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Interoception in Psychiatric Disorders: A Review of Randomized Controlled Trials with Interoception-based Interventions

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Abstract

Interoception, or the process of sensing, interpreting and integrating internal bodily signals, has grown in scientific research over the past decade, but is still not well known in clinical practice. The aim of this article is to review clinical treatment interventions that utilize interoception, to synthesize the current research knowledge, and to identify the gaps where future research is needed. We conducted a comprehensive literature search on randomized controlled trials (RCT) that both include interoception in treatment interventions for individuals with psychiatric disorders and measure aspects of interoception using self-report measurements. Out of fourteen randomized controlled trials identified, seven found that interventions with interoception were effective in ameliorating symptoms. These included individuals with anxiety disorders, eating disorders, psychosomatic disorders, and addictive disorders. All of the intervention studies with positive clinical outcomes also demonstrated changes on interoceptive measurements; however, these measures were often related to specific illness symptoms. Interoception may be a mechanism of action in improvement of clinical symptomatology; however, there is a paucity of studies incorporating general, symptom-independent interoceptive measures. To further our understanding of the role interoception has in psychiatric disorders and their treatment, more studies integrating interoceptive measures are needed, along with a clearer definition of interoceptive terms used.

Keywords

interoception; psychiatric disorders; interoceptive interventions; depression; anxiety disorders; substance use disorders; eating disorders

Introduction

Mental health clinicians and researchers have long been interested in the connection between emotions and the body.¹ William James (1842–1910), who has been called “the father of modern psychology”, theorized that physiological responses in the body return to the brain as a unique pattern of bodily sensations, giving each emotion its unique quality.² Elvin Semrad (1909–1976), a well-respected Harvard psychiatrist and psychoanalyst, was known to take patients on an “affect tour of the body” and had a keen interest in “making

connections between expressed emotions and where they are felt in the body.”³ Indeed, mental health providers commonly use the body and internal bodily signals to evaluate and treat individuals with psychiatric disorders. For example, it is common to explore a patient’s tolerability of bodily sensations during therapeutic sessions, or to use specific bodily input to evoke therapeutic experiences, such as using body movements to evoke and release emotion.^{4,5}

Recent advances in neuroscience elucidate different pathways of bodily sensations, bringing increased understanding to interoception -- the process of sensing, interpreting, and integrating signals originating from inside the body.⁶ Even as interoception research has grown considerably over the past decade, it remains a concept that is not well understood in the field of psychiatry.^{7,8} At the same time, interoception research may have important and far-reaching implications for understanding the genesis, development, and treatment of psychiatric disorders. An increased understanding about how interoceptive signals influence a patients’ moment-to-moment body experience could help clinicians understand the reciprocal and iterative neurobiological processes of sensation, experience, and expectation.⁹ In a therapeutic session, for example, a therapist may help a patient to recognize discrepancies between expectation and present experience in the body, which may be important to change neurobiological prediction processes.

Given the clinical implications of this research, we will briefly review important concepts related to interoception in psychiatric disorders, including interoceptive pathways, interoceptive dysregulation, and instruments used to measure aspects of interoception in clinical research. We next present a comprehensive literature review on randomized controlled trials for psychiatric disorders that incorporate psychotherapeutic interventions designed to engage interoception while also assessing for changes in interoceptive processes.

Interoception: What does it mean and how do we measure it?

All biological systems involved in maintaining bodily homeostasis utilize interoceptive processes. These processes encompass both non-conscious and conscious levels of information processing.⁶ Challenges exist in defining and measuring specific aspects of interoception. For example, the concept of interoception is complicated by multiple definitions (for recent reviews of variable definitions, see Khalsa 2016 and Farb 2015).^{6,8} In its *narrow* sense, interoception is defined as the awareness of internal bodily signals such as heart beat, breath, thirst, hunger, desire and pain, but the definition has evolved over decades to become more comprehensive.^{7,8} The *broad* definition goes beyond pure body sensation representations and includes how individuals interpret and react to these sensations.¹⁰ Figure 1 illustrates how interoceptive processes like the perception of interoceptive stimuli (*narrow* definition) and attention and appraisal processes shape interoceptive experience and result in different interoceptive regulation (*broad* definition) strategies. In summary, interoception in the narrow sense refers to what we sense and how accurate that sensory process is, while the broader definition encompasses how we relate to what we are sensing (e.g., appraisal), as well as how we process, integrate and regulate what we are experiencing.

Table 1 includes a list of interoceptive concepts related to the self-report measurements used in clinical trials we reviewed. We follow Farb's framework as the primary scaffolding, while connecting it with other respected definitions in the current literature. Therefore, the table may not do full justice to rich literature and research related to interoception, but is meant to introduce the reader to the scope of the conceptual landscape and to guide the reader through the review that follows.

Understanding Interoception- The Narrow Definition

A well-cited classification, which is particularly useful to understand interoception in its *narrow* sense, stems from Garfinkel et al. who provide empirical support for differentiating interoceptive *accuracy* from related but distinct concepts.¹⁵ Interoceptive *accuracy* or “the objective accuracy with which a patient can report internal sensations”, can be assessed in behavioral tests such as heartbeat detection, and seems to be altered in some psychiatric conditions.^{8,15} One example is a study that finds decreased accuracy in a heartbeat detection task in individuals with Major Depressive Disorder (MDD),³⁴ and this capacity further declines with age.³⁵ Another recent study demonstrates that poor respiratory accuracy is associated with heightened anxiety scores.³⁶

Despite these findings, there are a number of drawbacks to relying on accuracy measurements, such as the variability across organ systems and between rest and dynamic states.^{6,36} Moreover, recent studies suggest a stronger association between anxiety symptoms and *insight*, a term described by Khalsa and Lapidus as self-knowledge about one's performance on interoceptive tasks.^{6,36} Garfinkel refers to the same concept as ‘metacognitive awareness’, while Farb describes it as *coherence*, as it can be calculated as the correspondence between reported self-knowledge (confidence) and objective performance (accuracy).⁶

Understanding Interoception- The Broad Definition

We turn to the *broad* definition of interoception, given that interoception in clinical trials has mostly been assessed using self-report measures that examine attention and appraisal processes. Interoceptive *quality of attention* is a concept described by Mehling and colleagues that includes aspects of interoceptive attention and *self-efficacy*.¹⁶ Appraisal has been described by Mehling as interoceptive *attitude*.¹⁶ We describe these attention and appraisal processes in more detail below.

