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REVIEW

# A Systematic Review of Interoception in Substance Use Disorders

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## Abstract

**Purpose of Review** Despite the growing number of studies on interoception in addiction research, a comprehensive review of these findings is still lacking. The goal of this paper was to conduct a systematic review of empirical studies to assess the evidence for interoceptive deficits in individuals with substance use disorders (SUDs), identify gaps in the existing literature, and propose directions for future research.

**Recent Findings** From 1,544 papers identified in APA PsycINFO, PubMed, CINAHL, and Embase using predefined search terms, 39 studies met eligibility criteria. Of these, 14 studies addressed alcohol use disorder, 12 heterogeneous substance use, 6 opioid use disorder, 4 nicotine use, 2 cocaine use disorder, and 1 cannabis use. Regarding interoceptive dimensions (accuracy, sensibility, awareness), 12 studies assessed accuracy only, 19 sensibility only, and 8 both; only one additionally evaluated interoceptive awareness. Behavioral tasks (e.g., heartbeat counting task) and self-report questionnaires (e.g., Multidimensional Assessment of Interoceptive Awareness; MAIA) were the most common measures of interoceptive accuracy and sensibility, respectively. Neuroimaging studies were scarce, with only 4 examining neural correlates.

**Summary** Across studies of interoception in SUDs, the most consistent finding is reduced interoceptive accuracy relative to healthy controls, particularly in alcohol use disorder; findings for other substances show greater variability. Evidence for interoceptive sensibility is mixed, and research on interoceptive awareness remains sparse. The literature is constrained by a narrow focus on two interoceptive dimensions, a heavy reliance on the cardiac domain, and the widespread use of the heartbeat counting task, which has been criticized for its validity. Future research should assess multiple interoceptive dimensions across modalities, develop and validate more robust measures, and appropriately address potential confounders such as smoking status.

**Keywords** Interoception · Substance use disorders · Addiction

## Introduction

Interoception refers to the perception of the body's internal state, which involves sensing, interpreting, and integrating information from within the body [1, 2]. Over the past two decades, interoception has received increasing attention due to growing evidence suggesting that interoceptive dysfunction may contribute to various mental disorders [2–6]. Substance use disorders (SUDs), in particular, have been linked to dysfunctional interoceptive processing, although empirical evidence remains limited primarily to interoceptive accuracy and sensibility, with mixed findings across studies. Nevertheless, interoceptive dysfunctions are theorized to play a critical role in addiction-related mechanisms such as craving, withdrawal, and emotion regulation, all of which contribute to the development, maintenance, and recurrence of SUDs [5, 7, 8].

Several narrative reviews and opinion pieces have been published on the topic of interoception in SUDs [5, 8–15]. These works have provided valuable insights into potential mechanisms linking interoceptive processing to addiction vulnerability and maintenance. However, they were not

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designed to comprehensively or systematically evaluate the full breadth of empirical evidence. Additionally, many were published several years ago, and a substantial body of new empirical studies has since emerged. Therefore, a systematic review with transparent search methods, clearly defined inclusion and exclusion criteria, and a structured synthesis is needed to rigorously evaluate the consistency and quality of evidence on interoceptive alterations across SUDs.

This systematic review addresses this need by systematically synthesizing empirical studies of interoception in SUDs, evaluating the evidence for interoceptive deficits, identifying key methodological limitations, and outlining priorities for future research. The Introduction defines interoception, summarizes its major dimensions, reviews commonly used measurement approaches, and presents theoretical accounts of how interoceptive processes may contribute to addiction.

