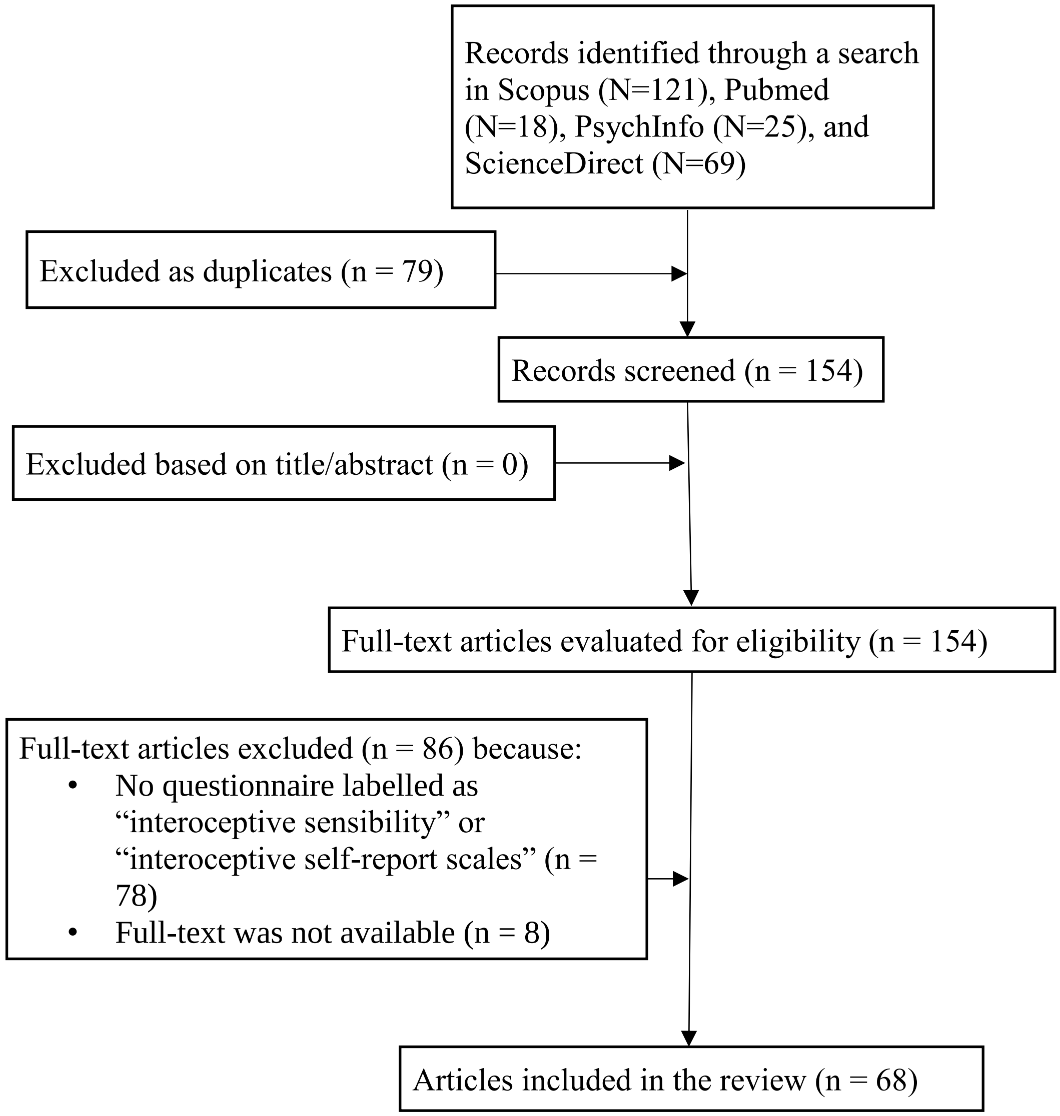
Results

[1] Note that we did not consider the questionnaires of studies included in meta-analyses and systematic reviews to avoid double-counting. This criterion was not pre-registered, as we did not anticipate this problem.
[2] This variable was not pre-registered. However, during the data extraction, we noticed that interoceptive sensibility was either conceptualized as Khalsa et al.’s (2017) or Garfinkel et al.’s (2015) definition.

