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Discrepancies in the Definition and Measurement of Human Interoception: A Comprehensive Discussion and Suggested Ways Forward

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Abstract

Interoception has been the subject of renewed interest over the past 2 decades. The involvement of interoception in a variety of fundamental human abilities (e.g., decision-making and emotional regulation) has led to the hypothesis that interoception is a central transdiagnostic process that causes and maintains mental disorders and physical diseases. However, interoception has been inconsistently defined and conceptualized. In the first part of this article, we argue that the widespread practice of defining interoception as the processing of signals originating from within the body and limiting it to specific physiological pathways (lamina I spinothalamic afferents) is problematic. This is because, in humans, the processing of internal states is underpinned by other physiological pathways generally assigned to the somatosensory system. In the second part, we explain that the consensual dimensions of interoception are empirically detached from existing measures, the latter of which capture loosely related phenomena. This is detrimental to the replicability of findings across measures and the validity of interpretations. In the general discussion, we discuss the main insights of the current analysis and suggest a more refined way to define interoception in humans and conceptualize its underlying dimensions.

Keywords

interoception, interoceptive accuracy, interoceptive sensibility, physiological fibers, homeostatic pathways

Interoception, the processing of internal bodily states, has been the subject of study for more than a century (Sherrington, 1906), and the number of empirical studies investigating interoception has grown considerably during the past 2 decades. The hypothesized involvement of interoception in a broad diversity of fundamental human processes (e.g., decision-making, emotion regulation, and reward seeking; Dunn et al., 2010; Füstös et al., 2013; Verdejo-Garcia et al., 2012) has led researchers to suggest that interoception may play an important role in mental health (e.g., depression and alexithymia; Herbert et al., 2011; Paulus & Stein, 2010) and physical health (e.g., obesity and medically unexplained symptoms; Bogaerts et al., 2010; Herbert & Pollatos, 2014).

Although considerable progress has been made in the study of interoception, we argue that the current definition of interoception and the conceptualization of its underlying dimensions need further refinement. First, there is a discrepancy between the physiological and phenomenon-based definitions of interoception, which are most often endorsed within the same article. Indeed, many researchers define interoception as both (a) the processing of signals within the body and (b) the activation of specific physiological fibers (Khalsa et al., 2018).

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The physiological definition is based on neuroanatomical studies that show that these fibers allow the central nervous system (CNS) to process signals coming from all tissues within the body (Craig, 2002). Although it may make sense to distinguish these physiological fibers from other ones at the peripheral level, the central and subjective processing of internal states involves additional physiological and nervous pathways.

Second, consensual conceptual articles (Garfinkel et al., 2015; Khalsa et al., 2018) have distinguished between several interoception dimensions. These classifications are conceptually useful and improve the efficiency of communication in interoception research. However, conceptualization is an ongoing process, and empirical evidence indicates that the dimensions that have been identified are largely detached from existing measures, as indicated by the low convergence between measures underlying the same dimension (e.g., Desmedt et al., 2022; Ferentzi et al., 2018). These conceptual issues pose a major threat to the interpretation of current empirical results and are at risk of leading to replication failures in which researchers mistakenly assume that an effect should replicate on another interoception measure because the latter is said to measure the same dimension despite this measure being largely uncorrelated to the original one.

In the first part of this article, we review the current definitions of interoception, noting that a consensus has been achieved on what interoception means within the phenomenon-based and physiological levels but that significant discrepancies exist between these two levels. The coexistence of differing definitions—even within the same article—relying on different assumptions is neither desirable nor necessary. In the second part, we discuss the interoception dimensions identified in the literature and their empirical disconnection to measurement in human studies. This second discrepancy threatens the construct validity of the measures and the replicability of the findings across measures. In the general discussion, we propose recommendations to refine the definition of interoception. We also provide a hierarchical framework that is aimed at increasing consistency between (a wider set of hierarchically organized) constructs and measures.

Discrepancies Between the Physiological and Phenomenon-Based Definitions of Interoception

In this first section, we discuss past and contemporary definitions of interoception and highlight discrepancies between the physiological and phenomenon-based definitions of the concept.

Past and contemporary definitions of interoception

Originally, interoception was defined as the processing of signals located in the viscera that were, at that time, equated with the intestine (Sherrington, 1906). The definition of the viscera eventually evolved to include the cardiovascular, respiratory, gastrointestinal, and genitourinary systems (e.g., Airapetyantz & Bykov, 1945; Freeman & Sharp, 1941). Interoception was differentiated from exteroception (i.e., the processing of signals located on the external surface of the body, the skin) and proprioception (i.e., the processing of limb position and movements). These two latter terms are sometimes lumped together within the label "somatic sense" (i.e., the sense of signals coming from the muscles, joints, connective tissues, and skin; Ceunen et al., 2016).

From this perspective, visceral signals are relayed by the brainstem to the thalamus and then to the insular cortex (Craig, 2015). Conversely, the primary and secondary somatosensory cortices are responsible for somatic sensations. These anatomical distinctions would explain the differences observed in the subjective experience of visceral and somatosensory sensations because the former includes more diffuse sensations and the latter includes more localized ones. From this perspective, pain and temperature processing are qualified as somatic signals and are subserved by the somatosensory cortices (i.e., they are excluded from the definition of interoception).

On the basis of his (e.g., Craig et al., 2000) and others' (e.g., May, 1907; Vallbo et al., 1999) neuroanatomical experiments, Craig (2002), however, concluded that there is a physiological pathway that allows the CNS to sense the physiological condition of the entire body that is distinct from the somatosensory system related to skin perception. This "interoceptive system" (for details, see Table 1) is composed of specific neurons (e.g., lamina I) of the spinal cord and the solitary nucleus (NTS), sensory fibers (i.e., thinly myelinated Aδ and unmyelinated C small-diameter sensory fibers[1]), lower brain regions (e.g., the thalamus), and higher brain regions (e.g., the dorsal posterior insula and the anterior insular cortex). All these elements form "homeostatic pathways" as they allow the CNS to process the physiological condition of the body and react to maintain the stability of the "interior milieu" (i.e., homeostasis; Ceunen et al., 2016; Craig, 2015).

This physiological model led Craig (2009) to broaden the definition of interoception to encompass the whole "sensory input representing the condition of the entire body" (for a summary, see Table 1). This conceptualization implies that interoception now includes the sense (conscious or not) of any change in the mechanical,

Table 1. Summary of the Neural Components and Stimuli Included in the Physiological Definition of Interoception

	Interoception (homeostatic pathways)	Somatic system (nonhomeostatic pathways)
Physiological fibers	Thinly myelinated Aδ and unmyelinated C small-diameter sensory fibers	Large-diameter sensory fibers of A cells
Lamina neurons	Neurons in the lamina I, the outer lamina II, and a small part of lamina V	Neurons in the lamina IV, lamina V, lamina III, and the inner part of lamina II
Cortical regions	Insula, cingulate cortex, and amygdala	Somatosensory cortices
Stimuli	Any change in the mechanical, thermal, or chemical conditions of the tissues (including the skin)	Mechanical contact between the skin and external stimuli (e.g., pressure, vibration); changes in force, length, and position in muscle and joints

thermal, or chemical conditions of the tissues (including the skin). From this point of view, interoception thus relates to physiological conditions as diverse as cardiovascular, respiratory, and gastrointestinal activity but also temperature changes, immune and hormonal activity (e.g., cytokines), mechanical stress or damage, local metabolism (e.g., hypoglycemia), skin-parasite penetration (histamine, proteinases), hunger, satiety, thirst, fatigue, pain, and itching (Craig, 2002, 2003, 2009). In other words, according to this broader definition, interoception refers to the (conscious and nonconscious) processing of signals (via homeostatic pathways) that inform physiological needs, organ integrity, and homeostatic control.

Conversely, the somatic system (being part of exteroception) is composed of large-diameter sensory fibers of Aβ cells[2] (a) from the skin, which signal mechanical contact with external stimuli (e.g., pressure, vibration), and (b) from muscle and joints, which signal changes in force, length, and position. Large-diameter sensory fibers of A cells make up the first step (i.e., primary afferents) of nonhomeostatic pathways, the physiological basis of exteroception. Conceptualized in this light, interoception is the sensory part of the autonomic nervous system that was previously considered a motor system exclusively activating smooth muscles, whereas exteroception is the sensory part guiding movements produced by the skeletal (striated) muscle.

Although some researchers still endorse the more restrictive definition that limits interoception to visceroception (Critchley & Harrison, 2013; Paulus et al., 2009; for a summary, see Table S1 in Appendix), most researchers currently agree with Craig's (2009) more inclusive approach (with some variations; see Barrett & Simmons, 2015; Cameron, 2001b; Couto et al., 2013; Khalsa & Lapidus, 2016). This is further illustrated by the recent endorsement it received from a panel of experts that proposed that interoception "refers collectively to the processing of internal bodily stimuli by the nervous system" (Khalsa et al., 2018, p. 501) and "broadly relates to all physiological tissues that relay a signal to the central nervous system about the current state of the body, including the skin and skeletal/smooth muscle fibers, *via lamina I spinothalamic afferents*" (Khalsa et al., 2018, footnote p. 501), that is, homeostatic pathways. Nowadays, the inclusive definition of interoception appears to be the most widely accepted one, although exceptions exist (e.g., Chen et al., 2021).