**Table 1** Summary of proposed interoception dimensions

| Dimension | Definition |
|---|---|
| Accuracy | Objective accuracy in detecting internal bodily sensations (Garfinkel et al., 2015); Correct and precise monitoring (Khalsa et al., 2018; Suksasilp & Garfinkel, 2022) |
| Attention | Observing internal bodily sensations (Khalsa et al., 2018; Suksasilp & Garfinkel, 2022) |
| Attribution | Interpretation of interoceptive sensations and their causes, such as perceived threat (Suksasilp & Garfinkel, 2022) |
| Awareness (or Insight) | Metacognitive evaluation of experience/performance (Refers to as 'awareness' by Garfinkel et al., 2015 and 'insight' by Khalsa et al., 2018; Suksasilp & Garfinkel, 2022) |
| Detection | Presence or absence of conscious report (Khalsa et al., 2018) |
| Discrimination | Localize sensation to a specific channel or organ system and differentiate it from other sensations (Khalsa et al., 2018) |
| Magnitude | Perceived intensity (Khalsa et al., 2018) |
| Neural representation | Central nervous activity associated with interoceptive processing (Suksasilp & Garfinkel, 2022) |
| Preconscious impact of afferent signals | Effect of fluctuations in afferent signals on central neural representation and the processing of external stimuli (Suksasilp & Garfinkel, 2022) |
| Sensibility | Self-perceived dispositional tendency to be internally self-focused and interoceptively cognizant (Garfinkel et al., 2015) |
| Self-report scales | Psychometric assessments via questionnaire (Khalsa et al., 2018) |
| Self-report and belief | Measures of beliefs, both available to and beyond conscious access, concerning individuals' interoceptive sensations and experiences (Suksasilp & Garfinkel, 2022) |
| Strength of afferent signals | Strength and nature of signals originating from the periphery that communicate interoceptive states to the central nervous system (Suksasilp & Garfinkel, 2022) |

## Interoception: Definition and Dimensions

Interoception is defined as the process by which the nervous system senses, interprets, and integrates internal signals across conscious and non-conscious levels [2]. Interoception is a multi-dimensional construct that spans from lower levels (i.e., the strength of afferent signals) to higher levels (i.e., attribution/interpretation) of processing interoceptive signals [16]. Prior to 2015, the terminology used to describe interoceptive dimensions was highly inconsistent and heterogeneous. Specifically, researchers often used different terms interchangeably to refer to the same interoceptive dimension or used a single term to refer to conceptually different interoceptive dimensions [17, 18].

In 2015, Garfinkel and colleagues [18] proposed a three-dimensional model of interoception, which differentiates interoception into (1) interoceptive accuracy, (2) interoceptive sensibility, and (3) interoceptive awareness, based on the types of measurement. Interoceptive accuracy describes the objective ability to detect internal sensations, and is typically measured using performance-based tasks (e.g., heartbeat detection tasks). Interoceptive sensibility refers to the subjective evaluation of one's interoception, which can be assessed using self-report questionnaires or confidence ratings during interoceptive tasks. Interoceptive awareness captures the correspondence between objective accuracy and subjective sensibility, reflecting metacognitive insight into one's own interoceptive performance.

This three-dimensional model has provided an important step towards unifying terminology in the field and has been widely adopted by the interoception research community. However, this framework is not without limitations. It lacks comprehensiveness, as it does not capture other relevant interoceptive phenomena, and each of its dimensions includes highly heterogeneous measures [17, 19]. For example, although interoceptive sensibility is often treated as a single dimension encompassing self-report measures, these instruments actually assess a broad range of distinct aspects [20]. To address these limitations, more comprehensive frameworks have been proposed. Notably, a panel of experts in the interoception community introduced the eight interoceptive dimensions [2], and Suksasilp and Garfinkel [16] revisited and updated the original three-dimensional model to include eight interoceptive dimensions. While these newer frameworks offer greater conceptual breadth, challenges remain, including heterogeneous measures within single dimensions or overlapping content across dimensions. An overview of these proposed dimensions is provided in Table 1.

The conceptualization of interoception is an ongoing process, with new terms, frameworks, and theoretical proposals regularly emerging [21, 22]. Despite this progress, no gold-standard criteria have yet been established, and consensus within the community is still developing. For the purposes of this review, the three-dimensional model will serve as the primary framework given its widespread recognition and acceptance. Nevertheless, our review is not confined to these three dimensions; additional interoceptive dimensions identified in the reviewed literature will also be considered when relevant.