Selection process

Figure 1

Flow diagram



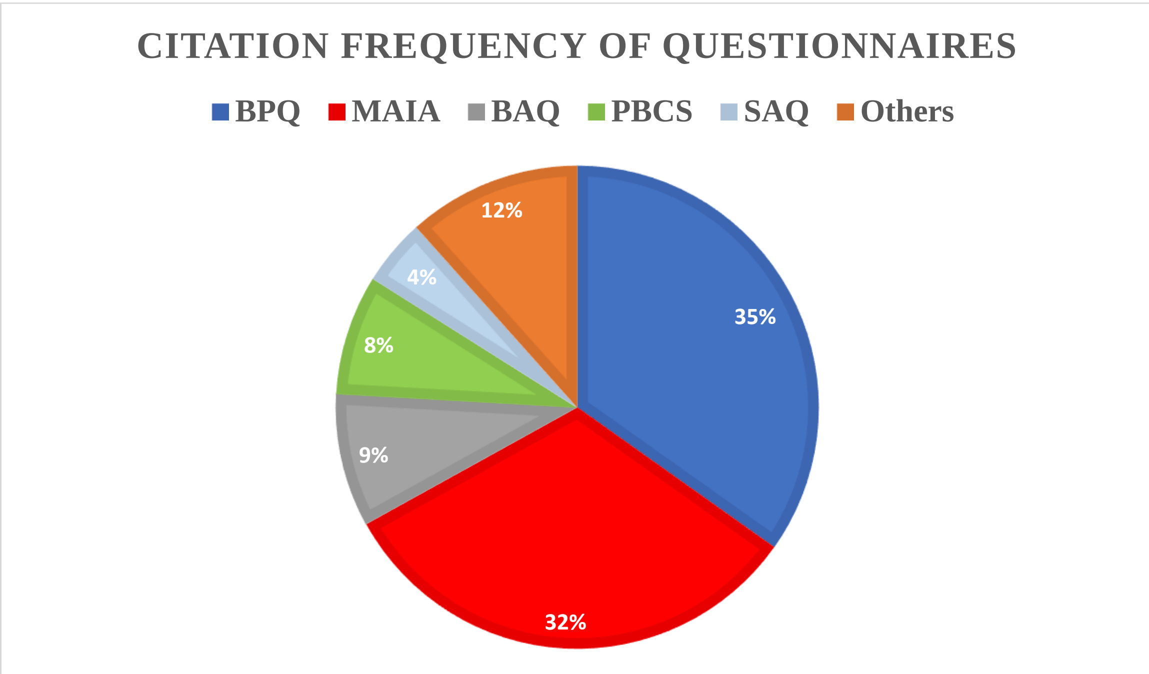
Synthesis of results

The results of individuals studies have been summarized in *Table S2* in the Supplementary Materials. Sixty-eight studies met the inclusion criteria. Fourteen questionnaires were identified: BPQ (34%), MAIA (32%), BAQ (9%), Private subscale of the Body

Consciousness Questionnaire (PBCS; 8%; Miller et al., 1981), Self-Awareness Questionnaire (SAQ; 3.5%; Longarzo et al., 2015), EDI (0.03%), Body Sensations Questionnaire (0.02%; Chambless et al., 1984), Five Facet Mindfulness Questionnaire (0.01%; Baer et al., 2006), Emotional Susceptibility Scale (0.01%; Caprara et al., 1985), Autonomic Perception Questionnaire (0.01%; Mandler & Uviller, 1958), Visceral Sensitivity Index (0.01%; Labus et al., 2007), Body Vigilance Scale (0.01%; Schmidt et al., 1997), Somatic Absorption Scale (0.01%; Köteles et al., 2012), Interoceptive Awareness Questionnaire (0.01%; Bogaerts et al., 2020). *Figure 2* shows the citation frequency of questionnaires.

Figure 2

Citation frequency of questionnaires



Legend. Others: EDI, Body Sensations Questionnaire, Five Facet Mindfulness Questionnaire, Emotional Susceptibility Scale, Autonomic Perception Questionnaire, Visceral Sensitivity Index, Body Vigilance Scale, Somatic Absorption Scale, Interoceptive Awareness Questionnaire.

Factor and Network Analyses

Method

Preregistration and data sharing

The study design, data collection, and analysis plan were preregistered at https://osf.io/fzreh/. Our R code and de-identified data are available at https://osf.io/e2ax7/files/.

Participants

We recruited 1003 participants (M_{age} = 35.57, SD_{age} = 12.77) on Prolific. There were 60.3% of women (N = 605), 39.6% of men (N = 397) and 0.001% of other (N = 1). Participants were from different ethnicity: Asian or Pacific Islander (7.78%), Black or African American (4.09%), Hispanic or Latino (1%), Native American or Alaskan Native (0%), White or Caucasian (81.65%), multiracial or biracial (4.29%), and others (1.49%). Participants had to (1) be between 18 and 70 years old, (2) have English as their first language, (3) live in the UK, Ireland, USA, Canada, or Australia[3], (4) be free of current mental conditions, and (5) be free of any chronic diseases (e.g., diabetes, heart disease, stroke).

Materials and Procedure

We expected that participants may experience fatigue and would be at risk of routine questionnaire completion in case the task was too long. Therefore, we selected only the most frequently used questionnaires of interoceptive sensibility or interoceptive self-report scales (as identified in the systematic review). The task was pre-tested for the duration. The presentation order of questionnaires, and the presentation order of items within questionnaires, were randomized.

[3] This criterion was not pre-registered. Given that Prolific includes, by default, many countries around the world, we thought it was important to restrict our study to English-speaking countries and ensure that participants had a sufficient level of English to correctly understand the items.

Statistical analyses

Outliers detection and handling. Multivariate outliers[4] were detected via Mahalanobis Distance larger than the critical chi-square value for df=the number of DVs at alpha=.001 (Mahalanobis, 1936).

Factor analysis. Exploratory Factor Analysis (EFA) was performed with *psych* (Revelle, 2020) and *GPArotation* (Jennrich, 2014) R packages. We first performed Bartlett's Test of Sphericity (Bartlett, 1954) and Kayser-Meyer-Olkin's (which should be above 0.7; Kaiser, 1970, 1974) test to verify correlation and sample adequacy with factor analysis. An oblique rotation (i.e., oblimin) was applied as we expected correlations between factors. The model was estimated with maximum likelihood (ML) as our data were normally distributed (Costello & Osborne, 2005; Goretzko et al., 2019). To decide the number of factors extracted, we used the Kaiser Criterion (Kaiser, 1960), Scree Plot, parallel analysis (Horn, 1965), the comparison data (CD) approach (Ruscio & Roche, 2012), and the interpretability of factors. Results coming from these different methods were compared to reach a final decision. We also achieved a simple structure by running several rounds of analyses after having removed items that do not load (r >.30) on any factor and items that load on more than one factor. Finally, we also computed reliability statistics (i.e., Cronbach's alpha) and fit indices (i.e., the goodness of fit and residual statistics) including the Tucker-Lewis index (TLI), comparative fit index (CFI), root mean square error of approximation (RMSEA), and root means square of the residual (RMSR).

Network analysis

[4] Although we initially planned to identify univariate outliers (i.e., values greater/smaller than three times the interquartile), we dispensed with it since this approach is not optimal for ordinal variables as their values are constrained from 1 to n and thus, no answer can generally be considered as an outlier (Riani et al., 2011).