Physiological pathways underlying the processing of internal states by the nervous system

In the previous subsection, we showed that interoception is often defined as both the processing of internal bodily stimuli by the nervous system (phenomenon-based definition) and homeostatic pathways or lamina I spinothalamic afferents (physiological definition). This view is problematic because, as we now discuss, the processing of internal states also involves nonhomeostatic pathways (i.e., pathways besides lamina I spinothalamic and NTS afferents). Our review focuses on cardiac, respiratory, and gastrointestinal signal processing, these three systems being the most extensively investigated. The other body systems (not discussed here) include proprioception (Tuthill & Azim, 2018), genitourinary system (including sexual arousal; Drake et al., 2010), thermoreception (Bligh et al., 1990), and nociception (Simons et al., 2014). Other researchers have argued that interoception is not limited to homeostatic pathways (Ceunen et al., 2016; Khalsa et al., 2009). To our knowledge, however, the present contribution is the first to discuss extensive evidence in the cardiac, respiratory, and gastrointestinal domains supporting this claim.

The cardiovascular system. Several physiological pathways underlying cardiac processing have been identified (Park & Blanke, 2019; Tallon-Baudry et al., 2018). Two of them can be categorized as "homeostatic" and thus correspond to the most widely accepted physiological definition of interoception. Nevertheless, the third pathway would be considered "nonhomeostatic."

The first pathway originates in baroreceptors, which are stretch sensors that detect arterial-pressure changes within and across cardiac cycles (Garfinkel & Critchley, 2016). These receptors are mainly located at the aortic arch and the carotid arteries. Increases (or decreases) in arterial pressure activate (or deactivate) baroreceptor firing and trigger parasympathetic vagal-nerve output (or sympathetic nerve activity), which subsequently decreases (or increases) arterial pressure (Park & Blanke, 2019). The increased firing of baroreceptors further activates the vagal nerve, which projects to the brainstem and thalamus. Finally, the signal ends in the insula, cingulate cortex, and amygdala.

The second pathway involves cardiac afferent neurons at the heart wall (i.e., the surface of the heart) that detect mechanical and chemical changes from the atria and ventricles (Tahsili-Fahadan & Geocadin, 2017). Two types of neurons exist: chemotransduction and mechanical neurons. Whereas chemotransduction neurons fire at a relatively low frequency, mechanical neurons reflect regional muscle-fascicle deformation within each cardiac cycle. Cardiac neurons communicate with both the vagal nerve and the spinal cord (e.g., the lamina I spinothalamic afferents; Craig, 2003; Critchley & Harrison, 2013). Then these pathways continue into the NTS and thalamus, ending in the insula, amygdala, and cingulate cortex.

In addition to these homeostatic pathways, the somatosensory pathway is another candidate responsible for communicating cardiac information to the brain (Park & Blanke, 2019). This pathway would involve Aβ large-diameter mechanosensitive sensory fibers (e.g., Pacinian corpuscles; Knapp et al., 1997), which are usually considered exteroceptive pathways (Craig, 2015). Indeed, a recent study (Knapp-Kline et al., 2021) showed that both Pacinian and non-Pacinian somatosensory mechanoreceptors are involved in heartbeat detection. The researchers achieved their results by asking participants to perform the method of constant stimuli heartbeat-detection task (Brener et al., 1993) under vibrotactile stimuli on the sternum masking the Pacinian or non-Pacinian channels (vs. control condition). Under the masking conditions, participants performed worse than under the control condition, suggesting that these somatosensory channels (usually dedicated to exteroception) are involved in heartbeat detection.

At the cortical level, heartbeat-evoked potentials (HEPs), which represent the cortical processing of cardiac signals, are directly recordable in the somatosensory cortex (Kern et al., 2013), a cortical region that is usually associated with exteroception, not interoception. Moreover, transcranial magnetic stimulation on the somatosensory cortex influences heartbeat perception (Pollatos et al., 2016), showing that this region is a biological substrate of internal state perception. Khalsa et al. (2009) demonstrated that a patient with bilateral insular damage had normal cardiac awareness that disappeared when the patient's chest skin was anesthetized, suggesting that heartbeats may be perceived via somatosensory pathways. These results are consistent with studies that have shown that participants in other studies reported feeling their heartbeats (or more precisely, the blood movements generated by these heartbeats) in their head, neck, and abdomen but also in their arms (Jones, 1994; Jones et al., 1987; Ring & Brener, 1992).

In conclusion, although homeostatic pathways are likely involved in CNS cardiac processing, the somatosensory (nonhomeostatic) pathway also appears to be a contributor. These observations suggest that the prevalent physiological definition of interoception, which is limited to homeostatic pathways, is at odds with the phenomenon-based definition of interoception (i.e., the processing of internal bodily states).

The respiratory system. Respiratory-sensory feedback does not depend on a single receptor system (Harver et al., 1988). In humans, this feedback originates in the diaphragm, chest wall, lung, and upper airways. Physical stimuli leading to this feedback include respiratory-muscle contractions, lung-volume changes, and motor efforts (Gottfried et al., 1984; Killian et al., 1982; Tack et al., 1983).

The identification of the receptor systems responsible for respiratory interoception is complex because multiple potential sources of respiratory signals exist (Harver et al., 1988). Consequently, there is no agreement on the receptor mechanisms underlying respiratory afferents. There are three main types of afferents involved in breathing: chemosensitive, mechanosensitive, and mechano-chemosensitive (Schroijen et al., 2020). In Paulus's (2013) review, seven sensory-airway receptors were proposed: slowly adapting receptors (SARs) and rapidly adapting receptors (RARs), bronchial and pulmonary C-fiber receptors, high-threshold Aδ receptors, cough receptors, and neuroepithelial bodies (NEBs). Widdicombe (2001) identified five receptors in the larynx (pressure, cold, drive, and irritant receptors and C-fiber endings) and four in the trachea and bronchi (SARs, RARs, C-fiber endings, and NEBs).

At the fiber level, small unmyelinated (C fibers) and thinly myelinated (i.e., Aδ fibers) fibers and large myelinated fibers (i.e., Aβ fibers) may be involved in the sense of signals coming from the respiratory tract (Mazzone & Undem, 2016). As mentioned above, C fibers and Aδ fibers are part of homeostatic pathways (i.e., qualified as interoceptive), whereas Aβ fibers are categorized as belonging to nonhomeostatic pathways (i.e., qualified as exteroceptive; Craig, 2015). Mazzone and Undem (2016) conducted a thorough review of the vagal afferent innervation of the respiratory tract. They found that there are approximately 8 times more C fibers than Aδ and Aβ fibers in the sensory vagus nerves (Mei et al., 1980). Moreover, they noted that the majority of respiratory afferent nerves (mainly C fibers and some Aδ fibers) are activated by nociceptors to convey painful signals from the lungs, leading to defensive reflexes (e.g., cough and apnea; Mazzone & Undem, 2016).

Regarding mechanical activation, almost all sensory nerves of the respiratory tract are involved (Mazzone & Undem, 2016). C fibers are high-threshold mechanosensors and, therefore, are activated only when mechanical force is relatively large, except for some pulmonary C fibers, which weakly respond to inspiration. Aδ fibers are also high-threshold mechanosensors and are mostly insensitive to tissue stretch. On the other hand, Aβ fibers are very responsive to tissue distension because they are low-threshold mechanosensors. They mostly respond to lung distention caused by inspiration (Lee & Yu, 2011). For instance, cutaneous mechanoreceptors are located on the thorax and activate following physical movement created by respiratory motion (Schroijen et al., 2020). Finally, high-threshold sensory nerves (i.e., C fibers) and slow-conducting fibers (i.e., Aδ fibers) respond directly to chemical stimulation (e.g., endogenous autacoids and inhaled irritants).

Davenport and Vovk (2009) described two processes by which respiratory signals are processed at the subcortical and cortical levels. The first is discriminative processing that provides awareness of the spatial, temporal, and intensity respiratory components. It involves somatosensory pathways (i.e., structures often associated with exteroception). The second is affective processing, which concerns the evaluative and emotional components of breathing and involves the amygdala, anterior cingulate, and insular cortex (i.e., "limbic" regions thought to underlie interoception).

In conclusion, respiratory signals can be conveyed both by homeostatic pathways (e.g., from C fibers and Aδ fibers to "limbic" regions) and nonhomeostatic pathways (i.e., from Aβ fibers to somatosensory cortices). Here again, the involvement of nonhomeostatic pathways is difficult to reconcile with the physiological definition of interoception.