## Measures of Interoception

Measures of interoception vary across several dimensions and physiological domains, including cardiac, respiratory, and gastrointestinal systems. Among these, the cardiac domain has been most extensively studied, with the heartbeat counting task being one of the most frequently used measures of interoceptive accuracy [23], presumably due to its measurement convenience. In heartbeat counting tasks, participants are instructed to count their heartbeats silently during specified time intervals (e.g., 25, 35, and 45 s) without manually feeling their pulse and to report the count at the end of each trial, while simultaneously recording the electrocardiogram [23]. Accuracy is typically calculated based on the ratio of actual to reported heartbeats [18]. Variants of the original heartbeat counting task exist, differing in instructions (e.g., prohibiting guessing), number of trials, interval durations, and rest periods between trials [17].

Despite its popularity, the heartbeat counting task has been widely criticized. Concerns include psychometric and construct validity issues, such as the influence of prior knowledge of resting heart rate, intelligence quotient, and time estimation abilities [24–26]. Counting accuracy often correlates poorly with actual heart rates [26]. Moreover, counting accuracy is contaminated by non-interoceptive processes such as guessing [27], shows limited test-retest reliability (ICC = 0.41) [28], and fails to align with more rigorous measures of cardiac interoception [29]. Other cardiac tasks have been developed, such as the heartbeat discrimination task, in which participants judge whether auditory tones are synchronized with or delayed relative to their heartbeats [30, 31]. However, despite ongoing development of new tasks [19], no gold-standard measure of cardiac interoception has yet emerged.

Interoceptive sensibility is typically assessed using self-report questionnaires or confidence ratings collected during or following interoceptive tasks. According to a systematic review [20], the most frequently cited self-report measures between 2015 and 2020 include the Body Perception Questionnaire [32] and its short form [33], the Multidimensional Assessment of Interoceptive Awareness (MAIA) [34], the Body Awareness Questionnaire [35], the Private Body Consciousness subscale [36], and the Self-Awareness Questionnaire [37]. Among these measures, the MAIA [34] has gained substantial traction in recent years due to its multidimensional structure and research applicability. It assesses eight dimensions: noticing, not-distracting, not-worrying, attention regulation, emotional awareness, self-regulation, body-listening, and trusting. Updated versions have since been developed, including the MAIA-2 [38] and the Brief MAIA-2 [39].

Interoceptive awareness, a metacognitive construct reflecting the correspondence between objective interoceptive accuracy and subjective confidence, can be assessed by correlating accuracy and confidence scores from performance-based tasks. However, this simple correlation approach is confounded by ceiling or floor effects in task performance and violations of normality assumptions [40]. The Area Under the Receiver Operating Characteristic curve (AUROC) provides a more robust metric [41], and the meta-d' framework addresses these limitations by statistically controlling for task performance when estimating metacognitive sensitivity [42]. This systematic review examines interoceptive alterations across SUDs using all assessment approaches discussed above, including additional measures identified in the retrieved literature.

## Role of Interoception in Addiction

Several theoretical frameworks have been proposed to explain the specific mechanisms by which interoceptive processes contribute to addiction. Central to these perspectives is the idea that interoception is fundamental to maintaining physiological equilibrium, and that repeated substance use progressively distorts this regulatory function. The allostatic model proposes that chronic drug use shifts the brain's hedonic set point such that abstinence comes to be experienced as a genuinely aversive somatic state, with drug-seeking driven by the need to restore bodily equilibrium rather than by the pursuit of pleasure [43]. Interoceptive dysfunction within this framework may manifest as a progressive erosion of sensitivity to non-drug-related homeostatic signals, impairing the ability to recognize and respond to naturally occurring bodily cues, while withdrawal-related sensations acquire disproportionate salience. Incentive salience theory offers a complementary account, proposing that the dopamine system attributes motivational salience to drug-associated cues, generating a powerful wanting state experienced as craving independently of the actual pleasure the substance produces [44, 45]. This wanting state has a distinct interoceptive dimension, manifesting as bodily sensations of arousal, tension, or urgency; when interoceptive processing is altered, individuals may misattribute these cue-evoked states, or more general negative affect and stress, to an urgent need for the substance, a process that may reinforce and perpetuate compulsive drug-seeking over time.