Network estimation. We present a graphical Gaussian model (GGM) that was regularized via the graphical LASSO (Least Absolute Shrinkage and Selection Operator) algorithm (Friedman et al., 2015), which has two main goals. First, it estimated regularized partial correlations between pairs of nodes, thereby excluding spurious associations (or edges) resulting from the influence of other nodes in the network. Second, it shrunk trivially small associations to zero, thus removing possibly "false positive" edges from the model and returning a sparser network including only the strongest edges (Epskamp et al., 2018). We did so via the R package *qgraph* (Epskamp et al., 2012, 2018), which automatically implements the graphical LASSO regularization in combination with Extended Bayesian Information Criterion (EBIC) model selection (Foygel & Drton, 2011). In this procedure, 100 models with varying degrees of sparsity are estimated; a final model is selected according to the lowest EBIC value, given a specific hyperparameter gamma (γ), which regulates the trade-off between including false-positive edges and removing true edges. The hyperparameter γ can be set between 0 (favoring a model with more edges) and 0.5 (promoting a simpler model with fewer edges). Following recent recommendations (e.g., Epskamp et al., 2018), we set γ to 0.5 to be confident that our edges are true. To assess the accuracy of the edge weights, we implemented a nonparametric bootstrapping procedure (with 1,000 bootstrapped samples with replacement) to bootstrap the edge weights' confidence regions using the R package bootnet (Epskamp et al., 2018). Using a bootstrapped difference test (Epskamp et al., 2018), we also examined whether the edge weights significantly differed from one another.

Centrality estimates. To quantify each node's importance in the regularized GGM, we computed the expected influence centrality indices (Robinaugh et al., 2016). This centrality index quantifies the cumulative importance of each node and describes the sum of the edge weights attached to this node, considering both positive and negative values (Robinaugh et al., 2016). Hence, higher values indicate greater centrality in the network and so greater importance (McNally, 2016). The plot represents the raw expected influence value of each node. The stability of this metric's estimates was assessed using the case-dropping subset bootstrap procedure (Costenbader & Valente, 2003), with 1,000 bootstrapped samples. In this procedure, the correlation between the original centrality indices and the centrality indices as obtained from smaller subsets, with up to 75% of participants dropped, is assessed. To quantify the stability of the indices, we also calculated the centrality stability correlation coefficient (CS-coefficient). The CS-coefficient represents the maximum proportion of participants that can be dropped to maintain, with a 95%-probability, a correlation with the original centrality indices of at least .70. A minimum CS-coefficient of .25 (and preferably of at least .50) is recommended for interpreting centrality indices (Epskamp et al., 2018). Capitalizing on this case-dropping subset bootstrap procedure, we performed a bootstrapped difference test (Epskamp et al., 2018) to examine whether nodes significantly differ from one another in terms of expected influence.

Community detection. We investigated the GGM's community structure—that is, whether nodes (i.e., items) cohere as a unitary network structure or whether they cluster into distinct communities of nodes by implementing the Spinglass modularity-based community detection algorithm (Reichardt & Bornholdt, 2006). As in previous studies (Heeren et al., 2018; Robinaugh et al., 2014), we chose this algorithm given its suitability for revealing the community structure of signed networks, i.e., networks including both positive and negative edge weight values (Traag & Bruggeman, 2009; Yang et al., 2016). We implemented this algorithm using the *spinglass.community* function of the R package *igraph* (Csardi & Nepusz, 2006).

Following previous studies (e.g., Everaert & Joormann, 2019; Heeren et al., 2020), we also identified important nodes that may serve as bridges between the resultant communities by computing the bridge expected influence of each node. Bridge expected influence reflects the sum of all edges that exist between a given node and the nodes in the other communities. To do so, we relied on the bridge function of the R package *networktools* (Jones et al., 2019). The plot represents the raw expected influence value of each node. As with the expected influence, the stability of the bridge centrality indices was assessed using a case-dropping subset bootstrap procedure and the computation of the related CS-coefficient. We likewise performed a bootstrapped difference test (Epskamp et al., 2018) to examine whether nodes significantly differ from one another in terms of bridge expected influence.

Results

Internal consistency of questionnaires

Internal consistency was excellent for BPQ (α = 0.96) and SAQ (α = 0.93), good for MAIA (α = 0.88) and BAQ (α = 0.88), and almost acceptable for PBCS (α = 0.69). This last relatively low Cronbach's alpha can be explained by the small number of items (n = 5). Overall, the internal consistency of questionnaires, therefore, suggests that our data are reliable.

Correlation between questionnaires

We first tested the bivariate correlation for each pair of questionnaires. We found correlations ranging from r = 0.03 to 0.55 (see *Table 1*). These correlations were surprisingly low for questionnaires that should measure the same construct (see Discussion).

Table 1

Pearson correlations between total scores of questionnaires.

	BPQ	MAIA	BAQ	PBCS	SAQ
BPQ	-				
MAIA	0.21*	-			
BAQ	0.26*	0.55*	-		
PBCS	0.35*	0.34*	0.41*	-	
SAQ	0.48*	0.03	0.14*	0.32*	-

* < .001

Factor analysis

An exploratory factor analysis (EFA) was used to investigate the underlying factors in these questionnaires. One hundred and twenty-six multivariate outliers were detected and removed based on the Mahalanobis distance.[5] Multivariate assumptions (i.e., additivity, normality, linearity, homogeneity, and homoscedasticity) were met. No missing data was found. KMO test (*MSA* = 0.95) and Barlett's test ($X^2(7260) = 54387.39$, $p < .001$) indicated a good sampling and correlation adequacy, respectively.

The number of factors to extract depended on the factor retention criterion. The Scree Plot, Kayser criterion, comparison data approach, and the parallel analysis suggested 5 or 6, 8, 9, and 11 factors, respectively. We thus tried to extract each of these solutions and selected the most interpretable one. The 8, 9, and 11-factor solutions[6] were particularly difficult to interpret. In particular, the seventh to eleven factors had very few items loading on only one factor, rendering the factor solution particularly difficult to interpret. For instance, the eighth factor comprised items related to the trustworthiness of body sensations and the awareness of the dryness of mouth or throat. The 5 and 6-factor solutions were much more interpretable. For ease of interpretability, we thus selected the 6-factors solution.