The gastrointestinal system. At the receptor level, the gastrointestinal system includes several types of receptors, including chemoreceptors, osmoreceptors, mechanoreceptors, and thermoreceptors, that transmit information on tension, volume, and chemical changes (Camilleri et al., 1996, 2001). Mechanoreceptors are located in the esophagus, stomach, small intestine, colon, rectum, and gallbladder (Mei, 1983). They respond to contraction and distension (muscular mechanoreceptors), mucosal stroking or pinching (mucosal mechanoreceptors), and movement or strong distension of the viscus (serosal mechanoreceptors; Camilleri et al., 1996). As with the respiratory system, mechanoreceptors can be categorized as SARs and RARS (Camilleri et al., 1996). SARs provide information on the state of tone, stretch, or position of the viscus, and RARs convey superficial sensations or vigorous contractions and distentions. Pacinian corpuscles (i.e., structures involved in somatosensory perception) also respond to the movement of the mesentery or strong distention of the viscus (Camilleri et al., 1996).

At the fiber level, two main types of primary sensory fibers can be distinguished (Camilleri et al., 1996; Jänig & Koltzenburg, 1990). Myelinated Aδ fibers, which follow RARs and SARs, are responsible for the sensation of initial pain (localized and discriminative) and terminate in the laminae I, V, and X. Unmyelinated C fibers, which follow RARs, are responsible for the long-lasting second pain (diffuse and lasting beyond the duration of the stimulus) and terminate in the laminae I and V. Unmyelinated C fibers and myelinated Aδ fibers can be considered as making up a homeostatic pathway (Craig, 2015). However, in addition to these fibers, Aβ large-diameter mechanosensitive sensory fibers that follow Pacinian corpuscles may also play a role in gastrointestinal perception.

At the (sub)cortical level, gastrointestinal signals project centrally via two ascending pathways: the spinothalamic and spinoreticular tracts (Camilleri et al., 1996; Cross, 1994). The spinothalamic tract contains fibers arising from wide dynamic range neurons (which respond to gentle or soft stimulations and are located in laminae IV, V, VI) and nociceptive-specific neurons (which respond to noxious stimuli and are located in lamina I). These neurons then project to the medial (i.e., the substrate for the affective-motivational sense of pain) and lateral thalamic nuclei (i.e., the substrate for the discriminative sense of pain). Neurons in the medial thalamic nucleus project to the limbic, parietal, and frontal regions, such as the anterior cingulate gyrus, and those in the lateral thalamic nucleus project to the somatosensory cortex. The spinoreticular tract, the second ascending pathway, projects to the reticular formation, the medial thalamus, and then to the hypothalamus.

In conclusion, just as for cardiac and respiratory signals, gastrointestinal signals are processed by the CNS via homeostatic (from unmyelinated C fibers and myelinated Aδ fibers to higher cortical regions via the lamina I and the medial thalamic nucleus) and nonhomeostatic (from Aβ large-diameter fibers to the somatosensory cortex via laminae IV, V and VI and the lateral thalamic nuclei) pathways. Again, this shows that the processing of internal states (the phenomenon-based definition) involves more than homeostatic pathways, contrary to what the physiological definition of interoception assumes.

Interim discussion on discrepancies in the definition of interoception

The evidence provided in the first section suggests that under natural conditions, an individual's CNS processes cardiac, respiratory, and gastrointestinal signals through both homeostatic and nonhomeostatic pathways. Although it can make sense to divide "homeostatic" and "nonhomeostatic" pathways at the peripheral level, it is contradictory to define interoception as simultaneously being (a) the processing of internal states by the nervous system (i.e., the phenomenon-based definition) and (b) the activation of homeostatic pathways (i.e., the physiological definition). This is because, at least in humans, the processing of internal states involves nonhomeostatic receptors, fibers, neurons, subcortical regions, and cortical regions. In other words, when the nervous system processes (consciously or not) internal states, it may involve both homeostatic and nonhomeostatic pathways. This is consistent with Berntson and Khalsa's (2021) recent description of the neural circuits of interoception showing that many pathways are involved (e.g., vagal, cranial, sacral, spinothalamic, and somatosensory).

The physiological definition equates interoception with slow and high-threshold bodily processing and dissociates it from rapid and low-threshold bodily processing. It also assumes that interoception is relevant for homeostasis (by calling its underlying pathway "homeostatic") but exteroception is not. These two assumptions are problematic when scrutinized separately and even more so when considered together. First, to our knowledge, there are no theoretical reasons to exclude rapid and low-threshold processing from interoception. Second, rapid and low-threshold processing of internal/external states is directly relevant to homeostasis (e.g., mechanical contact between the skin and external stimuli may necessitate fast reactions for survival).

The inconsistency between the phenomenon- and physiological-based definitions of interoception can be described as a lack of conceptual clarity. This is particularly problematic because it might lead to validity and replicability issues. First, there is a high risk of a mismatch between the construct and its measures (i.e., low construct validity; Adcock & Collier, 2001; Goertz, 2006; MacKenzie, 2003; Podsakoff et al., 2016). Indeed, if one strictly adheres to the prevalent physiological definition of interoception (i.e., the processing of internal states subserved by homeostatic pathways), almost any measure of the processing of internal states in humans would be considered nonpure and biased because they may involve nonhomeostatic pathways. This issue concerns physiological (e.g., receptor sensitivity), cerebral (e.g., HEPs), behavioral (e.g., objective detection ability), and self-reported (e.g., self-perceived detection ability) measures. This is problematic for almost the entire field of human interoception.

Second, this conceptual ambiguity might be associated with difficulty to distinguish the focal construct (e.g., interoception) from other similar ones (e.g., visceroception) in the field (i.e., low discriminant validity; Podsakoff et al., 2016). Third, conceptual ambiguity might prevent the development of coherent theories given that constructs are the building blocks of theories (Aquino & Thau, 2009; MacKenzie, 2003; Popper, 2002; Sober, 1981; Tepper & Henle, 2011). Finally, this physiological definition of interoception is often used by researchers to defend the view that some phenomena (e.g., pain, temperature perception, and affective touch; Crucianelli & Ehrsson, 2023) should be described as interoceptive. However, these phenomena do not entirely correspond to the processing of internal bodily states. Consequently, researchers conflate phenomena that are not necessarily comparable (at the peripheral, central, and subjective levels).

Therefore, the definition of interoception needs to be adapted by considering theoretical, empirical, and pragmatic criteria. In the general discussion below, we examine the current options and propose a more comprehensive definition of interoception.

Discrepancies in the Measurement of Interoception Dimensions

We now turn to a second major discrepancy within the field of interoception studies: inconsistencies between the conceptualization of conscious interoception dimensions and how these may be measured. Two conceptualizations of conscious interoception dimensions have garnered considerable consensus in contemporary human-interoception research. The first one was proposed by Garfinkel and colleagues (2015), who aimed to standardize the terminology to reach more consistency across studies. The second conceptualization was proposed by a consensus panel on interoception (Khalsa et al., 2018). These conceptualizations are useful to organize research and have greatly improved communication between researchers. However, conceptualization is an ongoing process, and we argue that these dimensions are largely detached from current measures. This is consequential for the interpretation and replication of findings in interoception research. In this section, we first describe the two currently and widely accepted conceptualizations of interoception, and then we discuss the gap between conceptualization and measurement by reviewing the convergent validity of their associated measures. Finally, we analyze the implications of this second discrepancy for human-interoception research.

The proposed dimensions of interoception

The terminology and conceptualization of interoception dimensions varies considerably across the field. The term "interoceptive awareness" was first used to describe what can be measured through self-report scales (Garner et al., 1983), but its meaning was rapidly broadened to include all measures involving reports of interoceptive signals (i.e., questionnaires and performance-based measures; Khalsa et al., 2017). The terms "interoceptive sensitivity and accuracy" were traditionally used as synonyms of "interoceptive awareness" (Garfinkel et al., 2015), but "interoceptive accuracy" has increasingly been used to characterize behavioral performance (Ceunen et al., 2013).

Given these inconsistencies, Garfinkel et al. (2015) proposed a useful three-dimension model that differentiates interoception based on measurement types. According to this model, "interoceptive accuracy" refers to the objective accuracy in detecting internal signals and is assessed by performance-based measures. "Interoceptive sensibility" is the self-perceived dispositional tendency to focus on internal signals and the capacity to detect them, and it is assessed by self-report measures. "Interoceptive awareness" is the correspondence between the objective performance during an interoceptive-accuracy task and the self-reported confidence in this performance. It is assessed by the measure of the degree to which objective accuracy is associated with subjective confidence (e.g., with the area under the receiver operating characteristic curve analyses). This terminology has been widely endorsed by the interoception community, perhaps partly because of its simplicity. However, it has also led researchers to pose constrained and homogeneous research questions because it relates to mainly detection abilities, whereas other interoceptive phenomena (e.g., interoceptive attention) are largely overlooked.

Khalsa and colleagues (2018) recently agreed on a new and broader terminology proposing eight dimensions: attention (i.e., observing internal states), detection (i.e., the presence or absence of report), magnitude (i.e., the perceived intensity of internal states), discrimination (i.e., localization sensations and differentiation of it from other sensations), accuracy (i.e., correct and precise monitoring of internal signals), sensibility (i.e., the self-perceived tendency to focus on internal states), and self-report (i.e., reporting subjective experiences and judging their outcomes). Finally, they replaced the label "interoceptive awareness" (i.e., the correspondence between confidence and accuracy) with "interoceptive insight."