Another proposed mechanism is grounded in predictive coding and active inference models, which propose that adaptive behavior depends on appropriately weighting prior beliefs against incoming sensory signals [46]. Within this framework, the brain continuously generates predictions about internal bodily states and updates them through prediction errors, defined as discrepancies between anticipated and actual afferent input. It has been proposed that substance use may be driven by attempts to reduce what is termed a body prediction error, particularly when aversive internal states deviate from expected equilibrium [5, 47]. In this context, impaired interoceptive precision, such as reduced or biased weighting of bodily signals, may amplify prediction errors and lead to maladaptive decision making. More broadly, computational accounts propose that biased prior beliefs or reduced reliance on afferent input contribute to transdiagnostic psychopathology. In SUDs, this may manifest as reduced precision weighting of non-drug-related bodily signals, diminishing sensitivity to adverse physiological consequences, or as overweighting of drug-associated interoceptive cues, amplifying their motivational salience.

Interoceptive alterations in SUDs are best understood not as isolated phenomena but as embedded within a broader network of neural and psychological dysregulation, with the insular cortex serving as the key substrate. The insula integrates visceral afferent signals with prefrontal, limbic, and striatal systems involved in reward, impulse control, and emotion regulation [9, 13], and this anatomical overlap likely explains why interoceptive dysfunction in SUDs is consistently associated with difficulties in emotion regulation, alexithymia, and impulsivity [8, 63, 64], in relationships that are probably bidirectional. The nature of interoceptive alteration itself also varies considerably across substances, dimensions, and individuals: some may exhibit reduced accuracy reflecting blunted sensitivity to non-drug-related states, while others show elevated sensibility reflecting hypervigilance to drug-associated somatic cues, with both representing theoretically meaningful but distinct forms of dysregulation. This heterogeneity has direct implications for treatment, as it suggests that rather than assuming enhanced interoceptive ability is universally beneficial, interventions may need to be tailored to the specific profile of dysregulation present.

Neurobiological models further implicate dysfunction within interoceptive neural circuitry, particularly the insular cortex, in addiction. The insula integrates visceral signals with emotional, motivational, and cognitive systems, supporting both the subjective experience of craving and the evaluation of bodily states during decision making [13]. Altered insular structure, function, and connectivity have been reported in individuals with SUDs [9, 13, 48, 49], suggesting that disrupted integration of interoceptive information with executive and reward systems may contribute to addiction-related processes. Importantly, interoceptive processes are closely intertwined with psychological constructs such as emotion regulation, impulsivity, and alexithymia [6, 10, 50–53]. Because internal bodily states form a core component of emotional experience, difficulties in accurately perceiving, interpreting, or tolerating interoceptive signals may impair adaptive regulation strategies. In this context, substance use may function as an external regulator of poorly differentiated or aversive internal states.

Taken together, these theoretical accounts suggest that interoception may influence addiction through multiple, partially overlapping pathways: (1) altered homeostatic/allostatic regulation, (2) maladaptive precision-weighting and predictive processing of bodily signals, and (3) disrupted integration of interoceptive information within neural and emotional regulatory systems. However, the extent to which these proposed mechanisms operate in SUDs, and how they relate to specific interoceptive dimensions, remains to be established and requires further empirical validation. Depending on substance type, chronicity, and stage of addiction, individuals may exhibit reduced, heightened, or dysregulated interoceptive processing. This theoretical heterogeneity provides an important context for interpreting the mixed empirical findings reviewed below and underscores the need for systematic evaluation of interoceptive dimensions across SUD populations.

### Aims

This systematic review aims to examine empirical studies on interoception in individuals with SUDs, with three primary objectives: (1) to examine the evidence for interoceptive deficits across different dimensions and SUD populations, (2) to identify gaps in the existing literature, and (3) to propose priority areas for future research.