Mode of attention describes the dichotomy between a direct, experiential awareness of body sensations versus a reflective, labeling and at times, ruminating on interoceptive signals. The training of an experiential, immediate, and non-judgmental experience represents a core aspect of many mindfulness and related mind-body interventions. Thus, interoceptive *mode of attention* may be an important component to assess mindful emotion regulation strategies. Although not the only measure, the Five Facets Mindfulness Questionnaire (FFMQ) is the most widely used mindfulness measurement that partly captures the ability to take a “mindful stance” towards interoceptive signals.¹⁷

Mehling and colleagues use the term *intensity*, which refers to a tendency to pay attention versus ignore body sensations.^{16,18} This aspect of interoceptive *attention quality* is similar to

interoceptive *attention tendency*, a trait which Farb et al. describe as “habitually attending to particular interoceptive signals.”⁸ The Scale of Body Connection is one self-report tool that has been shown to have good validity to measure interoceptive *attention tendency*, although it also overlaps with other interoceptive components (e.g. *self-efficacy* and *attitude*, see definition below).^{18,37}

Self-efficacy as it relates to interoceptive attention describes an individuals’ confidence in his or her ability to focus on a sensation, to sustain or control the *mode of attention* (see definition below), and to attain an anticipated outcome from the experience.¹⁸ By enhancing confidence, this quality may influence someone’s ability to regulate interoceptive processes. Mehling and colleagues categorize the Body Perception Questionnaire as one that measures interoceptive attention *self-efficacy*.³⁸ It includes self-report of awareness of body processes such as “swallowing frequently” or “how fast I am breathing” in general and during stressful situations.³⁸ Some components of the Eating Disorder Inventory may also be applicable here; for example, items such as “I get confused as to whether or not I am hungry” and “I don’t know what’s going on inside me” seem particularly related to the confidence aspect in interoceptive *sensibility*²², an umbrella term for assessing subjective assessment of interoceptive tendencies and skills.¹⁵

Mehling and colleagues describe interoceptive *attitude*, distinguishing between appraising body sensations as helpful (trusting *attitude*) or menacing (catastrophizing *attitude*).¹⁸ *Attitude* is another component that could be important to assess in clinical populations. Maladaptive appraisals such as catastrophizing may be captured by measurements such as the Anxiety Sensitivity Index (ASI), in items such as “When I notice that my heart is beating rapidly, I worry that I might be having a heart attack” that highlight beliefs about harmful consequences, fears of cognitive dyscontrol and somatic consequences in relation to interoceptive signals.^{16,39}

Interoceptive pathways

Interoceptive somatic and visceral signals originate from sensory receptors in the body, which relay through the spinal cord and brainstem, before reaching higher cerebral cortical areas. There, the information is represented in the posterior insular cortex, while a progressive integration of interoceptive signals with contextual, motivational and hedonic aspects occurs in anterior portions of the insula.^{39,7} This integration and contextualization is hypothesized to constitute the basis of conscious feelings, and subjective awareness.^{6,40–42}

Multiple other brain structures interact in interoceptive processes. Importantly, the anterior cingulate cortex (ACC) is highly connected with the anterior insula, and is related to appraisal and regulation of interoceptive signals.⁴ More generally, the insula and ACC are crucial hubs in the processing of salient information and guiding behavior.⁴² Finally, interoceptive experience is further shaped by (emotion) regulation and attention tendencies, related to prefrontal – “top-down” – cortical areas.⁴³

Multiple imaging studies demonstrate functional alterations in these areas related to psychiatric conditions. For example, MDD has been related to hypo-activation in the insula, while anxiety disorders and craving states in addictive disorders were related to increased

insula activation.⁴⁴ Converging evidence provided a recent, large meta-analysis of structural neuroimaging studies, which found gray matter loss across six DSM-IV Axis I diagnoses in the ACC and insula.⁴⁵ Functional MRI studies link symptom improvement MDD, anxiety disorders, and substance abuse disorder to normalizations of activity in the insula, underlying the potential clinical relevance of this interoceptive key structure.^{34,46,47} Finally, emerging evidence suggest clinically relevant changes in the functional connectivity between limbic (involved in emotional processes) and sensory systems (involved in body perception).^{48,49}

Given the complexity and non-linear translation of bodily sensations to perceptions, certain researchers characterize interoceptive perceptions as “constructed by the brain” through an active and iterative process comparing the brain’s anticipation of sensations (prediction) with incoming sensations.^{6,50} Predictions are based on previous interoceptive experiences. Thus, previous experience influences current brain representations, and highlight the role of anticipatory signals (primarily stemming from limbic systems) in influencing an individuals’ moment-by-moment body experience.^{6,9,50,51}

Interoceptive Dysregulation

Research studies in cognitive and affective neuroscience note that psychiatric disorders, particularly depression, anxiety, post-traumatic stress disorder, substance use disorder, eating disorder, and psychosomatic pain, are often accompanied by a lack of ability to detect, appraise, or respond to interoceptive signals.⁴⁵ And a growing body of literature supports the importance of interoceptive dysregulation in these disorders.^{8,9,52–55}

The idea that components of interoception can be altered through treatment is important for the mental health field. *Interoceptive regulation* is a term described by Farb et al. as “how well a person can match an interoceptive signal to his or her desired state” and involves at least two approaches.⁸ One main way that individuals may achieve regulation includes techniques of reappraisal, suppression or distraction (an approach Farb et al. call *active inference*).