The mismatch between conceptualization and measurement

We argue that the conceptualization of these dimensions, although laudable, is at odds with current measures and that this undermines their construct validity and any attempts at replication that may be undertaken. In this section, we discuss the convergence of measures thought to assess each dimension proposed by Garfinkel et al. (2015) and Khalsa et al. (2018). Because interoceptive accuracy and detection are generally not distinguished in the literature, we group them into one subsection. Furthermore, even though interoceptive sensibility has a more specific definition than interoceptive self-report scales, the former is generally used to describe all questionnaires of interoception. For this reason, these two dimensions are also grouped in one subsection. Interoceptive awareness (Garfinkel et al., 2015) and insight (Khalsa et al., 2018) are synonymous and thus considered jointly. Finally, the remaining dimensions (interoceptive attention, magnitude, and discrimination) were proposed by Khalsa et al. only. For these dimensions, we discuss the convergence in measures that Khalsa et al. identified as assessing the respective dimensions.

Interoceptive accuracy and detection. Interoceptive accuracy (Garfinkel et al., 2015; Khalsa et al., 2018) and detection (Khalsa et al., 2018) are measured via performance-based tasks based on various abilities related to diverse body systems. Indeed, these tasks may require participants to detect their heartbeats (Schandry, 1981), synchronize an external stimulus (e.g., sound) with their heart rate (Whitehead et al., 1977), detect the amount of water in their stomach (Van Dyck et al., 2016), evaluate the bitterness level of a liquid (Ferentzi et al., 2017), detect pain sensations (Amanzio & Benedetti, 1999), reproduce limb position (i.e., proprioceptive acuity; Goble, 2010), balance on one leg with their closed eyes (Ferentzi et al., 2018), or discriminate the duration of respiratory occlusions (Van Den Houte et al., 2021).

Across bodily systems, current evidence suggests that there is little convergence between measures assessing the objective capacity to monitor or detect internal signals (for a review and empirical evidence, see Ferentzi et al., 2018). Early studies that correlated performance-based measures of interoception found moderate associations between them (Herbert et al., 2012; Steptoe & Noll, 1997; Whitehead & Drescher, 1980). However, although significant, these associations indicate that only 13% to 25% of the variance is shared between measures. This hardly supports the existence of a general interoceptive accuracy/detection ability.

More recent studies have depicted an even more somber picture of convergence between performance-based measures of interoception. These studies generally found no significant association between cardiac, respiratory, gastric, pain, bitterness, and balance sensitivity (Ferentzi et al., 2017; Garfinkel et al., 2016, 2017; Harver et al., 1993; Werner et al., 2009). These results again suggest that interoceptive accuracy/detection ability in a specific system (e.g., cardiovascular) is not predictive of this ability measured through another system. This conclusion is further supported by a recent study (N = 118; Ferentzi et al., 2018) that carried out correlation and factor analyses on six different sensory channels. Overall, the "findings [of this study] strongly support the idea that interoceptive accuracy assessed with a single modality cannot be generalized across various channels" (Ferentzi et al., 2018, p. 6).

Perhaps even more concerning is the fact that low convergence is also found between performance-based measures within the same bodily system. In particular, a recent meta-analysis (Hickman et al., 2020) investigated the relationship between the heartbeat-counting task (HCT; Dale & Anderson, 1978; Schandry, 1981) and the heartbeat-discrimination task (HDT; Whitehead et al., 1977), which are thought to measure the same construct (i.e., interoceptive accuracy) within the same system. On the basis of 22 studies, Hickman et al. (2020) found that performance on these tasks shared only 4.4% of the variance. This clearly calls into question the assumption that these two tasks measure the same construct. More studies investigating the association between performance-based measures within the same bodily domain are, nevertheless, needed for other domains.

The low convergence between measures can be explained either by imprecise conceptualization (i.e., the dimensions are too broad) or by inadequate measurement (i.e., the measures do not capture the targeted construct). In support of the latter, some of the administered measures have well-established limitations (e.g., Brener & Ring, 2016) or have not been psychometrically validated yet. For instance, the most used measure of interoceptive accuracy—the HCT—has been shown to be largely contaminated by guessing strategies (Corneille et al., 2020; Desmedt et al., 2018, 2020; Phillips et al., 1999; Ring & Brener, 1996; Ring et al., 2015; Windmann et al., 1999). This could explain why low correlations are found between the HCT and other measures of interoceptive accuracy in the cardiac and other domains. Future studies should thus test the convergence of interoceptive accuracy/detection measures with well-validated measures. This would allow researchers to determine the generalizability of interoceptive accuracy/detection within a body domain and across bodily domains.

Interoceptive sensibility and self-report scales. "Interoceptive sensibility" has been increasingly used to label any self-report measure of interoception. Interoceptive self-report scales, proposed by Khalsa et al. (2018), explicitly cover all the self-report measures of interoception. In this section, we thus examine the convergence between questionnaires of interoception.

Self-report measures of interoception cover many phenomena, such as the self-perceived (a) capacity to detect accurately internal sensations (Murphy, Catmur, & Bird, 2019); (b) frequency of awareness of one's neutral, positive, and negative internal sensations (Mehling et al., 2012, 2018; Porges, 1993); (c) capacity and tendency to focus on internal sensations (Mehling et al., 2012, 2018); (d) capacity to regulate distress by paying attention to body sensations (Mehling et al., 2012, 2018); (e) active listening to the body for insight (Mehling et al., 2012, 2018); (f) trust given to one's body (Mehling et al., 2012, 2018); (g) tendency not to worry about or distracted by negative sensations (Mehling et al., 2012, 2018); (h) frequency of uncomfortable, painful, or symptomatic bodily sensations (Longarzo et al., 2015); and (i) capacity to predict body reactions to internal (e.g., "there seems to be a 'best' time for me to go to sleep at night") and external variables (e.g., "I notice differences in the way my body reacts to various foods"; Shields et al., 1989).

At the self-report level, interoception conceptualization and measurement also strongly diverge (Desmedt et al., 2022). As mentioned above, interoceptive sensibility is the self-perceived tendency to focus on internal sensations and/or the capacity to detect them (Garfinkel et al., 2015; Khalsa et al., 2017). The previous paragraph clearly shows that different or more specific constructs are also encompassed by self-report interoception measures. This suggests a discrepancy between definitions and measures. This low construct validity is further confirmed by empirical evidence that shows low convergence between self-report interoception measures.

Although few studies have explored the correlations between interoception questionnaires, they generally have reported low to moderate correlations (r range = –.63 to .65; Bornemann et al., 2014; Brewer et al., 2016; Brytek-Matera & Kozieł, 2015; Fiene et al., 2018; Hughes et al., 2019; Murphy, Catmur, & Bird, 2019; Sze et al., 2010).[3] This suggests that they do not measure the same construct. A recent study (Desmedt et al., 2022) directly tested this question. In this study, the most cited questionnaires of interoceptive sensibility were first identified via a systematic review. The questionnaires' correlations, overall factorial structure, and network structure were investigated in a large community sample (n = 1,003). The results confirmed that these questionnaires tap into distinct constructs and have low overall convergence. Five factors were identified: (a) neutral and negative body sensations awareness (i.e., awareness level of neutral and uncomfortable bodily sensations), (b) functional interoceptive processes (i.e., detection, attention, regulation, insight, and trust abilities), (c) negative-feelings propensity (i.e., the frequency with which one feels uncomfortable, painful, or symptomatic bodily sensations), (d) extero-interoceptive awareness (i.e., the capacity to notice and predict body reactions to internal and external factors, such as weather, seasons, foods, diseases, and energy level), and (e) interoceptive not-distracting (i.e., the tendency not to ignore or distract oneself from sensations of pain or discomfort).

Interoceptive awareness or insight. Interoceptive awareness/insight is the correspondence between objective and self-reported performance on interoception tasks (Garfinkel et al., 2015; Khalsa et al., 2017). Given that objective performance is not correlated between tasks, it is highly probable that interoceptive awareness/insight does not converge across tasks because interoceptive accuracy is one contributor to interoceptive awareness/insight. To our knowledge, no empirical study has directly tested the convergence of interoceptive awareness/insight between bodily domains.

Interoceptive attention. Interoceptive attention is the capacity to focus attentional resources on internal sensations (Khalsa et al., 2018). It is essentially measured by assessing the cerebral activity (with functional MRI) of participants when they direct their attention toward the heart, the respiratory tract (from nose to diaphragm), or the stomach compared with a condition in which they pay attention to external stimuli (Farb et al., 2013; Simmons et al., 2013). However, these neuroimaging measures can hardly tell what is the interoceptive attentional capacity of participants. To our knowledge, no study has tested whether cerebral activation (e.g., in the insula) is highly correlated with the capacity to focus attention on internal sensations, which should be measured via performance-based tasks. This again suggests a discrepancy between the definition and measures of interoception. Finally, the convergence between the cerebral activity related to the attentional focus within and across bodily systems has, to our knowledge, not been tested.