Next, we tried to achieve a Very Simple Structure (VSS) by removing items that did not load ($r < 0.30$) on any factor or that loaded on several factors. We thus removed 13 items. The final solution was the following (see *Table 2*)[7]:

[5] Analyses were performed with and without outliers. Similar conclusions were reached with outliers. Data and R codes for analyses with outliers can be found at https://osf.io/e2ax7/files/. Outputs are available upon request.
[6] The 9 and 11-factor solution did not converge with the *oblimin* rotation. We thus performed a *promax* rotation.
[7] Factor labels were chosen based on our content analysis.

- Factor 1 – *Neutral and Negative Body Sensations Awareness*: It included all items (i.e., 26) of the BPQ that assesses awareness of neutral and uncomfortable bodily sensations (e.g., “During most situations I am aware of watering or tearing of my eyes).
- Factor 2 – *Functional Interoceptive Processes*: It included 24 (out of 37) items from the MAIA assessing the functional relationship with body sensations. In particular, (1) the capacity to notice and focus on uncomfortable, comfortable, and neutral body sensations (e.g., “I notice where in my body I am comfortable” and “I can pay attention to my breath without being distracted by things happening around me”), (2) the capacity to regulate distress by attention to body sensations, (3) active listening to the body for insight (e.g., “when I feel overwhelmed I can find a calm place inside”), and (4) experience of one’s body as safe and trustworthy (e.g., “I feel my body is a safe place”).
- Factor 3 – *Negative feelings propensity*: It included 32 (out of 35) items from the SAQ assessing the frequency with which one feels uncomfortable, painful, or symptomatic bodily sensations (e.g., “I feel a pain that seems to migrate around the body”)
- Factor 4 – *Extero-Interoceptive Awareness*: It included 17 (out of 18) items from the BAQ assessing the capacity to notice and predict body reactions to internal and external factors such as weather, seasons, foods, blows, diseases (e.g., the flu), and energy level (e.g., “I can accurately predict what time of day lack of sleep will catch up with me”).
- Factor 5 – *Interoceptive Not-Distracting*: It included 6 (out of 37) items from the MAIA assessing the tendency not to ignore or distract oneself from sensations of pain or discomfort (e.g., “I try to ignore pain” [reversed]).

- Factor 6 – *Interoceptive Worrying:* It was negatively correlated to 3 (out of 37) items from the MAIA assessing the tendency not to worry about uncomfortable body sensations (e.g., "I start to worry that something is wrong if I feel any discomfort" [reversed]).

Table 2

6-Factor Model Standardized Loadings.

Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
BPQ_1	**0.72**	0.01	0.07	0.06	0.03	-0.04
BPQ_2	**0.72**	-0.02	-0.03	-0.07	-0.06	-0.02
BPQ_3	**0.74**	-0.01	0.01	0.01	-0.01	0.00
BPQ_4	**0.63**	0.10	0.12	0.02	0.05	0.02
BPQ_5	**0.80**	-0.04	-0.05	-0.02	-0.03	0.02
BPQ_6	**0.64**	-0.05	0.00	0.03	-0.05	0.08
BPQ_7	**0.73**	0.00	0.00	0.04	0.02	-0.04
BPQ_8	**0.80**	-0.04	-0.13	-0.04	-0.04	0.05
BPQ_9	**0.67**	-0.01	0.11	0.08	0.02	-0.05
BPQ_10	**0.61**	0.02	0.03	0.05	0.05	0.09
BPQ_11	**0.57**	0.15	0.15	0.04	0.02	-0.08
BPQ_12	**0.76**	0.04	-0.07	-0.03	0.01	0.02
BPQ_13	**0.75**	-0.07	0.02	-0.01	-0.07	0.07
BPQ_14	**0.70**	-0.12	0.00	0.05	-0.02	0.14
BPQ_15	**0.68**	0.08	0.05	0.01	0.08	-0.06
BPQ_16	**0.76**	0.02	-0.08	-0.05	-0.01	-0.04
BPQ_17	**0.66**	0.13	0.11	-0.03	0.08	-0.10
BPQ_18	**0.66**	0.00	-0.03	-0.02	-0.01	-0.02
BPQ_19	**0.62**	0.06	0.08	0.05	-0.02	-0.10
BPQ_20	**0.53**	0.07	0.05	0.05	0.02	-0.14
BPQ_21	**0.67**	-0.05	0.07	0.01	-0.01	0.08
BPQ_22	**0.70**	0.11	-0.02	0.01	0.01	-0.10
BPQ_23	**0.60**	-0.06	0.11	0.01	-0.04	0.08
BPQ_24	**0.75**	0.01	0.03	0.01	-0.02	-0.02
BPQ_25	**0.61**	0.07	0.12	-0.03	0.10	0.12
BPQ_26	**0.75**	-0.06	-0.06	0.03	0.01	0.03
MAIA_1	0.07	**0.43**	-0.02	0.13	-0.05	0.15
MAIA_3	0.07	**0.52**	-0.05	0.11	-0.04	0.16
MAIA_4	0.13	**0.39**	0.09	0.03	0.01	0.18
MAIA_5	0.00	0.09	-0.03	-0.07	**0.64**	0.05
MAIA_6	0.02	-0.23	0.00	0.06	**0.58**	-0.05
MAIA_7	-0.05	-0.09	0.04	-0.08	**0.64**	0.03
MAIA_8	0.02	0.07	-0.04	0.00	**0.76**	0.08