In anxiety disorders, interoceptive dysregulation can result in increased focus and sensitivity to interoceptive stimuli.⁵³ For example, an individual with panic disorder may anticipate a bodily sensation such as heart rate increase and when this occurs during daily activities, such as exercise, the individual might interpret the heart rate increase as an impending panic attack. The neurobiologic concept that “what you experience is in large part a reflection of what your brain predicts is going on inside your body” may ring true here.⁹ One can understand this experience using an interoceptive framework: for example, catastrophizing interoceptive *attitude* leads to increased fear and potentially leads to a more ruminative interoceptive *mode of attention*. This may lead to a high level of interoceptive *attention tendency* and leave an individual with low levels of interoceptive attention *self-efficacy* and the belief that he or she is no longer in control.

A provider might help this individual to regulate her interoceptive experience by either *active inference* techniques, such as distracting from feeling the heart (find tools to move the attention away from the interoceptive stimulus, e.g. listen to music). A provider might also

help this individual to re-interpret the meaning of increased heart rate through cognitive reappraisal. Indeed, this set of techniques are most often used in clinical psychiatry, as the goals of our treatments are often aimed at decreasing symptoms through active means, such as taking a medication or using an active coping skill.

A second main approach to *interoceptive regulation* involves shifting the desired state by “updating the expected simulation map to more accurately reflect the immediate sensation” through more contemplative techniques such as using equanimity, curiosity, or acceptance.⁸ The simulation map is an integrated, abstracted and interpreted representation of the current body state, which forms the basis of a person’s embodied experience, and which might differ more or less from the actual, ‘raw’ ascending interoceptive signals.⁸ This approach, described by Farb et al. as *perceptual inference* is how many mindfulness-based approaches are thought to work (see Figure 1). Whereas mindfulness in this context is most commonly defined as paying attention, on purpose, without judgment to the present moment, perceptual inference can be thought of as applying this approach to the body.^{8,56} Returning to the case of an individual with anxiety disorder, a mental health provider might invite the individual to become curious about the sensations in the chest experienced as a racing heart and to observe it without attempting to change it, using a variety of mindfulness-based techniques.^{57,58} An example is the concept of “observe and describe” used in Dialectical Behavior Therapy.⁵⁹

Methods

A comprehensive literature review was done on interoceptive treatment interventions and specific psychiatric disorders, by searching for affective disorders, anxiety disorders, eating disorders, addictive disorders and psychosomatic disorders. The authors searched “interoceptive”, “interoception”, or “body awareness” and each psychiatric disorder separately in PubMed, Harvard On-Line Library Information System (Hollis+), and PsychInfo by searching: “interoception” or “body awareness” AND either “affective disorders”, “depression”, “anxiety”, “eating disorders”, “psychosomatic”, and “addiction” or “addictive disorders.” To be comprehensive and inclusive, the authors also searched separately for “body awareness AND treatment” in PubMed. Criteria for inclusion: randomized controlled trials, studies with adult, adolescents or children populations who had known psychiatric disorders (clinical populations), intervention studies including at least one measurement with an interoceptive component AND interoception-based interventions. Interoception-based interventions were broadly defined as interventions that include “first-person reflection upon or cultivation of specific modes of experience, and practices that explicitly involve interoceptive awareness” as discussed by Farb et al.^{8,60,61} Abstracts were read and excluded if they were not related to psychiatric disorders, i.e, non-clinical populations, or were not primarily intervention studies. Additionally, studies were excluded if the only intervention was psychotropic medications. These studies were reviewed by two different doctoral-level staff who reached consensus about the results and quality of study, and the search was continued throughout the writing phase to ensure an up-to-date review. Thus it includes articles published until August 2016. All included studies concerned adult clinical populations.

In addition, to better understand the results of the studies reviewed, we attempt to classify the commonly used clinical and general interoception-related self-report measures and include this in the Interoception Measurement (Component) section of Table 2.

Results

A comprehensive review of interoceptive intervention studies yielded fourteen randomized controlled trials and seven of these revealed statistically significant positive results with respect to primary outcomes and interoceptive measurements (see Table 2).

These include:

1. Three studies using interoceptive exposure as part of the intervention for panic disorder, which found statistically significant decreases in anxiety symptoms, such as panic attack frequency and panic severity, with corresponding decreases on the ASI.^{39,63,64,66} While components of the ASI clearly overlap with anxiety symptoms, specific components (such as Factors 1 and 4) measure catastrophizing interoceptive *attitude*, per our review.
2. One study examining a self-help intervention, which incorporated self-monitoring of binge eating triggers and finding pleasure from eating for individuals with binge eating disorder.⁶⁷ This intervention resulted in statistically significant decreases in binge eating behaviors and corresponding decreases in Eating Disorders Inventory (EDI) subscales, including the interoceptive awareness subscale (EDI-IA).^{22,67} As part of our review, we characterize the EDI-IA as measuring primarily interoceptive *self-efficacy*.
3. One study including individuals with irritable bowel syndrome found improved outcomes on several indices for interoceptive exposure therapy over attention control, and some improvement over the stress management intervention, with corresponding changes on the Visceral Sensation Index (VSI) and the Pain Vigilance and Awareness Questionnaire (PVAQ) measures.^{25,26,72} We characterize the VSI and PVAQ as measuring primarily interoceptive *attitude*.
4. One study involving women with substance use disorders (primarily alcohol but also opiates and stimulants), which found that a Mindful Awareness in Body-Oriented Therapy program had a moderate to large effect; outcomes of the intervention included significantly fewer days using substances compared with treatment as usual three months post-intervention.³⁷ However, at nine month follow-up, the primary outcome of percent days abstinent was no longer significant, while components of the Scale of Bodily Connection (SBC) such as bodily dissociation, had improved.^{19,37} We characterize SBC as primarily measuring interoceptive *attention tendency*.
5. One study examining individuals with chronic pain and co-morbid depression found that Mindfulness-Based Cognitive Therapy increased Self-Regulation, Emotional Awareness, and Not-Distracting subscales of the MAIA and that the Not-Distracting subscale mediated depression severity.^{18,69} We characterize

these subscales of the MAIA as measuring primarily *interoceptive attention quality*, including interoceptive *attention tendency*, *self-efficacy* and *mode of attention*.