## Methods

This systematic review was conducted under the 2020 Preferred Reporting Items for Systematic Reviews (PRISMA) guidelines [54] and was preregistered using the International Prospective Register of Systematic Reviews (PROSPERO, registration number: CRD420251157656).

### Search Strategy

The literature search included the following databases: APA PsycINFO, PubMed, CINAHL, and Embase. No limitation was placed on the publication date, and eligible studies published up to October 1, 2025 were included. The search strategy included the following terms using a wildcard search: ("interocept*") AND ("substance use" OR "substance abuse" OR "substance depend*" OR "drug addiction" OR "drug use" OR "drug abuse" OR "alcohol" OR "cannabis" OR "marijuana" OR "hallucinogen*" OR "phencyclidine" OR "inhalant" OR "opioid" OR "heroin" OR "sedative" OR "hypnotic" OR "anxiolytic" OR "stimulant" OR "cocaine" OR "methamphetamine" OR "amphetamine" OR "tobacco" OR "nicotine" OR "smoking" OR "cigarettes"). The types of substances were selected from the criteria for substance use disorders from the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5). During the subsequent screening process, relevant papers were identified and added manually by checking the references of studies.

### Inclusion and Exclusion Criteria

Inclusion and exclusion criteria are presented in Table 2.

### Data Screening

Study screening and selection were conducted independently by three researchers (two graduate-level students [J.J.I. and K.K.] and one undergraduate research assistant [E.S.]). All reviewers completed training on PRISMA guidelines and the specific inclusion/exclusion criteria before beginning screening. Screening was performed using Rayyan, a web-based platform designed to optimize the systematic review process, with each reviewer blinded to others' decisions during initial screening [55]. After screening, blinding was removed, and disagreements were resolved through structured consensus discussion: all three reviewers examined the cases together and discussed their rationale until agreement was reached. If disagreement persisted, a fourth senior researcher (W.Y.A.) was available to make the final determination; however, consensus was achieved for all cases.

Following duplication removal, screening of titles and abstracts of the identified studies ($n$=1,544) was conducted according to the inclusion and exclusion criteria described above. Disagreements regarding study eligibility were resolved through consensus discussion, resulting in 45 studies retrieved for full-text assessment. After full-text review, six studies were excluded due to a lack of data on interoceptive dimensions, ineligible population, or ineligible publication type. A total of 39 studies were included in the final synthesis. The screening process is summarized in the PRISMA flow diagram (Fig. 1).

**Table 2** Inclusion and exclusion criteria

| | |
|---|---|
| Inclusion criteria | •Published in English<br>•Clinical population with a substance use disorder according to validated diagnostic criteria such as the DSM-5, DSM-IV or 10th Revision of the International Classification of Diseases (ICD-10), as well as nicotine and cannabis users, with or without a formal diagnosis of substance use disorder.<br>•Includes an experimental task (e.g., heartbeat counting task) or self-report questionnaires that measure at least one interoceptive dimension. Interoceptive dimensions include but are not limited to interoceptive accuracy, sensibility, and awareness. |
| Exclusion criteria | •Animal study<br>•Wrong publication type (e.g., case studies, book chapters, reviews, conference abstracts, dissertations, study protocols, clinical trials without results, letters, opinion papers)<br>•Wrong population (e.g., studies restricted to subclinical samples or clinical populations with comorbid psychiatric disorders)<br>•Wrong outcome (e.g., studies on SUD populations that did not assess any interoceptive dimension)<br>•No reported data (e.g., studies that did not report data on the measured interoceptive dimension) |

### Data Extraction and Synthesis

Data were independently extracted by three researchers and cross-verified for accuracy. Extracted information included author(s), publication year, sample characteristics, addiction-related measures, interoception measures, non-interoceptive measures, and key findings with relevant statistics. Supplementary materials were reviewed when data were not reported in the main text.