MAIA_9	-0.03	-0.22	-0.02	0.02	**0.56**	-0.09
MAIA_10	-0.03	-0.23	-0.07	0.07	**0.52**	-0.11
MAIA_11	-0.02	-0.05	-0.10	-0.03	-0.04	**-0.53**
MAIA_12	-0.13	-0.07	-0.04	0.00	-0.03	**-0.54**
MAIA_15	-0.08	0.00	-0.09	-0.04	-0.03	**-0.47**
MAIA_16	-0.02	**0.67**	0.02	0.00	-0.05	-0.14
MAIA_17	0.08	**0.63**	0.09	0.05	0.03	0.02
MAIA_18	0.00	**0.46**	0.01	0.06	-0.07	-0.07
MAIA_19	0.04	**0.71**	0.05	-0.07	-0.10	0.00
MAIA_20	0.01	**0.69**	0.06	0.06	-0.03	-0.03
MAIA_21	0.00	**0.56**	-0.01	0.11	-0.16	-0.05
MAIA_22	0.01	**0.69**	0.01	0.04	-0.06	0.03
MAIA_23	0.04	**0.36**	0.05	0.14	-0.02	0.26
MAIA_25	0.02	**0.48**	0.00	0.11	-0.04	0.27
MAIA_26	0.05	**0.46**	-0.05	0.13	-0.05	0.24
MAIA_27	0.00	**0.50**	0.04	0.20	0.03	0.29
MAIA_28	-0.09	**0.72**	-0.03	-0.02	-0.05	-0.10
MAIA_29	-0.02	**0.62**	0.01	0.11	-0.02	0.05
MAIA_30	0.02	**0.65**	0.02	0.00	-0.02	-0.10
MAIA_31	0.03	**0.72**	0.01	-0.04	0.02	-0.08
MAIA_32	0.00	**0.50**	0.03	0.17	0.05	0.28
MAIA_33	0.01	**0.59**	0.13	0.05	0.07	0.17
MAIA_34	0.04	**0.58**	-0.03	0.13	0.01	0.18
MAIA_35	-0.03	**0.53**	-0.22	0.06	-0.01	-0.09
MAIA_36	0.02	**0.59**	-0.17	0.03	-0.05	-0.11
MAIA_37	0.08	**0.57**	-0.18	0.11	-0.08	0.06
BAQ_1	0.05	0.03	0.05	**0.51**	-0.07	0.19
BAQ_2	0.05	-0.06	0.00	**0.49**	0.00	0.03
BAQ_3	0.02	0.00	-0.02	**0.50**	-0.11	0.06
BAQ_4	0.02	0.06	0.09	**0.56**	-0.02	0.09
BAQ_5	-0.02	0.01	0.10	**0.47**	-0.01	0.03
BAQ_6	0.00	0.07	0.01	**0.47**	-0.04	-0.06
BAQ_7	0.00	0.02	-0.08	**0.57**	-0.02	-0.05
BAQ_8	-0.05	-0.02	0.04	**0.70**	-0.02	-0.11
BAQ_9	-0.01	0.13	0.02	**0.60**	-0.03	-0.03
BAQ_11	-0.01	0.03	0.04	**0.64**	0.02	-0.04
BAQ_12	0.04	0.01	0.03	**0.52**	0.08	-0.07
BAQ_13	0.02	-0.04	0.02	**0.53**	-0.10	0.14
BAQ_14	0.04	0.03	0.07	**0.42**	-0.04	0.11
BAQ_15	0.02	0.08	-0.11	**0.59**	0.09	-0.08
BAQ_16	0.03	0.10	-0.05	**0.65**	0.03	-0.03
BAQ_17	0.02	-0.01	-0.09	**0.54**	0.05	-0.02
BAQ_18	0.06	-0.06	0.02	**0.49**	-0.02	0.14
SAQ_1	0.04	0.00	**0.49**	0.02	-0.06	-0.02
SAQ_2	0.07	0.02	**0.49**	-0.01	0.12	0.14

SAQ_3	-0.01	0.11	**0.55**	-0.07	0.04	0.01
SAQ_4	0.03	0.00	**0.46**	0.05	-0.04	-0.04
SAQ_5	-0.02	0.07	**0.58**	0.03	0.00	-0.08
SAQ_6	0.01	-0.09	**0.63**	0.07	0.02	0.00
SAQ_7	0.02	0.06	**0.61**	-0.04	0.00	0.08
SAQ_8	0.02	-0.03	**0.48**	-0.03	-0.09	-0.04
SAQ_9	0.01	-0.07	**0.47**	0.13	0.00	0.08
SAQ_10	0.01	-0.09	**0.43**	0.04	-0.11	0.08
SAQ_11	0.06	-0.07	**0.48**	-0.06	-0.10	0.00
SAQ_12	0.05	-0.06	**0.59**	-0.04	-0.08	0.05
SAQ_13	-0.02	0.11	**0.58**	-0.08	0.06	0.07
SAQ_15	0.11	-0.13	**0.42**	0.08	-0.12	0.11
SAQ_16	-0.02	0.08	**0.63**	0.02	0.04	-0.12
SAQ_17	0.01	0.05	**0.62**	0.01	-0.01	-0.06
SAQ_18	0.05	-0.02	**0.58**	-0.04	-0.07	0.09
SAQ_20	0.18	-0.12	**0.38**	0.04	-0.08	0.02
SAQ_21	0.05	0.02	**0.61**	-0.05	0.03	-0.05
SAQ_22	0.15	-0.12	**0.39**	-0.01	-0.08	0.08
SAQ_24	0.03	-0.10	**0.59**	0.06	-0.05	-0.04
SAQ_25	0.10	-0.05	**0.50**	0.03	-0.03	0.05
SAQ_26	-0.03	0.02	**0.68**	-0.05	-0.02	0.09
SAQ_27	0.03	0.07	**0.60**	-0.08	0.08	0.11
SAQ_28	0.08	-0.04	**0.48**	0.08	-0.06	0.10
SAQ_29	-0.10	0.02	**0.68**	0.08	0.01	-0.07
SAQ_30	-0.04	-0.08	**0.67**	0.04	-0.06	0.04
SAQ_31	0.09	0.08	**0.52**	0.01	0.03	-0.11
SAQ_32	0.07	0.05	**0.60**	-0.05	0.03	-0.04
SAQ_33	0.01	-0.04	**0.57**	0.04	0.00	-0.02
SAQ_34	0.20	0.05	**0.38**	-0.01	0.00	-0.03
SAQ_35	0.03	-0.04	**0.63**	0.00	0.03	-0.07

Legend. Items' labels are available in *Table S3* in Supplementary Materials.