All of the RCTs with a positive finding on the primary outcome also found changes in interoceptive measurements. However, many of these studies are difficult to interpret. For example, the RCTs examining the role of interoceptive exposure for panic disorders utilized measurements such as the Anxiety Sensitivity Index with substantial overlap between the primary outcome and an interoceptive measurement. Additionally, self- versus clinically-reported differences are interesting to note. For example, Craske and colleagues found no difference in the ASI between individuals with panic disorder engaging in Cognitive-Behavioral Therapy (CBT) + interoceptive training compared with supportive therapy, and no differences in self-monitored panic record; however, the authors found significant differences in the clinician-rated Anxiety Disorders Interview Schedule-Revised (ADIS-R), which similarly measures worry about panic symptoms and appraisal of interoceptive cues.^{27,65}

Notably, the recent study by de Jong et al. was the first study using the MAIA in a sample of patients with chronic pain and acute depression.⁶⁹ This study suggests that a –Mindfulness-Based Cognitive Therapy (MBCT) intervention that enhances *perceptual inference* through mindfulness training and *active inference* through cognitive therapy can improve *interoceptive regulation*. Compared with the Treatment as Usual Group, the MBCT group had significantly greater increases on the MAIA factors of Self-Regulation, Not Distracting, and Emotional Awareness, as well as decreases in Pain Catastrophizing. Specifically, improvements in depression severity were related to the factor Not Distracting, which suggests that enhancing this *quality of attention* (not avoiding uncomfortable body sensations), may be crucial to improving symptoms of depression in chronic pain populations. This study supports the notion that body awareness mediates the effects of MBCT on depression.

Studies like de Jong et al.'s, which use diagnosis-independent, interoceptive questionnaires, are still rare in clinical intervention studies. The rarity of diagnosis-independent interoceptive questionnaires make it hard to draw conclusions about the effects of interoceptive trainings on changes in interoception in general.

Two other studies used a non-diagnosis specific measure of interoception. One such study was the one by Price and colleagues involving women with substance use disorders discussed above, which had significant outcomes at three months but not at nine months post-intervention.³⁷ The other is the study by Danielsson and colleagues that used the Scale of Body Connection (SBC) questionnaire and depression measures to study the effects basic body awareness training versus aerobic exercise or single a physical activity consultation, in sixty-two patients with current major depressive disorder.^{19,24} In this study, only aerobic training resulted in significant improvements in depression severity compared to the single consultation, and body awareness training was not superior to aerobic training regarding changes in SBC scores.

Discussion

A comprehensive review of interoceptive intervention studies for psychiatric disorders revealed fourteen randomized controlled trials, half of which were effective for improving primary outcomes, such as psychiatric symptoms and functioning. All of these positive trials also demonstrated some positive change in self-report interoceptive measurements. The seven positive randomized control trials included individuals with panic disorder, binge eating disorders, psychosomatic disorders, co-morbid chronic pain and depression, and addictive disorders. Importantly, this review found a small sample of studies and had some methodological limitations. Yet, the evidence in this initial systematic review suggests the possibility that some interventions targeting interoceptive regulation may offer a potential benefit for various types of psychiatric disorders. This demonstrates the need for more well-designed RCTs across several categories of psychiatric diagnoses investigating the efficacy of interoception-focused interventions while also utilizing instruments that measure the effects on multiple facets of interoceptive regulation.

In our review, some interventions were more often investigated than others, especially those particularly suitable for certain disorders. For example, the most common type of interoceptive intervention for psychiatric disorders was interoceptive exposure as part of CBT training. In this review, interoceptive exposure with CBT was found to be effective in four of the five studies for individuals with panic disorder, one study of individuals with Binge Eating Disorder, and in a study on individuals with Irritable Bowel Syndrome.^{63–67,72}

Additionally, a preliminary review of non-randomized trials also suggested efficacy of interoceptive exposure for individuals with panic disorders; two pilot studies examining the use of interoceptive exposure demonstrated decreased ASI, as well as decreases in other measures of anxiety symptoms.^{74,75} A third study of individuals with panic disorder found that CBT with interoceptive exposure training was effective in reducing anxiety symptoms, and was significantly associated with changes in self-report measures of attention focus to internal bodily sensations (the Body Vigilance Questionnaire, or BVQ), and fear associated with common autonomic arousal sensations (the Body Sensation Questionnaire, or BSQ).⁷⁶

The prominence of studies related to panic disorder may explain the reason for interoception being mentioned primarily as part of the negative valence system of acute threat (fear) in the National Institute of Mental Health Research Domain Criteria.⁷⁷ As further research on the role of the insula and interoceptive interventions across others psychiatric conditions occurs, it seems likely that interoception may have a role in multiple National Institute of Mental Health Research Domain Criteria (RDoC) systems, such as other aspects of negative valence, some aspect of positive valence systems, as well as arousal and social processes. Due to the impact of interoception on multiple systems, Khalsa et al even proposed that interoception might represent its own RDoC domain.⁶