Interoceptive magnitude. Interoceptive magnitude is the perceived intensity of internal bodily signals (Khalsa et al., 2018). This interoception feature has been measured by asking participants to (a) rotate a dial to indicate their ongoing perceived intensity of heartbeat and breathing sensations after receiving isoproterenol (vs. saline) infusions (Khalsa et al., 2009), (b) rate their level of fullness after having drunk water (Herbert et al., 2012), (c) rate their pain or desire to void when filling or emptying their bladder with intravesical infusion (Jarrahi et al., 2015), (d) rate their pain level during heat administration to their forearm (Katz et al., 2009), or (e) rate their abdominal pain during colonic distension via colonoscopy (Kano et al., 2007).

As far as we know, the correlations between these different self-perceived intensities have never been explored. It is therefore unknown whether these measures tap into one dimension. Existing evidence from the literature on pain suggests that pain threshold, tolerance, intensity, and unpleasantness of different modalities such as heat, cold, pressure, temporal summation, and electrical stimulation loosely or moderately correlate with each other (r range = –.30 to .50; Bhalang et al., 2005; Hastie et al., 2005; Janal et al., 1994; Lautenbacher & Rollman, 1993; Neziri et al., 2011).

Interoceptive discrimination. Interoceptive discrimination is the capacity to localize sensations in the body and to differentiate them from noninteroceptive sensations (Khalsa et al., 2018). It would be measured by, for example, asking participants to localize their sensations during upper- and lower-esophageal stimulation (Aziz et al., 2000). However, one can hardly consider this task as a genuine measure of the capacity to localize sensations given that it does not allow for the calculation of interindividual differences and that guessing might be involved in the absence of real sensations. To measure this capacity, a direct comparison between stimulation localizations and stimulation sensations should be done. Besides this discrepancy between definition and measure, it is not known whether interoceptive discrimination is a capacity that is generalizable across bodily systems. In conclusion, most current interoceptive-discrimination measures do not correspond to the dimension definition, and it is unknown whether they correlate with each other.

Interim discussion on discrepancies in the conceptualization and measurement of interoception

The convergence validity of interoception measures is highly problematic. This could indicate either that the conceptualizations should be adapted or that measurements should be improved to better align with the different dimensions.

We believe that the main reason for this second discrepancy is that interoception measures have been designed at different times and in different contexts for different purposes. The two recent conceptualizations have then tried to standardize and simplify the terminology of the interoception domain by proposing broad constructs. However, the broader a construct is, the more likely it is to cover several heterogeneous phenomena and measures. As a result, the risk of low convergence between measures underlying the same construct increases. This has consequences for both the validity of interpretations and the replicability of findings.

Most existing measures were not designed to measure the dimensions proposed by the new conceptualizations but were rather aimed at different and often more specific goals (e.g., the Body Awareness Questionnaire was developed to assess the self-reported tendency to pay attention to normal, nonemotive, body processes; Shields et al., 1989). Discrepancies might, therefore, exist between the interpretation of findings and actual measurements. For illustrative purposes, consider a hypothetical intervention study in which participants are asked to practice mindfulness (vs. relaxation) for eight sessions. Before and after the interventions, participants perform the HCT, an "interoceptive accuracy" measure in which they have to count their heartbeats without taking their pulse. The closer their reported number of heartbeats is to the actual number of heartbeats, the better their performance is. The results would indicate that mindfulness led to a stronger increase in HCT performance than the relaxation program. The authors would therefore conclude that mindfulness is efficient in increasing individuals' interoceptive accuracy (i.e., the ability to detect internal states) compared with relaxation, potentially leading to clinical recommendations. However, as we have argued throughout this article, this conclusion may be misleading, which is consequential for theory and practice. Indeed, there is no evidence that these results will replicate with another cardiac task, let alone another bodily system. Hence, conclusions in such a study should be limited to HCT performance, and researchers should avoid generalizing it to "interoception," "interoceptive accuracy," or even "cardiac accuracy."

An associated risk is replication failure if researchers expect the findings in one study to apply to another measure. The low convergence between measures presumably assessing the same construct will likely lead to low replicability of findings across measures. Indeed, even though many measures are said and thought to evaluate the same construct (e.g., interoceptive accuracy), the evidence clearly contradicts this assumption and indicates that results found with one measure will likely not be replicated with another one. Carlson and Herdman (2012) mathematically demonstrated that if two measures (*a* and *b*) correlate to $r_{a,b}$ = .30 (as a reminder, the HCT and HDT correlate to r = .21) and the first measure (*a*) correlates with an outcome (*y*) to $r_{a,y}$ = .30, the correlation between the second measure (*b*) and this outcome (*y*) can range from $r_{b,y}$ = −.95 to .95. Yet if researchers give similar labels to all these measures, they may be tempted to conclude that the findings are inconsistent. This situation could result in a "replication crisis" despite the fact that such inconsistency is to be expected. In other words, no generalization should be expected when empirically unrelated tasks are concerned. In the general discussion below, we provide recommendations to better align conceptualization and measurement.

General Discussion

We have discussed two discrepancies in human interoception research so far. A first discrepancy concerns the differences between phenomenon-based and physiological definitions of interoception. A second discrepancy relates to the lack of empirical convergence between measures supposed to evaluate the same interoception dimensions. In this section, we discuss possible solutions that are aimed at overcoming these limitations. Addressing the first discrepancy, we discuss four existing definitions of interoception and then propose a more comprehensive definition that overcomes current limitations and inconsistencies. When considering the second discrepancy, we discuss ways to refine the conceptualization of interoception to achieve greater consistency between dimensions and measures.

Recommendations for the definition of interoception

As mentioned above, the most widely accepted physiological definition of interoception (Craig, 2015; Khalsa et al., 2018), which includes only homeostatic pathways, is at odds with the phenomenon-based definition, although they have often been endorsed by the same researchers—and sometimes within a same article. Three solutions could be considered to resolve this discrepancy.

The first solution may be to accept multiple inconsistent definitions and to recommend researchers be explicit about which definition they endorse in their article. How effective this option may be is contingent on the readers' capacity to remind themselves of how different researchers are conceptualizing the construct at different points in time. Because this assumption is likely to be violated, researchers may end up misunderstanding each other and drawing invalid inferences when relying on wrong definitional assumptions.

The second solution is to endorse a purely physiological definition of interoception. Nevertheless, this definition is based on the observation that signals from every tissue can be processed by the homeostatic physiological pathways, whereas these same tissues are also processed by nonhomeostatic pathways. This suggests that homeostatic pathways are not necessary for the nervous system to process internal signals. Because no physiological pathway has been identified as being necessary and sufficient for the processing of internal bodily states, we argue that physiology should not be used to define interoception. Furthermore, the physiological definition is associated with high costs and few benefits. The measurement of interoception would be almost impossible or restricted to physiological studies or very tightly controlled experimental conditions because it would be necessary to inhibit nonhomeostatic pathways. The notion of interoception would be nonoperational at the cerebral and psychological levels; in other words, its pragmatic value would be undermined.

The third solution, the one we propose here, is to endorse a definition that includes all pathways involved in the processing of internal bodily states (i.e., to favor a phenomenon-based definition), as implicitly proposed by, for example, Berntson and Khalsa (2021) or Chen and colleagues (2021). We think this last solution should be endorsed because it overcomes the limitations inherent in the first two solutions. Note that this phenomenon-based approach does not prevent the investigation of physiological pathways underlying interoception. It is also not inconsistent with the view that on the physiological level, interoception differs continuously from exteroception (e.g., interoception may be more subserved by unmyelinated and lightly myelinated fibers than exteroception; Carvalho & Damasio, 2021). We, however, argue that current knowledge does not allow researchers to categorically distinguish interoception from exteroception on the basis of physiological indices only (e.g., interoception is not only subserved by unmyelinated and lightly myelinated fibers, and exteroception can be subserved by these fibers, too).

Existing inclusive definitions

As for a phenomenon-based conceptualization of interoception, at least four broadly inclusive definitions have been proposed in the literature (Berntson & Khalsa, 2021; Cameron, 2001a; Ceunen et al., 2016; Chen et al., 2021). The first of these definitions considers interoception as the "afferent information that arises from anywhere and everywhere within the body—the skin and all that is underneath the skin, e.g., labyrinthine and proprioceptive functions—not just the visceral organs" (Cameron, 2001a, p. 697). This definition does not limit interoception to certain physiological pathways and, therefore, is consistent with current empirical evidence showing that there are currently no specific physiological pathways dedicated to interoception (as opposed to exteroception). However, we note two limitations of this definition. First, it does not specify that conscious and nonconscious perceptions are involved, whereas the current use of this construct involves the nonconscious processing by the CNS and the conscious perception of internal states. Second, the term "afferent information" runs counter to current theoretical models and empirical observations that show that the processing of internal and external stimuli involves bidirectional communication between brain and sensorial inputs (Barrett & Simmons, 2015; Friston, 2010).

The second definition casts interoception as a multisensory, multimodal integrated percept of the body state (Ceunen et al., 2016). It is the subjective experience of the body state that is built by the CNS using all available information (i.e., somatic tissue afferents and homeostatic afferents and visual, auditory, and vestibular sensory inputs) integrated into the mid insula (Ceunen et al., 2016). This definition implies that the perception of all stimuli perceived as information on the body status by the individual is considered interoceptive. For instance, perceiving heartbeats by touching the wrist (i.e., detecting blood flow exclusively through touch) would be seen as interoceptive. This definition thus considers that interoception is involved if (a) individuals consider a stimulus as a piece of information about their body status and (b) the mid insula is involved in the processing because this brain region is seen as the central hub of interoception. We identify two main issues with this definition. First, it restricts interoception to the conscious perception of internal states even though interoception is widely accepted as including nonconscious processing. Second, it restricts interoception to the involvement of the mid insula even though other brain regions (e.g., somatosensory cortices) are also involved in the processing of internal states (see above).