Then, we tested the internal reliability of each factor and computed the fit indices of the 6-factor solution. The reliability was excellent for Factors 1 (α = 0.96), 2 (α = 0.94), and 3 (α = 0.94), good for Factor 4 (α = 0.89) and 5 (α = 0.81), and acceptable for Factor 6 (α = 0.73). The 6-factor model had moderate fit. The RMSR and RMSEA indicated excellent fit at 0.03 and 0.035 (90% *CI*[0.035, 0.036]), respectively. However, CFI (0.87) and TLI (.85) were not good enough.

Network analysis

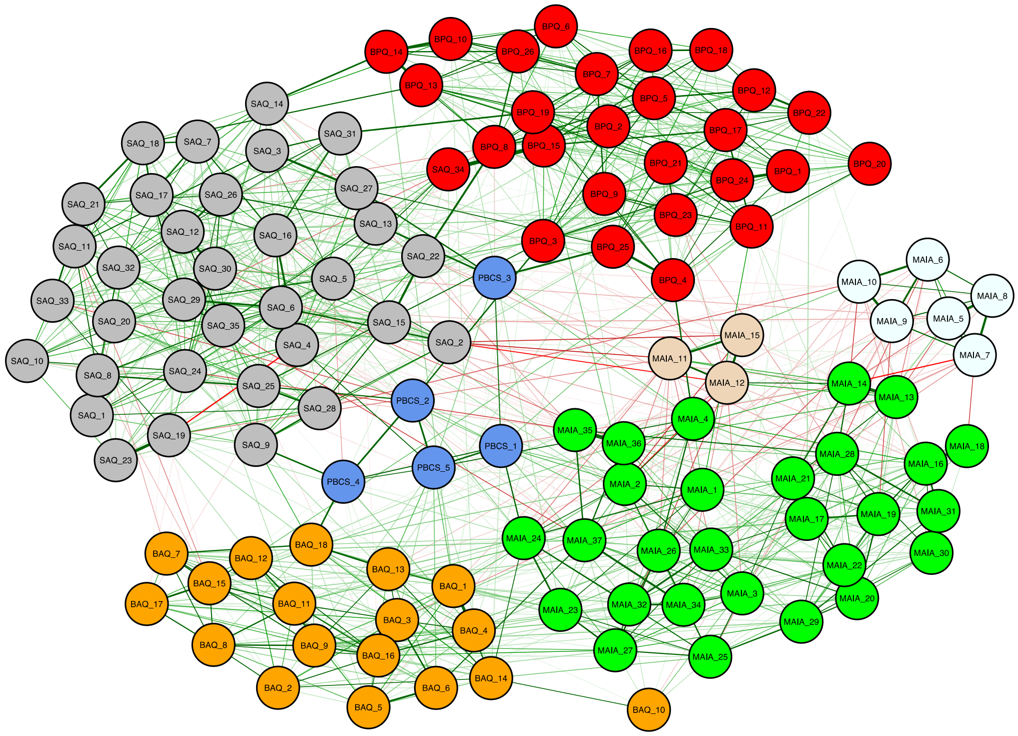
GGM. *Figure 3* shows the estimated GGM network wherein edges represent regularized partial correlations between nodes (i.e., the items). The thickness of the edge denotes the strength of the association, with a thicker edge indicating a larger association. Green edges represent positive regularized partial correlations, whereas red ones represent negative regularized partial correlations. The force-directed Fruchterman and Reingold's (1991) layout algorithm was used to visualize the network, which pulls nodes with the strongest associations nearer to the center of the graph.

Several features were immediately apparent. First, the thickest edges were noticeable between items coming from the same questionnaire. For instance, there were many strong associations between nodes denoting SAQ's items or BPQ's items. The only exception was BAQ_10 (the only reversed item of the BAQ), which was barely connected to the other BAQ's items but showed a few thin associations with MAIA's items. Second, most of the thinnest edges were between items of different questionnaires. For instance, only a few thin edges connected SAQ's nodes to BAQ's nodes and MAIA's nodes to BPQ's nodes. The only thick edge denoting a cross-questionnaire association was between SAQ_34 ("I feel my palms sweaty") and BPQ_15 ("During most situations, I am aware of palms sweating"). Third, six MAIA's items (i.e., MAIA_5; MAIA_6; MAIA_7; MAIA_8; MAIA_9; MAIA_10) emerged as a distinct cluster of nodes that were connected via negative edges to the other items of the MAIA. These items refer to the tendency not to ignore or distract oneself from sensations of pain or discomfort (e.g., “I try to ignore pain” [reversed]). Finally, three MAIA’s items (i.e., MAIA_11, MAIA_12, and MAIA_15) formed another distinct cluster of nodes that all allude to not worrying about uncomfortable body sensations (e.g., “I start to worry that something is wrong if I feel any discomfort” [reversed]).

The nonparametric bootstrapping procedure showed that the bootstrapped CIs for the edge-weights were small (see *Figure S1* in the Supplementary Materials), thus indicating that they were fairly accurate).

Figure 2

Graphical Gaussian model and community detection



Note. The thickness of an edge reflects the magnitude of the association (the thickest edge representing a value of .46). Items ' labels are detailed in *Table 3* in Appendices. Node's color reflects the community structure (see the Community detection analysis).

Centrality estimates. BPQ_13 ("During most situations, I am aware of stomach and gut pains"), BPQ_14 ("During most situations, I am aware of stomach distension or bloatedness"), BPQ_15 ("During most situations, I am aware of palms sweating"), and SAQ_27 ("I feel my heart thudding") were the nodes yielding the highest expected influence values (values are provided in *Figure S*2 in the Supplementary Materials). In contrast, BAQ_10 ("I don't notice seasonal rhythms and cycles in the way my body functions" [Reversed]), MAIA_11 ("When I feel physical pain, I become upset" [Reversed]), and MAIA_12 ("I start to worry that something is wrong if I feel any discomfort" [Reversed]) were the nodes with the lowest expected influence values.

Case-dropping subset bootstrap indicated the stability of this centrality metric in the present sample (see *Figure S3* in the Supplementary materials). The CS-coefficient was .52. The bootstrapped different test confirmed that SAQ_27, BPQ_13, BPQ_14, and BPQ_15 were significantly more central than the remaining nodes.