This review found evidence of interoceptive interventions and psychiatric illness being associated not just with the negative valence system of acute threat and panic disorder, but also with other psychiatric disorders related to positive valence systems. For example, studies of CBT with interoceptive exposure in eating disorders have demonstrated

statistically significant decreases in EDI-IA scores, perhaps reflecting primarily increased interoceptive *self-efficacy*, as well as decreased eating disorder symptoms.^{78–80} Interestingly, one of these studies also found that EDI-IA scores at baseline predicted outcome in the short term and at follow-up.⁷⁹ Additionally, a case series of twenty individuals with anorexia nervosa undergoing cognitive remediation therapy showed improved neuropsychological functioning and impulse control, along with improvements in body awareness (as measured with subscales of the EDI-IA).⁸⁰

In addition, our review found two studies using interoception in substance use disorders with differing results; the mindfulness based intervention showed some statistically significant results, while CBT for interoceptive cues did not.^{37,73} Paulus and colleagues review treatment for interoceptive dysfunction in addiction and highlight potential approaches to modulate interoceptive function and insular activation patterns, including mindfulness-based approaches and physical exercise.⁸¹ Paulus and colleagues also discuss the role of increasing the frontal control network and reducing urges through cognitive training.⁵⁴ Regardless of the treatment approach, Paulus and colleagues have demonstrated that remission status can affect interoceptive processing, using a series of fMRI studies with Methamphetamine users, noting that participants with active methamphetamine use had significant attenuation of both negatively- and positively-valenced interoceptive processing in the insula while those who were abstinent for at least one year showed attenuated processing of positively-valenced interoception alone.⁸²

These findings all together suggest that CBT with interoceptive training components may be particularly helpful for anxiety and eating disorders, and might be effective for some psychosomatic disorders. While clearly more research is needed to elucidate the role of interoceptive treatments in psychiatric disorders, it is imperative that mental health clinicians are aware of and utilize interventions that have demonstrated success, such as integrating interoceptive exposure in anxiety treatments. Despite the strong evidence base, a study revealed that only 12–20% of psychotherapists report including it in their treatment approach.⁸³

Interoceptive training in CBT interventions raises interesting questions about how each component of the intervention targets the two specific aspects of *interoceptive regulation* – *perceptual inference* and *active inference*.⁸ CBT with interoceptive training likely enhances both regulatory skills. While CBT includes *active inference* intervention components, interoceptive exposure techniques also include *perceptual inference* strategies of intentional observation with curiosity and acceptance and an assumption that an interoceptive experience can change simply by allowing and observing this experience.

In fact, many of the interventions reviewed use a combination of *interoceptive regulation* techniques. For example, the guided online self-help intervention, which was found to be effective in an RCT for individuals with binge eating disorder, involves both regulation techniques. The intervention included *active inference* techniques, such as cognitive restructuring, problem solving, and also techniques that focus on self-observation and mindful eating exercises, which train *perceptual inference* strategies.⁶⁷

While offering training on both *perceptual inference* and *active inference* within an intervention is likely to increase the treatment's efficiency, it is still valuable to study components separately and to elucidate which mechanisms might be particularly helpful for which patient population. Such studies are still very rare. In one such study, Arntz and colleagues compared interoceptive exposure (IE) to cognitive training (CT) without exposure training for individuals with panic disorder and failed to show any between-group difference in panic frequency, anxiety scores or idiosyncratic assumption questionnaire.²⁹ In fact, both treatments were effective in reducing panic frequency and anxiety scores, although only in the cognitive therapy arm did idiosyncratic beliefs about the catastrophic nature of bodily sensations correlate strongly with symptoms at follow-up; this suggests that reduction in these beliefs may be essential in CT but not in IE and that the two types of treatment use different mechanisms.²⁹

Current evidence on efficacy and mechanisms related to *interoceptive regulation* after Mindfulness-Based Interventions (MBI) or related interventions (e.g. body awareness training) that target *perceptual inference* more directly, is less clear. This is mainly due to the lack of separate measures related to aspects of *interoceptive regulation* in RCT's on MBIs, and thus the very low number of RCT's in clinical populations. Our review included one RCT on MBCT with an outcome measure of interoception and four RCT's on body awareness training. From those studies, only the MBCT for chronic pain and depression and the body awareness training among people with substance use disorders seemed to improve both symptoms as well as interoceptive measures.^{37,69} Body awareness studies in chronic pain and depression alone, or in eating disorders did not show significant improvements in these measures compared to a control group. Certainly more work is needed to examine the effects of MBIs and similar trainings on body awareness mechanisms in different populations; from our preliminary data, they appear not superior to more cognitive-based interventions that include interoceptive elements.

A main finding in the sparse number of RCT's in our review is that even though interventions with interoceptive elements are studied, they do not often include measurements related to body awareness. Additional RCT's with measures related to body awareness and interoception are needed to clarify mechanisms of improved *interoceptive regulation* on symptom outcomes. Another problem is the lack of a common framework for assessing *interoceptive regulation*. Using clear definitions of interoceptive terms and mechanisms is thus needed in studies incorporating measures of interoception.

Most studies reviewed here included primary outcome measurements related to interoception, because they were closely related to core problems in their studied population, e.g. increased sensitivity and reactivity to internal stimuli in panic disorders (assessed by the ASI). We categorized the ASI as measuring catastrophizing interoceptive *attitude*, but it also is closely linked to the symptoms of anxiety disorders. For studying mechanisms related to *interoceptive regulation* more generally, the authors recommend using overarching questionnaires, such as the MAIA. Strengths of the MAIA self-report measure include that it is general and non-diagnosis specific, with components that can capture many facets of *interoceptive regulation*. Preliminary studies with non-clinical populations using *perceptual*

inference interventions such as contemplative training suggests that multiple facets of the MAIA can be improved through interoceptive interventions.⁸⁴