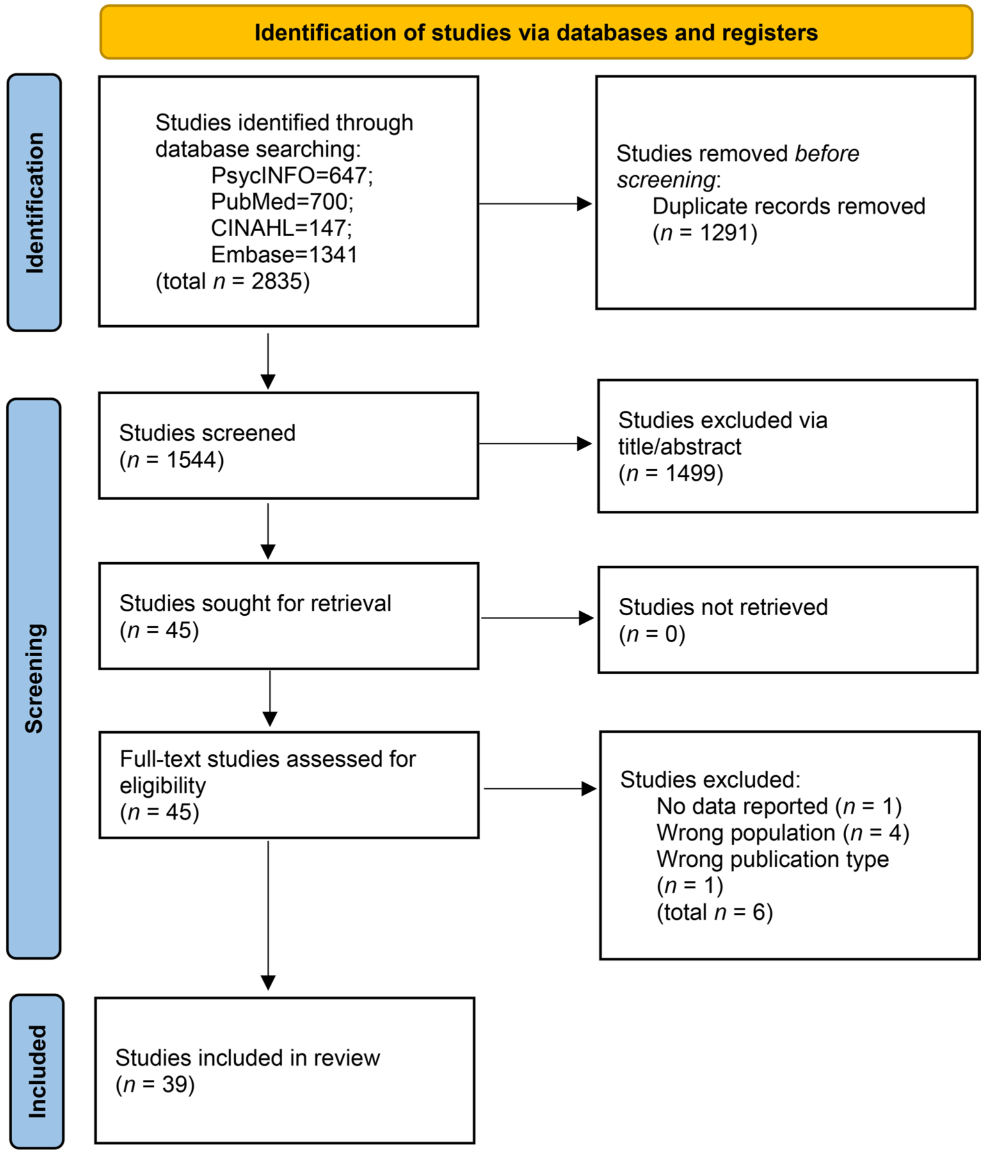
Table 3 summarizes findings organized by substance type, with interoception measures categorized by dimension and assessment method. Findings were designated as primary when directly assessing interoceptive dimensions, and as secondary when examining indirect associations. Treatment-focused studies are summarized separately in Table 4, as their primary purpose was to evaluate intervention efficacy rather than to characterize interoceptive functioning, and many lack healthy control groups or baseline data.