Community detection. The spinglass algorithm detected 7 communities ("subnetworks") of nodes. The communities are represented by distinct colors in *Figure 3*. The first community (i.e., red nodes in *Figure 3*) comprised all the BPQ's items and the item SAQ_34. The second community (i.e., orange nodes in *Figure 3*) comprised all the BAQ items. The third community (i.e., blue nodes in *Figure 3*) comprised all the PCBS items. The fourth community (i.e., grey nodes in *Figure 3*) consisted of all the SAQ items except the SAQ_34. The fifth community consisted of the MAIA_5, MAIA_6, MAI_7, MAIA_8, MAIA_9, and MAIA_10 (i.e., light blue nodes in *Figure 3*). The sixth community included the MAIA_11, MAIA_12, and MAI_15 (i.e., sandy tan nodes in *Figure 3*). The seventh community included the remaining MAIA's items: from MAIA_1 to MAIA_4 and from MAIA_16 to MAIA_37 (i.e., green nodes in *Figure 3*).

The bootstrapped different test revealed that PBCS_3, SAQ_34, BPQ_25, PBCS_2, BPQ_3, and SAQ_14 yielded significantly higher bridge expected value than the remaining nodes (see *Figure S5* and *Figure S6* in the Supplementary materials). The case-dropping subset bootstrap procedure confirmed the stability of this metric (see *Figure S3* in the Supplementary materials) and the CS-coefficient was .51.

Discussion

The main question we sought to address in the present research was whether various questionnaires thought to measure interoceptive sensibility (and "interoceptive self-report scales") do indeed measure a common construct. To do so, we (1) identified in a systematic review the most frequently cited questionnaires of interoceptive sensibility, and we (2) examined their correlations, (3) their overall factorial structure, and (4) their network structure. In the general discussion, we summarize the main results and discuss their implications for the interpretation and replicability of the findings in interoception research. We also discuss future directions for interoception research.

What are the most frequently mentioned questionnaires and their inter-relations?

The first aim was to identify the most frequently mentioned interoceptive sensibility questionnaires. Our systematic review indicated that no less than 14 different questionnaires have been identified to measure interoceptive sensibility. Among them, five (BPQ, MAIA, BAQ, SAQ, and PBCS) cover 86.5% of all citations of interoceptive sensibility questionnaires. Correlational analyses revealed inexistent to moderate associations between these questionnaires (range from $r = 0.03$ to 0.55). This finding casts preliminary doubts on the assumption that the most frequently cited questionnaires of interoceptive sensibility measure a common construct. Even a correlation of 0.55 does not reach satisfactory measurement convergence (that should be above 0.70; Carlson & Herdman, 2012), and this may be consequential (see below).

Self-report interoception: A single dimension?

Another central question was to test whether the items from the different “interoceptive sensibility” questionnaires assess a single dimension. Both the factor and the network approaches supported the existence of one factor/community per questionnaire except for the MAIA, which appeared to be underpinned by 3 factors. The PBCS was removed from the final factor solution because its items loaded on several factors. However, the network approach identified the PBCS as a subnetwork, although some of its items (e.g., "I am sensitive to internal bodily tensions » [PBCS_1]; I can often feel my heart beating [PBCS_3]) show strong associations with items belonging to a different questionnaire (see the results of the bridge centrality analysis). These results, therefore, suggest that the various questionnaires measure different constructs that cannot be subsumed under a common conceptual umbrella. In short, interoception researchers wrongly assume that they work on the same construct when they use or compare responses on different questionnaires (i.e., a jingle fallacy).

What are the consequences for the reliability and validity of results?

This is most concerning for the interpretation and the replicability of findings in interoception research. The current analysis suggests that results found with one specific measure (e.g., BPQ) are unlikely to be replicated with another measure (e.g., BAQ), given the low correlations between questionnaires and the presence of at least one factor/community by questionnaire. Carlson and Herdman (2012) have indeed mathematically demonstrated that, if two measures (a and b) correlate to $r_{a,b} = 0.50$ and the first measure (a) correlates with an outcome (y) to $r_{a,y} = 0.30$, the correlation between the second measure (b) and this outcome (y) can range from $r_{b,y} = -0.68$ to 0.98. Hence, assuming that two measures assess the same construct while evidence indicates only a moderate association between the two can lead to huge between-studies heterogeneity and, as a result, to low robustness/replicability of the results.

This is also particularly concerning for meta-analyses that aggregate “interoceptive sensibility” measures. For instance, a recent meta-analysis by Trevisan et al. (2019) tested the relationship between alexithymia and interoceptive sensibility (among other dimensions) by aggregating several loosely related questionnaires of interoception (Desmedt et al., 2020). Given that these questionnaires measure different constructs, the results cannot be meaningfully interpreted, which seriously questions the validity of the meta-analytical conclusions.

This situation is also problematic with regards to the construct validity of self-report measures of interoception. An important gap exists between the definition of interoceptive sensibility (Garfinkel et al., 2015; Khalsa et al., 2017) and the constructs that are measured by questionnaires meant to indicate it. As a reminder, interoceptive sensibility is (1) the self-perceived tendency to focus on internal sensations and the capacity to detect them (Garfinkel et al., 2015) or (2) only the self-perceived tendency to focus on internal sensations (Khalsa et al., 2017). Our systematic review indicates that the first definition is the most largely shared across authors. However, a content analysis of the items used in the questionnaires included in this study indicates that the questionnaires measure distinct—and often more specific—constructs. Here are a few examples. The BPQ measures awareness of neutral and uncomfortable bodily sensations. The BAQ measures the capacity to notice and predict body reactions to internal and external factors such as diseases (e.g., the flu) and food. Finally, the SAQ measures the frequency with which one feels uncomfortable, painful, or symptomatic bodily sensations. This discrepancy between construct definition and measurement might lead to invalid interpretations, as researchers might draw conclusions on the role of interoceptive sensibility without considering what the specific questionnaire is actually measuring.

Are differences in questionnaire format an issue?