Finally, this review included randomized controlled trials that utilized interoception-related self-report measurements only. In addition to assessing overarching questionnaires, i.e., MAIA, several other measurement options could be considered in future trials. One recent suggestion by Khalsa and colleagues is to develop a standardized psychophysiological battery, which assesses a patient's responses to interoceptive challenges across several systems (e.g., cardiovascular, respiratory, and gastrointestinal) to obtain "real time calibrated dose" and a "patient-specific 'interoceptive profile,' which can demonstrate "where abnormalities occur."⁶ Additionally, the utility of including measurements such as interoceptive *insight* (as referred to by Khalsa and colleagues) or metacognitive awareness about interoceptive task performance (as referred to by Garfinkel and colleagues) may be a promising route for future studies utilizing psychiatric populations.^{6,15}

Challenges/Limitations

This review may underestimate the efficacy of interventions that target interoception due to strict inclusion criteria in the review. For example, there exist positive interoceptive intervention studies that do not include interoceptive measurements, such as a RCT by Pollack and colleagues.⁶⁷ While not included in our review, this study demonstrated efficacy of CBT for reducing sensitivity to interoceptive cues associated with drug craving when compared with counseling for women with substance use disorders.⁶⁷ In addition, by excluding non-clinical populations, this review excludes a large body of literature on interoception. On the other hand, publication bias (i.e. not reporting null findings) is a potential limiting factor for our review, and would lead to over-estimating the efficacy of these interventions. Finally, the scope of this review was limited by the breadth of the type of interventions included in the review. As stated in the methods, studies were excluded that did not involve an interoception-based intervention broadly defined as including "first-person reflection upon or cultivation of specific modes of experience, and practices that explicitly involve interoceptive awareness"; therefore, excluding studies in which the only intervention was psychotropic medications. While it was important to narrow the focus of the review, future efforts to review the literature may choose to include other interventions as well.

Another limitation refers to search terms utilized. For example, a search was used for "addictive disorders" rather than "substance use disorders." The former search term was chosen as a way of capturing past evidence base, since we thought that recent DSM-V changes in terminology would result in the latter search team only capturing the most recent studies. In addition, search results are influenced by author's chosen key-words such as "body awareness" or "interoception", which some authors would use for highly symptom related questionnaires (ASI); other authors might not tag studies using diagnosis-independent questionnaires such as the MAIA with the key-word "body awareness", as it might only be one of many outcome variables or a secondary outcome variable in their study. Thus, as specific questionnaires were not searched for, this review might have missed other studies that failed to tag "interoception" or "body awareness." Moreover, a recent study indicates that the number of articles measuring facets of interoception without

referencing the concept has grown exponentially over the years, which further complicates a comprehensive review of the literature and limits the results of our findings.⁶

A lack of clear definitions of interoceptive terms in the literature challenged our ability to capture all studies involving interoception in this review, but a number of techniques were used to try to mitigate these challenges. Additionally, interoceptive concepts were compiled and clarified by reviewing and comparing taxonomy by a few respected authors in the field and including concepts as applicable to assessments used in clinical studies. Certainly, the variability of the interventions included in this study, as well as the variability of follow-up (ranging from zero to eighteen months post-intervention completion) makes it difficult to draw direct comparisons.

In sum, more studies are needed that focus attention on specific aspects of interoception, in terms of measurements used to estimate *interoceptive regulation* and interventions that seek to enhance it. This review demonstrates a current understanding of interoception in terms of known neurobiologic pathways, and attempts to clarify how interoceptive terms relate to measurement tools currently used in clinical intervention studies. *Interoceptive regulation* as a model of potential symptom improvement and enhanced well-being may have future relevance for a myriad of psychiatric disorders.

Conclusions

Despite limited evidence, a number of RCTs show efficacy of interventions incorporating interoceptive components for several psychiatric disorders. These RCTs revealed symptom reduction and corresponding improvements on interoception-related measures. The most studied interoceptive intervention-type in RCTs for psychiatric disorders was CBT with interoceptive exposure, which incorporates both *active* and *perceptual inference* techniques and appears to enhance *interoceptive regulation*. However, most interoceptive measures reported in these studies had some overlap with typical symptoms related to the disorder. Assessments using diagnosis-independent measures of interoception and interoceptive regulation, e.g., Multidimensional Assessment of Interoceptive Awareness (MAIA), are still rare in clinical and intervention studies. Future studies that incorporate more general measures and that clearly target the various facets of interoception will enhance our knowledge of interoceptive mechanisms involved in treatment for psychiatric disorders.

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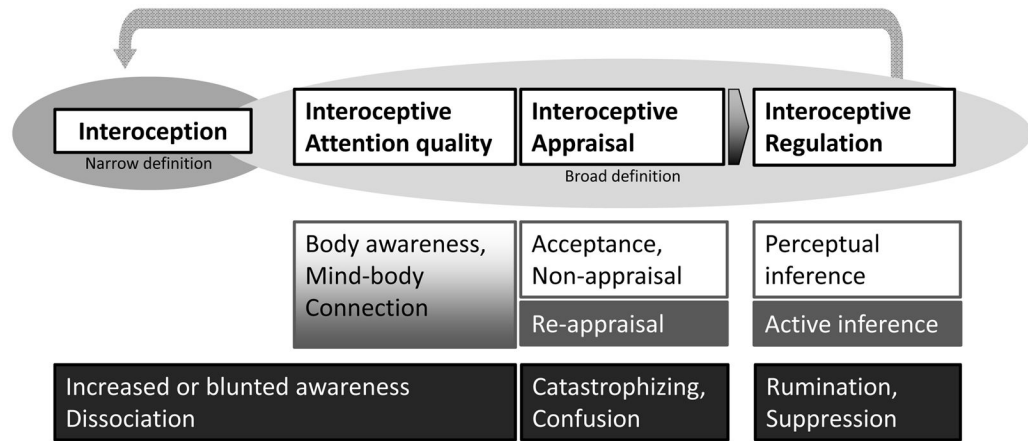


Figure 1.