The third definition, proposed by Chen et al. (2021), overcomes some of the above-mentioned issues: "Interoception includes the processes by which an organism senses, interprets, integrates, and regulates signals from within itself" (Chen et al., 2021, p. 4). This definition does not restrict interoception to some physiological pathways or systems, such as the CNS, but also includes components of the endocrine, immune, and vascular systems. However, there are two further observations worth making about this definition. First, although the term “regulates” allows for the specification that communication between the body and the brain is bidirectional (Chen et al., 2021), we find this term questionable. Indeed, it implies that regulatory processes (e.g., fat metabolism) that the CNS implements when receiving information from the body (e.g., low blood sugar) are included in the definition of interoception. Second, debates exist regarding the inclusion of some aspects of exteroception in the definition of interoception. In response to this second point, Chen et al. proposed that perception be considered interoceptive when the signal represents (rather than originates from) the internal world. Consequently, proprioception, gustation, taste, and balance perception (i.e., the vestibular system) are included in the definition of interoception. More importantly, it could mean that, for example, hearing one’s heartbeats represents interoception. We think a more appropriate solution would be to limit interoception to the processing of signals located below the skin (signals processed via the external surface of the skin being excluded) and to exclude the exteroceptive senses altogether (i.e., vision, audition, gustation, and smell) from the definition to avoid overlaps between interoception and exteroception.

The fourth definition, which was proposed by Khalsa et al. (2018), originates from Craig’s initial proposal by restricting interoception to specific physiological pathways. It has recently been endorsed by authors who specify that interoception is underpinned by several heterogeneous physiological pathways (e.g., vagal, cranial, sacral, spinothalamic, and somatosensory; Berntson & Khalsa, 2021), thereby implicitly modifying the definition of interoception. Interoception is defined by these authors as “the overall process of how the nervous system (central and autonomic) senses, interprets, and integrates signals originating from within the body, providing a moment-by-moment mapping of the internal landscape of the body across conscious and nonconscious levels” (p. 18). This definition has the advantage of (a) including all relevant physiological pathways and (b) specifying that both conscious and nonconscious processing are included. However, it does not explicitly include top-down and bottom-up perceptual processes. Furthermore, it restricts interoception to the peripheral system and CNS, whereas nonneuronal pathways (i.e., vascular, endocrine, and immune) are also involved in the processing of internal states (Chen et al., 2021).

Our recommended definition and its implications

Given the definitions discussed above and their respective limitations, we propose the following definition (for a summary of all criteria and their rationale, see Table S2 in the Appendix): Interoception includes the top-down and bottom-up processes by which an organism senses, interprets, and integrates signals from within itself and below the skin, across conscious and nonconscious levels.

Debates exist about the inclusion of certain types of signal processing in the definition of interoception. These signals include temperature, pain signals, affective touch, mechanical skin contact, and other signals (e.g., light, noise, and bitterness) processed by exteroceptive senses (i.e., sight, hearing, smell, and taste). We now discuss whether these types of signal processing are part of interoception in light of our proposed definition.

Our pragmatic definition considers the skin as the barrier of interoception, consistently with a phenomenon-based approach whereby interoception is equated with internal body processing. In addition to this criterion, however, we also exclude the involvement of the other senses (i.e., sight, hearing, smell, taste, and touch) to avoid overlap between constructs. In other words, the processing of internal states via the classical senses is not considered interoceptive. Types of processing that are excluded from this definition include tasting foods within the mouth, hearing one’s heartbeats, seeing one’s breathing-related chest movements, and seeing the redness of one’s skin. In practice, this definition means that measures intended to gauge interoceptively pure phenomena should not be contaminated by the other senses. For instance, in a task designed to measure the objective capacity to detect inspiratory occlusions (i.e., interruptions in inspiration) while breathing, subjects should not be able to hear the occlusions (Van Den Houte et al., 2021).

In addition, this definition implies that processing temperature and pain through the external surface of the skin is excluded from the definition. This is contrary to Craig’s (e.g., 2003) proposal, which considers that temperature and pain are interoceptive signals. His proposition is based on the observation that temperature and pain are perceived via small-diameter (Aδ and C) primary sensory fibers and lamina I neurons. However, as explained above, these physiological pathways should not be the key criterion used to define interoception. Moreover, although temperature and pain can indeed be perceived by C and Aδ fibers, they can also be processed by low-threshold, slowly adapting, mechanoreceptive fibers (i.e., Aβ fibers; Filingeri, 2016; Lawson, 2002).

However, although we exclude the processing of signals through the external surface of the skin, we acknowledge that homeostatically relevant external stimulations can induce internal signals (e.g., Crucianelli et al., 2021). Thermal and painful external stimuli and affective touch are all instances of external stimulations inducing internal physiological consequences or affect (Björnsdotter et al., 2010; Craig, 2008). The valence of this affect is directly related to one's current physiological needs. If someone is cold, warm stimuli will feel very pleasant. On the contrary, if people are feeling warm and remain in a hot room, they will feel discomfort. These affective triggers generate behavioral motivations aimed at maintaining homeostasis. We thus consider the processing of thermal and painful external stimuli and affective touch as the successive contribution of exteroception (i.e., the processing of external cutaneous stimulations) and interoception (i.e., the processing of internal consequences induced by external stimulations).

Furthermore, we note that our proposed definition explicitly mentions that interoception represents both bottom-up (i.e., the detection of incoming signals) and top-down (i.e., the brain's priors about the incoming signals and their causes) processes, which is consistent with the active inference theory (e.g., Friston, 2010; Seth & Friston, 2016) and recent computational models of interoception (e.g., Legrand et al., 2021; Smith et al., 2020). This means that perceptive outcomes are often the result of both types of processes. For instance, people are more likely to experience abdominal pain if they expect it (e.g., individuals know that they have overeaten) and there is an objective painful stimulation (e.g., the person's stomach is overfilled). In some contexts, it may be important to differentiate the types of priors. In particular, the outcome of tasks designed to assess the objective ability to detect internal signals (i.e., interoceptive-accuracy scores) can be influenced by detection-related priors (e.g., people that often feel their heartbeats could subsequently have a low threshold over which they acquire conscious access to these signals) but not by response-bias-related priors (e.g., people think their heart rate is high and answer accordingly). Also, although we include top-down processes related to the processing of internal states, we do not include the efferent control of the body by the CNS (i.e., regulatory aspects).

Finally, we note that our proposition may seem inconsistent with Carvalho and Damasio's (2021) recent theoretical article. In this article, the authors argued that interoception is structurally and functionally distinct from exteroception, contributing to the unique experience of feelings. Their argument consists of five main points. First, they argued that contrary to exteroception, the subject of perception (generated by the CNS) operates entirely within the object of perception (the body). Second, they claimed that interoceptors are located peripherally and centrally and that exteroceptors are located only in the distal extremities of the body. Third, the interoceptive nervous system (INS) is mainly composed of unmyelinated or lightly myelinated axons (i.e., they conduct information at low speed). Fourth, the INS signaling is disproportionately nonsynaptic. Finally, the INS is characterized by localized gaps in the blood-brain barrier, exposing these structures to blood-borne proteins and metabolites. For the authors, these different structural and functional characteristics of the interoceptive system explain the subjective nature of feelings, that is, the vagueness of some feelings (e.g., nausea) and the uninterrupted flow of sensations.

Despite the contrasting objectives of Carvalho and Damasio (2021) and ours—the former focuses on a physiological approach while we tackle the subject from a psychological point of view—our perspectives are compatible. Indeed, we do not deny that interoception can be differentiated from exteroception on the basis of physiological characteristics (e.g., the interoceptive system involves proportionally more unmyelinated fibers than the exteroceptive system), which explains the different subjective nature of the two modalities. However, we argue that physiological pathways generally assigned to exteroception (e.g., nonhomeostatic pathways) are also partly involved in interoception, and this implies that they should not be excluded from the definition of interoception. Likewise, although we agree that the conscious perception of internal states (vs. external signals) is more often vague and continuous, we also emphasize that some internal sensations are well localized and discrete (e.g., heartbeat perception). Yet performance-based measures of interoception generally focus on well-localized and discrete internal signals, therefore omitting a large part of interoception. This suggests that more behavioral measures should be developed to gauge the perception of vague and continuous internal sensations.

Recommendations for the conceptualization and measurement of the dimensions of interoception

In the second section of this article, we demonstrated that the dimensions of interoception are relatively detached from measurement. In particular, each dimension is broad and covers many loosely related phenomena. This is problematic for both the interpretability and replicability (across measures) of findings. We, therefore, recommend the development of a more comprehensive and precise conceptualization of interoception that will overcome these issues. We discuss its rationale below, paving the way for the emergence of this new conceptualization without defining its content because our aim is to offer a framework to be completed and specified in future work.