Our factor/community solution, broadly pointing to the very questionnaires included in the analysis, might partly result from variations in item presentation, instructions, option label, and/or the number of levels on the Likert scale across questionnaires. We respected the original format of the questionnaires (e.g., instructions) to maintain their psychometric properties. This could have "artificially" increased the internal consistency of each questionnaire. However, if true, this would also necessarily question the very notion of psychological assessment via questionnaires, as differences in presentation format do currently apply to different questionnaires. Of importance too, if these questionnaires were capturing a common construct, nothing should have prevented a common factor to emerge.

What is the factorial structure of the MAIA and PBCS?

Our results also question the factorial structure of two questionnaires: the MAIA and the PBCS. This is particularly important to consider given that this study relied on a very large sample size and included participants with broad variations in age, gender, and ethnicity. Although responses to the MAIA are thought to be organized around eight factors, both our EFA and network analyses suggest three distinct sets of items (see Factors 2, 5, and 6). Of note, however, contrary to what was done in the original validation studies of the MAIA (Mehling et al., 2012, 2018), our factor and network analyses included other questionnaires, potentially explaining the discrepancy between our results and those found in these studies.[8] Moreover, it would be necessary to perform confirmatory factor analysis to confirm this three-factor structure.

This is precisely what Ferentzi et al (2020) did in a recent study. They showed, via confirmatory factor analysis, that six factors are covered by an overarching factor (our Factor 2) and two factors (i.e., not-distracting and not-worrying; our Factors 5 and 6) are only weakly

[8] Note, however, that an EFA performed on the MAIA individually replicated this 3-factors structure depending on the factor retention criterion used.

related to this factor. This is consistent with our results, although we did not test a hierarchical factor structure (this could not be achieved, even in a confirmatory analysis, because of the poor correlations between questionnaires). Perhaps even more important, although the MAIA is thought to comprehensively cover the most important subjective dimensions of interoception, our results indicate that several other important factors/communities are measured by other questionnaires.

Regarding the PBCS, our factor analysis did not find a factor underlying this questionnaire. Rather, the items moderately loaded on several factors and, also, the items rarely reached loading higher than 0.30. Therefore, our Very Simple Structure (VSS) procedure removed the PBCS from the final solution. These findings should, nevertheless, be tempered by those found with the network analysis (see the paragraph below).

What are the consistencies and discrepancies between the factor and network analyses?

Results from the factor and network approaches were generally very consistent which is not surprising given the assumed mathematical equivalence between them (Christensen et al., 2020; but see, Bringmann & Eronen, 2018 for a discussion on the ontological differences). However, a few minor discrepancies arose between the two approaches. First, the network analysis identified one additional community covered by PBCS items. On the contrary, the factor analysis showed that these items did not load on the same factor. Second, the network analysis assigned one item from the SAQ to the same community as the BPQ items. This can easily be explained by a strong association (r = 0.63) between BPQ_15 ("During most situations, I am aware of palms sweating") and SAQ_34 ("I feel my palms sweaty") that both evaluate the self-perceived awareness of palms sweating. Third, two items from the MAIA, that were removed from the final factor solution following the VSS procedure, were included in the second community. These discrepancies could be explained by the arbitrary decisions made in the factor analysis. In particular, several steps of the factor analysis are subject to the subjectivity of the researchers, as they have to choose, e.g., the (1) rotation method, (2) factor retention criteria, and (3) the most interpretable solution.

What are the future directions?

The present research questions the pragmatic value of the “interoceptive sensibility” construct, as it is dissociated from its measurement (various questionnaires used to capture the construct do not converge). We have discussed above that this is not just a mere terminological issue, but one that has the potential to greatly threaten interpretations, replications, and more generally a sound communication between researchers in interoception research.

Together with other empirical studies, and more generally, the present research also questions the *pragmatic* value of current conceptualizations of interoception. This is because, besides interoceptive sensibility, low convergence also applies to other dimensions of interoception. Notably, recent evidence shows that measures of interoceptive accuracy also loosely correlate within (as for HCT and HDT outcomes; Ring & Brener, 2018) and between bodily domains (see a review and empirical evidence in Ferentzi et al., 2018). This is not to say that the current conceptualizations are faulty. To the contrary, we see merits in those. Rather, we note that current conceptualizations are disconnected from current measurement (as various measures do not converge).

We call for the development of measures that better fit with current conceptualizations (or vice-versa). In the meantime, researchers should select questionnaires according to the specific construct they intend to measure. For instance, if researchers seek to measure the awareness of neutral and negative bodily sensations, they should administer the BPQ, but if they seek to measure the tendency not to worry about internal sensations, they should administer the MAIA subscale. A helpful development in interoception research might also consist in differentiating self-report measures of interoception according to the phenomena of interest (e.g., attention vs accuracy; Gabriele et al., 2020; Jennifer Murphy et al., 2019), bodily domain (e.g., cardiac), or system (e.g., cardiorespiratory; Vlemincx et al., 2020), and type of physiological activation (e.g., activation vs deactivation; Vlemincx et al., 2020). Recent promising questionnaires have been recently developed that pursue this goal: e.g., The Three-domain Interoceptive Sensations Questionnaire (THISQ; Vlemincx et al., 2020) and the Interoceptive Accuracy Scale (IAS; Jennifer Murphy et al., 2019).

Conclusion

In conclusion, the present research indicates that current interoception questionnaires do not measure a common construct. Instead, these questionnaires inform distinct, insufficiently related, entities. This lack of empirical convergence between questionnaires threatens the validity of interpretations and the replicability and generalization of the findings. This sort of limitations is not specific to the interoception research, but also applies to a diversity of research domains including “depression” (Santor et al., 2006), “fear extinction” (Lonsdorf et al., 2019), “implicit attitudes” (e.g., Corneille & Hutter, 2020), and “impulsivity” (e.g., Stahl et al., 2014). Future research should aim at better matching conceptualization with measurement (for a discussion, see Flake & Fried, 2020). This can be achieved by adapting either the conceptualization or the measurement in self-report interoception research.

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