Interoceptive processes like the perception of interoceptive stimuli (Interoception in the narrow definition) and the following attention and appraisal processes, are influenced by trait-like tendencies and skills, such as accuracy, attention tendency, self-efficacy, mode and attitude towards interoceptive experiences. Together they can result in different – conscious or unconscious – regulation strategies, similar to classic emotion regulation processes. Interoceptive regulation influences the perception, attention, and appraisal processes of interoceptive signals.

In White boxes are the mindfulness-based approaches related to each step of the interoceptive process (perceptual inference). In Grey boxes are common psychotherapeutic and cognitive approaches (active inference). White/Grey box contains strategies pertinent to both. In Black boxes, are common, maladaptive approaches related to each step, which are often related to psychiatric symptoms/disorders. Together, they can be summarized as interoceptive dysregulation.

Table 1

Glossary of Interoceptive Terms

Interoceptive Terms	Definitions	Measures
Accuracy	Reliably discriminating interoceptive signals from noise or competing signals; correct and precise monitoring. ¹¹⁻¹³	Heart beat detection task (HBDT) via Mental Tracking Method or revised approach. ^{11,14}
Insight	Metacognitive awareness or self-knowledge about interoceptive task performance. ^{6,15} Farb refers to this as coherence. ⁸	Confidence-accuracy correspondence, quantified using a receiver operating characteristic (ROC) curve analysis. ¹⁵
Quality of Attention	An umbrella concept described by Mehling and colleagues that include some aspects of interoceptive attention and self-efficacy, as listed below.	
Mode of Attention	Thinking and labeling vs. experiencing the present moment immediacy of sensations. ¹⁶	<ul style="list-style-type: none"> • <i>FFMQ</i>⁷ • <i>MAIA</i>¹⁸
Attention Tendency	Attending preferentially or habitually to particular interoceptive signals (compared to exteroceptive signals). ⁸ Similar to Mehling and colleague's concept of intensity. ¹⁶	<ul style="list-style-type: none"> • <i>Scale of Body Connection (SBC)</i>¹⁹ • <i>Body Investment Scale (BIS)</i>²⁰ • <i>State-Trait Anxiety Inventory</i>²¹ • <i>Five Facet Mindfulness Questionnaire (FFMQ)</i>¹⁷ • <i>Multidimensional Assessment of Interoceptive Awareness (MAIA)</i>¹⁸
Self-efficacy	Confidence in interoceptive ability, such as ability to focus on sensations, control the mode of attention during interoception tasks or regulate interoceptive signals. ¹⁶	<ul style="list-style-type: none"> • <i>Eating Disorder Inventory (EDI) (inverse)</i>²² • <i>Body awareness rating scale (BARS)</i>²³ • <i>SBC</i>²⁴ • <i>MAIA</i>¹⁸
Sensibility	Umbrella term for subjective assessment of interoceptive tendencies and skills; the extent to which people believe they focus on and detect bodily sensations. ¹⁵	
Attitude	Trait-like bias towards appraisal or non-appraisal of the perceived sensation, i.e. cognitively modifying the perceived sensation ¹⁶	<ul style="list-style-type: none"> • <i>Visceral Sensitivity Index (VSI)</i>²⁵ • <i>Pain Vigilance and Awareness Questionnaire (PVAQ)</i>²⁶ • <i>Anxiety Sensitivity Index (ASI)</i>²⁷ • <i>BIS</i>²⁰ • <i>Body Attitude Test</i>²⁸ • <i>Idiosyncratic Assumptions</i>²⁹ • <i>Arthritis Self-Efficacy Scale (ASES)</i>³⁰ • <i>Coping Strategies Questionnaire</i>³¹ • <i>Pain Catastrophizing Scale</i>³² • <i>Hyperventilation questionnaire</i>³³
Interoceptive regulation	A term described by Farb et al. as "how well a person can match an interoceptive signal to his or her desired state" and involves at least two approaches. ⁸	
Perceptual inference	Updating the expected interoceptive sensation (simulation map) to more accurately reflect the actual sensation; broadening sensory expectations to reduce the disparity between expected and experienced states. Includes techniques such as acceptance, equanimity, and observance. The simulation map is an integrated, abstracted and interpreted representation of the current body state, which forms the basis of a person's embodied experience, and which might differ more or less from the actual, 'raw' ascending interoceptive signals ⁸	

Interoceptive Terms	Definitions	Measures
Active inference	Changing the actual interoceptive sensation to reflect the simulation map; reduce the disparity between expected and experienced states. Includes techniques of reappraisal, suppression or distraction. ⁸	

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Table 2

Randomized Controlled Trials of Interoceptive Interventions with Psychiatric Disorders