Overcoming the structural limitations of consensual conceptualizations. The current, widely accepted conceptualizations of interoception suffer from two main structural limitations: (a) an almost exclusive focus on broad and heterogeneous dimensions, generating overgeneralization (as explained above), and (b) a lack of exhaustivity through the exclusion of important interoception phenomena (e.g., nonconscious interoceptive processing). This limited coverage of interoception phenomena has several consequences. First, the literature on interoception is dominated by studies that have investigated the dimensions proposed in the accepted models. In particular, Garfinkel et al.'s (2015) model mostly focused on the detection of internal signals. Consequently, other relevant interoception phenomena (see below) remain understudied. Furthermore, researchers sometimes both endorse the accepted models and investigate interoception phenomena that are originally excluded from these same models. To overcome this discrepancy, they tend to misuse the labels from the models to describe phenomena that are actually overlooked by the models, generating conceptual confusion. For instance, the Multidimensional Assessment of Interoceptive Awareness (Mehling et al., 2012, 2018)—which includes subscales measuring the attitude toward internal states or emotional awareness—is often considered a measure of "interoceptive sensibility," although this latter term is defined as the self-perceived ability to detect internal signals and the tendency to focus on them. Besides the known measurement issues, these practices undermine the validity of interpretations in human-interoception research.

To overcome these issues, future models should include (a) constructs at different levels of specificity (i.e., have a hierarchical structure; see Comrey, 1988; Watson et al., 1994) and (b) more dimensions to cover all interoceptive phenomena. We acknowledge that broad constructs are important because they are sometimes consistent with theoretical assumptions (e.g., hypothesizing a general deficit of interoception in alexithymia; Brewer et al., 2016), structure interoception research and bridge related studies, simplify scientific exchanges (the use of specific terms can make communication overly complex), and convey a sense of belonging to researchers (i.e., belonging to the "interoception research" community). This type of broad labeling is prevalent in psychology (but also in other disciplines): for example, exteroception, cognition, emotions, attention, memory, and social cognition. However, in addition to broad dimensions, more specific constructs are also key for a research domain: By allowing more convergence between measures related to the same construct and reducing overgeneralization, they increase the validity in the interpretation and the replicability of findings across measures.

The field of memory research serves as an illustrative example. Here, a broad domain is recognized in which scholars universally agree they are studying "memory." Simultaneously, this domain is divided into subcomponents—episodic, autobiographical, or procedural memory—each explored by specialized subgroups. Among these researchers, a consensus is maintained: All are engaged in the exploration of memory, yet no one would claim that, for instance, procedural memory is equivalent to episodic memory. This organizational structure—encompassing a general concept while acknowledging distinct subcomponents—could provide an effective blueprint for studying interoception. By embracing such a model, it might be possible to maintain a coherent, unified field while still acknowledging and exploring the distinct facets within the concept of interoception.

An illustrative case: a hierarchical framework of interoception. We now illustrate how our recommendation may be operationalized. This discussion is illustrative only: The number of levels in the hierarchical framework, the number of dimensions proposed at each level, and even the very content of the proposed dimensions will require adaptations. Our main aim here is to illustrate how a new, hierarchical conceptualization may work and why it may constitute progress. Note that the hierarchy is based on only the level of specificity of constructs (vs. based on the level of psychological or physiological processing).

In this framework (for an illustration, see Fig. S1 in the Appendix), the highest level, which covers all dimensions, is interoception. We then divide interoception into broad categories (or factors). These factors are interoceptive attention (i.e., any attentional process related to internal signals), interoceptive sensing (i.e., the sense of internal signals by the nervous system across conscious and nonconscious levels), interoceptive interpretation (i.e., any interpretation, belief, attitude, and categorization of internal signals), and interoceptive memory (i.e., any memory process related to internal signals). In contrast with past conceptualizations, these factors include both conscious and nonconscious interoceptive processes, which is consistent with the definition of interoception we have proposed. Nonconscious interoceptive processes might, for instance, be measured through neuroimaging techniques, which track brain activations related to interoception, or indirect measures, which evaluate the impact of internal signals on motor reflexes (e.g., startle reflex; Alius et al., 2015), visual processing (e.g., Leganes-Fonteneau et al., 2021), and cognitive functions (Garfinkel et al., 2020).

Under these broad categories, we then identify more specific and homogeneous constructs (or subfactors). For example, interoceptive attention may include interoceptive attention bias (called "interoceptive sensibility" by Khalsa et al., 2018), interoceptive attention regulation (Mehling et al., 2018), and interoceptive distracting (Mehling et al., 2018). Interoceptive sensing may be underpinned by interoceptive detection (called "interoceptive accuracy" by Garfinkel et al., 2015), interoceptive magnitude (Khalsa et al., 2018), and interoceptive localization (called "interoceptive discrimination" by Khalsa et al., 2018). Interoceptive interpretation may be underpinned by interoceptive trusting (Mehling et al., 2018), interoceptive worrying (Mehling et al., 2018), somatosensory amplification (Barsky et al., 1990), and interoceptive emotional awareness (Mehling et al., 2018). Interoceptive memory has received less attention than previous categories. We can, however, cite the literature on retrospective bias in symptom reporting (Van den Bergh & Walentynowicz, 2016) and the memory of internal pain (Niven & Murphy-Black, 2000). We note that some constructs (e.g., somatosensory amplification) are more dysfunctional than others (e.g., interoceptive self-regulation). We, nevertheless, consider each of these constructs as being dimensional because they include functional, subclinical, and clinical levels. Finally, we also acknowledge that relationships can exist between factors and between subfactors.

Under these subfactors, we may have even more specific and homogeneous constructs. The lower level includes constructs whose definition is directly tied to the measure outcomes (i.e., measure-related subfactors). At this level, we have one measure for each construct. For instance, the original HCT (Schandry, 1981) may be considered a measure of the capacity to estimate heart rate via mental counting.

Past research has shown that low convergence exists between different measurement types (e.g., questionnaires, behavioral tasks, and imaging techniques) and bodily domains (e.g., cardiac, respiratory, and gastrointestinal; Ferentzi et al., 2018), which can lead to heterogeneous conclusions. Hence, when no evidence of sufficient convergence between measures or bodily domains exists or when there is evidence of divergence between them, we recommend specifying the type of measurement used (e.g., self-report vs. objective interoceptive accuracy) and the bodily domain (e.g., cardiac vs. respiratory interoceptive accuracy) under investigation to decrease the risk of overgeneralization. In some contexts, it may even be relevant to specify other sensory characteristics, such as the type of receptors, fibers, and neurons involved. Future empirical studies will be needed to identify the level of specificity of the conclusions that can be drawn, depending on the context of or theoretical framework applied by the researcher.

This framework illustrates our recommendations to solve the structural limitations of current conceptualizations of interoception. Future studies will be required to develop a more valid and complete hierarchical conceptualization of interoception. Yet we believe that a hierarchical and more comprehensive model will prove helpful. Various researchers have recently begun developing more homogeneous constructs. For instance, in the self-report domain, researchers have proposed to differentiate questionnaires based on the bodily system (e.g., cardiorespiratory and gastrointestinal; Vlemincx et al., 2021), the phenomenon (interoceptive attention vs. accuracy; Gabriele et al., 2022; Murphy, Brewer, et al., 2019), and the type of physiological activation (e.g., activation vs. deactivation; Vlemincx et al., 2021).

Even more recently, a new conceptual framework of interoception was proposed (Suksasilp & Garfinkel, 2022). Similar to our perspective, the authors proposed a comprehensive assessment of interoception and distinguished between bodily axes. Although they also proposed a "hierarchical" framework, their aim was to differentiate dimensions based on the level of processing (vs. the level of specificity). These dimensions go from the interoceptive signals (i.e., their strength and nature) to higher-order processes such as attention to and interpretation of the internal signal. The authors also included preconscious processing of internal signals. This framework is therefore very consistent with our proposition but also complementary; we recommend including (and differentiating) dimensions based on their level of specificity, whereas they proposed to differentiate dimensions based on the level of processing.

Construct validation. To develop a new conceptualization of interoception with valid measures, we recommend the construct-validity approach to objective scale development (Clark & Watson, 2016, 2019; Strauss & Smith, 2009). This will help researchers build new (homogeneous or heterogeneous) constructs and develop psychometrically sound measures. Recently, Clark and Watson (2019) proposed 13 steps to perform construct validation. This process encompasses the clear conceptualization of target constructs and the use of cross-method analyses (e.g., questionnaires and interviews) to validate them.

The development of a new conceptualization should integrate theoretical models and empirical data. Future studies could, for instance, administer multiple interoception measures (e.g., behavioral tasks and questionnaires), ideally under different conditions (e.g., at rest vs. under physiological activation), and perform factor (or network) analyses to explore the dimensions underlying current (psychometrically sound) measures or confirm previously developed theoretical models. This process has been used to develop several taxonomies, such as in personality psychology (e.g., the Big Five) and clinical psychology (Hierarchical Taxonomy of Psychopathology; Kotov et al., 2017). However, we note that conceptualizations based on factor analysis are more likely to be valid if the measures used have good psychometric properties. Otherwise, dimensions found by these analyses could be the result of noninteroceptive processes (e.g., social desirability or response bias) or error-based variance (e.g., semantic similarities between items). This is the reason why we also recommend the development of new measures with improved psychometric properties.