Psychiatric Disorder	Intervention	Control Group	Interoception Measurement (Component)	Primary outcome Measure	Results
Major Depressive Disorder					
Danielsson et al. (2014) ⁶² (n=62)	Basic body awareness treatment as augmentation	Exercise or advice	Scale of Body Connection (Tendency)	Depression severity, (MADRS, MADRS-S) or SBC	Not statistically significant in depression severity (MADRS, MADRS-S) or SBC
Panic Disorder					
Amtz (2002) ²⁹ (n=69)	Interoceptive exposure	Cognitive Training	Idiosyncratic Assumptions (Attitude) TAL-T (Tendency)	Panic frequency	No difference in panic frequency, anxiety scores or idiosyncratic assumptions
Botella et al. (2007) ⁶³ (n=37)	Virtual reality Exposure Panic Control Therapy	Waitlist	Anxiety Sensitivity Index (ASI) ^{**} (Attitude)	Panic severity and frequency, agoraphobia	↓ASI, Panic severity and frequency, agoraphobia, BDI [*]
Carter et al. (2003) ⁶⁴ (n=25)	CBT including interoceptive training	Waitlist	ASI ^{**} (Attitude) Hyperventilation questionnaire (HQC) (Attitude) STAI-T (Tendency)	Frequency of panic during SCID; severity of agoraphobic avoidance (MIAL/MIAC) Panic frequency	↓ASI, HQC, freq. panic, STAI-T, STAI-S, MIAL, MIAC [*]
Craske et al. (1995) ⁶⁵ (n=30)	CBT including interoceptive training	Supportive therapy	ASI ^{**} (Attitude) ADIS-R (Attitude)	Panic frequency (panic attack record); fear questionnaire	No difference on ASI or self-monitored panic record. ↓ADIS-R, ↓fear questionnaire self-rating, social subscales [*]
Peterson & Cesare (1996) ⁶⁶ (n=27)	CBT including interoceptive training	Waitlist	ASI ^{**} (Attitude)	Panic Attack Record, physiologic measures	↓ASI, panic attack frequency [*] ; no physiologic changes
Binge Eating Disorder					
Carrard et al. (2011) ⁶⁷ (n=74)	Guided self-help on internet	Waitlist	Eating Disorder Inventory-2 IA (EDI) (Self-efficacy)	Binge eating behavior, EDI subscales drive for thinness, body dissatisfaction, objective binge episodes, overall	↓Binge eating behavior, EDI subscales drive for thinness, body dissatisfaction, objective binge episodes, overall

Psychiatric Disorder	Intervention	Control Group	Interoception Measurement (Component)	Primary outcome Measure	Results
Eating Disorders (Anorexia nervosa & Bulimia nervosa)					
Catalan-Matamoros et al. (2011) ⁶⁸ (n=28)	Basic Body Awareness	Standard Treatment	Eating Disorder Inventory-2 IA (Self-efficacy) Body Attitude Test (Attitude)	Eating Attitude Test-40	Body Attitude Test trend towards effectiveness and ↓EDI-IA but not statistically significant
Chronic pain and Comorbid Depression					
De Jong, et al. (2016) ⁶⁹ (n=40)	Mindfulness- Based Cognitive Therapy	Treatment As Usual	MAIA (Self-efficacy, mode, tendency) Pain Catastrophizing Scale (PCS) (Attitude)	Quick Inventory of Depressive Symptoms-Clinician Rated (QIDS-CR)	↑Self-Regulation subscale, Not Distracting subscale mediated depression scores, ↓PCS, ↓QIDS-CR*
Fibromyalgia					
Kendall et al. (2000) ⁷⁰ (n=90)	Body Awareness training (BAT)	Mensendiaak System (MS)	Coping strategies questionnaire (Attitude) Arthritis Self-Efficacy Scale (ASES) (Attitude)	Fibromyalgia Impact Questionnaire (FIQ), Coping Strategies Questionnaire (CSQ), QOLS,	MS > BAT in ASES pain, FIQ, CSQ re- interpreting pain, CSQ ignoring sensation, CSQ catastrophizing, CSQ decrease pain at 6 months and ASES function at 18 mo*
Mannerkorpi & Amdorw (2004) ⁷¹ (n=36)	Body Awareness Treatment+ qigong	Control group	Body Awareness Rating Scale (BARS) (Self-efficacy)	FIQ, physical function tests	↑BARS*, no significant difference for FIQ or functional tests
Irritable Bowel Syndrome					
Craske et al. (2011) ⁷² (n=110)	CBT including Interoceptive exposure (IE)	Stress management (SM) or attention control (AC)	VSI, PVAQ (Attitude)	Bowel Symptom Severity Index (BSS)	↓ BSS, VSI, PVAQ in IE vs SM or AC*
Substance use disorder					
Price et al. (2012) ³⁷ (n=46)	Mindful Body Awareness Treatment (MBAT)	Treatment As Usual (TAU)	Scale of Body Connection (SBC) (Attention tendency) FFMQ (Mode, Tendency) Body Investment Scale (Attitude)	Time-line Follow-back interview, % days abstinent, urine toxicology	↑% days abstinent for MBAT vs TAU at 3 mo, not at 9 mo f/u, ↓ cravings in

Psychiatric Disorder	Intervention	Control Group	Interception Measurement (Component)	Primary outcome Measure	Results
Refractory Opioid dependence					MABT vs TAU; ↓ Bodily dissociation at 9 mo ; *; No change in SBC; †FEMQ in both groups
Otto et al. (2014) ⁷³ (n=78)	CBT for interoceptive cues	Individual counseling, +methadone	ASI (<i>Attitude</i>)	Oral toxicology, addiction severity index	No difference in oral toxicology, or ASI
* With bold indicates statistically significant results p<0.05					
** Overlap between interoceptive measurement and primary outcome measurement in studies using ADIS-R: Anxiety Disorder Interview Schedule Rev					
ASES: Arthritis Self-Efficacy Scale					
ASI: Anxiety Sensitivity Index					
BAT: Body Awareness training					
BSS: Bowel Symptom Severity Index					
EDI: Eating Disorder Inventory					
FIQ: Fibromyalgia Impact Questionnaire					
FEMQ: Five Facets Mindfulness Questionnaire					
HQC: Hyperventilation questionnaire					
MADRS: Montgomery-Asberg Depression Rating Scale, Clinician-rated; (-S) Self-Rated					
MAIA: Multidimensional Assessment of Interoceptive Awareness					
MBAT: Mindful Body Awareness Treatment					
MIAL: Mobility Inventory when Alone					
MIAC: Mobility Inventory when Accompanied					
PCS: Pain Catastrophizing Scale					
PVAQ: Pain Vigilance & Awareness Questionnaire					
QIDS CR: Quick Inventory of Depressive Symptoms-Clinician Rated					
QOLS: Quality of Life Scales					
SBC: Scale of Body Connection					
STAI-S: State-Trait Anxiety Inventory State					

STAI-T: State-Trait Anxiety Inventory, Trait

VSI: Visceral Sensitivity Index

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