In the meantime, conclusions based on results found on a specific measure should not be transferred to broader constructs (i.e., interoception and the broad categories) or other bodily domains until there is evidence of convergence between measures. For instance, it cannot be concluded that interoceptive accuracy is associated with depression based on studies showing a correlation between the HCT scores (Schandry, 1981) and depressive symptoms. This is because it is not known whether the HCT results will replicate with another measure and in another bodily system. Instead, one should adopt a conservative approach and consider that two measures, for which there is no evidence of convergence, assess two different constructs until proven otherwise.

The pragmatic value of the term "interoception." The goal of this article was not to discuss the theoretical and practical relevance of the "interoception" construct. Rather, our goal was to raise awareness of issues arising from the current use of this construct and to make constructive recommendations for better use. However, we think our conceptual analysis and recommendations will place researchers in a better position to investigate the pragmatic value of this construct. Indeed, besides providing a delimitation and simplification of reality, the construct of interoception should enable researchers to better predict other phenomena (e.g., psychopathological states) and indirectly act on them. To test this, valid interoception measures are needed. The "gold standard" for measurement validity is to quantify the convergence between measures that presumably assess the same construct and the divergence between measures that do not. A prerequisite of this convergence, however, is that the construct is specific enough. This is the reason why we recommend the development of a new conceptualization of interoception and its dimensions. Conceptual work should not be seen as separate to empirical work. To the contrary, it may be seen as its bedrock (see e.g., Bringmann et al., 2022).

Conclusion

One may be tempted to separate conceptual analyses from empirical ones. However, conceptual analyses may as well be considered the bedrock for sound scientific research. A poor conceptualization can inhibit scientific progress and generate invalid or nonrefutable theories because it is impossible to develop a coherent theory without coherent construct definitions (Aquino & Thau, 2009; Blalock, 1968; Le et al., 2010; MacKenzie, 2003; Morrow, 1983; Popper, 2002; Singh, 1991; Sober, 1981; Tepper & Henle, 2011).

Consistent with this view, in the present theoretical review, we have argued (a) that the conflation between physiological and phenomenon-based definitions of interoception is problematic and (b) that the dimensions of interoception are largely detached from their current measurement. Consequently, we called for a new phenomenon-based definition of interoception and for the development of a new hierarchical conceptualization of interoception along with the development of psychometrically sound measures.

Appendix

Table S1. Definitions of Interoception

Definitions by authors
"Interoception is a general concept which includes two different forms of perception: proprioception and visceroception" (Vaitl, 1996, p. 1).
"Perception of the functions and physiological activities of the interior of the body" (Cameron, 2001b, p. vii).
"The sense of the physiological condition of the entire body, not just the viscera" or "a homeostatic afferent pathway that conveys signals from small-diameter primary afferents that represent the physiological status of all tissues of the body" (Craig, 2002, p. 655).
"The CNS representation of visceral feelings" (Paulus et al., 2009, p. 1).
"The processing of bodily signals from the viscera and somatic tissues" (Couto et al., 2013, p. 1253).
"The encoding and representation of internal bodily signals reporting the body's physiological state" (Critchley & Harrison, 2013, p. 624).
"The sensory representation of the physiological condition of all tissues and organs of the body" (Craig, 2015, p. 304).
"The perception and integration of autonomic, hormonal, visceral and immunological homeostatic signals that collectively describe the physiological state of the body" (Barrett & Simmons, 2015, p. 14).
"The process of how the brain senses and integrates signals originating from inside the body, providing a moment by moment mapping of the body's internal landscape" (Khalsa & Lapidus, 2016, p. 2).
"The process by which the nervous system senses, interprets, and integrates signals originating from within the body, providing a moment-by-moment mapping of the body's internal landscape across conscious and unconscious level" (Khalsa et al., 2017, p. 501).
"Interoception is the representation of the internal world, and includes the processes by which an organism senses, interprets, integrates, and regulates signals from within itself" (Chen et al., 2021, p. 3).

Source: Adapted from Khalsa and Lapidus (2016, p. 2).

Table S2. Summary of the Recommended Definition of Interoception in Human Studies

Criteria	Rationale
No exclusion of some physiological pathways	The processing of internal signals involves many pathways, including those related to exteroception.
Interoception = sensing, interpreting, and integrating.	The organism senses a specific signal but also integrates multiple signals coming from different localizations and interprets them depending on its prior experiences and the context.
Proprioception and balance perception (i.e., the vestibular system) are included in the definition of interoception.	Proprioception and balance are based on information processed from the internal surface of the skin (i.e., subcutaneous tissues; muscles and connective tissues).
Exteroceptive senses (i.e., sight, hearing, smell, taste, and the somatosensory system) are excluded from the definition of interoception.	This helps to avoid overlaps between senses.
Central and peripheral nervous systems but also components of the endocrine, immune, and vascular systems are involved in interoception.	Interoception is now defined as the processing of internal signals instead of also specifying the systems involved.
Internal (vs. external) painful and temperature stimuli are included in the definition of interoception.	Interoception is now defined as the processing of internal (vs. external) signals instead of limiting it to some physiological pathways involved.
Some perceptions (e.g., temperature, pain, and affective touch) are the result of the successive contribution of exteroception (i.e., the perception of external cutaneous stimulations) and interoception (i.e., the perception of feelings induced by external stimulations).	Homeostatically relevant external stimulations can induce internal sensations.

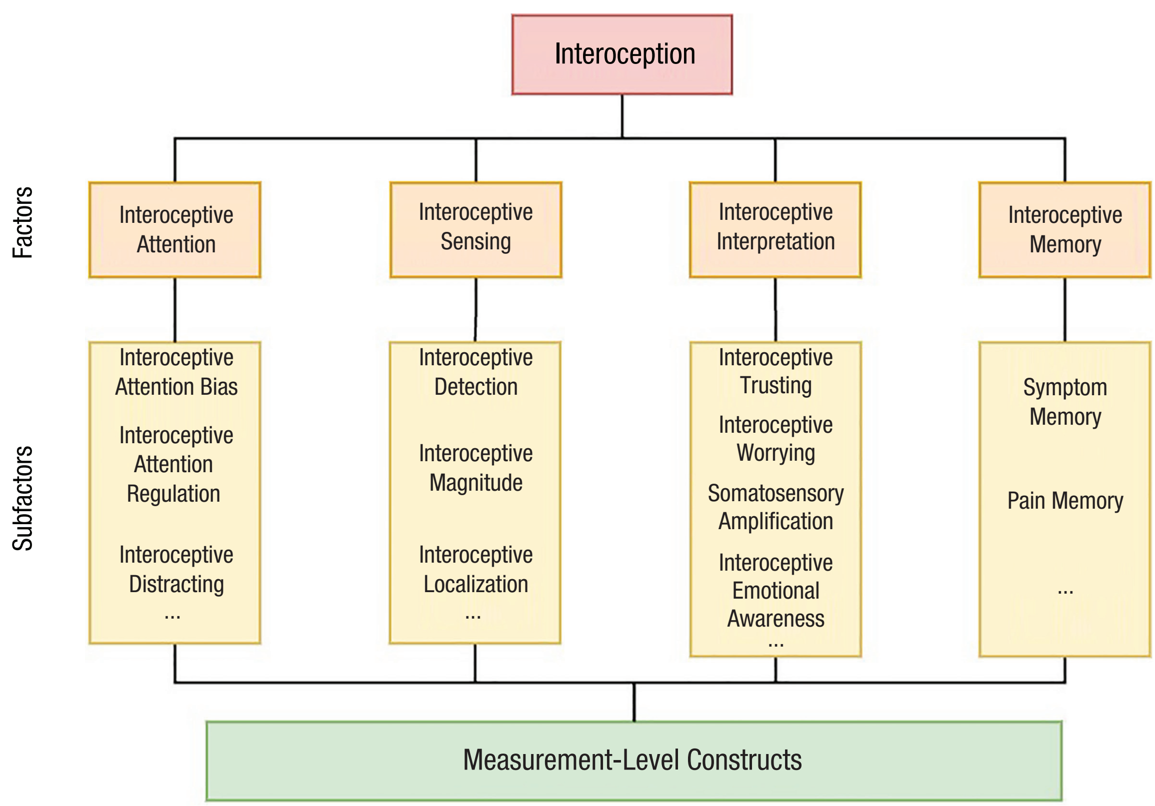

Fig. S1. The Hierarchical Framework of Interoception.
Note: The measurement type (e.g., self-report, performance-based, imaging techniques) and bodily domain (e.g., cardiac, respiratory, gastro-intestinal) should be specified.

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Notes

1. Aδ and C fibers are thinly and unmyelinated small-diameter fibers that conduct information at a slow speed.
2. Aβ fibers are myelinated large-diameter fibers that conduct information with high speed.
3. The negative correlations are generally explained by the way items are formulated. For example, some items measure detection abilities, whereas others measure the degree of perceived difficulty in interpreting nonaffective interoceptive states.

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