## Results

### General Characteristics of the Included Studies

This review covers thirty-nine studies examining interoception in SUD populations. Table 3 summarizes 29 non-treatment empirical studies, and Table 4 summarizes 10 treatment studies. Of the thirty-nine studies, fourteen ($n$=14/39, 35.9%) focused on individuals with alcohol use disorder (AUD), twelve ($n$=12/39, 30.8%) on heterogeneous substance users, six ($n$=6/39, 15.4%) on opioid use disorder (OUD), four ($n$=4/39, 10.3%) on smoking, two

**Fig. 1** PRISMA flow diagram




($n$=2/39, 5.1%) on cocaine use disorder (CUD), and one ($n$=1/39, 2.6%) on cannabis use.

The median sample size was 120 ($M$ = 173.3, $SD$ = 160), indicating considerable variability in sample sizes across studies. Fifteen studies ($n$ = 15/39, 38.5%) included fewer than 100 participants, eighteen ($n$ = 18/39, 46.2%) included between 100 and 300 participants, and six ($n$ = 6/39, 15.4%) included more than 300 participants. Among studies with samples exceeding 300 participants, three ($n$ = 3/6, 50%) drew samples from the Tulsa 1000 Project [56–58], two ($n$ = 2/6, 33.3%) from the MABT intervention studies [59, 60], and one ($n$ = 1/6, 16.7%) included 809 healthy controls and 50 individuals with AUD and 41 with Gaming Disorder [61]. Most studies with fewer than 100 participants incorporated behavioral tasks or physiological assessments (e.g., MRI).

## Interoception Measures

Regarding interoceptive dimensions, twelve studies ($n$ = 12/39, 30.8%) measured interoceptive accuracy only, nineteen ($n$ = 19/39, 48.7%) measured interoceptive sensibility only, and eight ($n$ = 8/39, 20.5%) measured both accuracy and sensibility. Only one study further evaluated interoceptive awareness [62]. Regarding methodological approaches, twelve studies ($n$ = 12/39, 30.8%) employed behavioral tasks only, seventeen ($n$ = 17/39, 43.6%) utilized self-reported questionnaires only, and ten ($n$ = 10/39, 25.6%) used both behavioral tasks and questionnaires.

Among behavioral paradigms, the heartbeat counting task was the most frequently employed ($n$ = 14/22, 63.6%) to assess interoceptive accuracy. The heartbeat tapping task [63] was utilized in four studies ($n$ = 4/22, 18.2%) [56–58,

**Table 3** Summary of empirical studies on interoception in SUDs

| Authors (Year) | Samples (*n*) | Addiction Measures(s) | Intero-ceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Alcohol (12) | | | | | | |
| Schmidt et al. (2013) | Alcohol Dependence[a] ($n=89$)<br>[a] Diagnosis based on ICD-10 | **Alcohol Use**: OCDS<br>**Alcohol Expectancy**: Tension Reduction Expectancies (TRE) | **IA**: HCT (classic) | Not Assessed | (1) HCT scores were reported (0.70 ± 0.19)<br>(2) No correlation between HCT, OCDS-G, and TRE<br>(3) Negative correlation between IA and OCDS-G only when participants have high TRE ($\beta$ = -0.31) | (1) No independent effect of IA on OCDS-Q<br>(2) Independent effect of TRE on OCDS-Q |
| Ates Col et al. (2016) | AUD[a] ($n=55$)<br>HC ($n=52$)<br>[a] Diagnosis based on DSM-4-TR | **Alcohol Use**: AUDIT; OCDS<br>**Alcohol Craving**: PACS | **IA**: HCT (classic) | Not Assessed | Lower HCT scores for AUD (0.58 ± 0.18) compared with HC (0.71 ± 0.16) ($p<0.05$) | Negative correlation between IA and AUDIT, PACS, OCDS ($\beta$ = -0.216, -0.330, -0.218) |
| Jakubczyk et al. (2019) | AUD[a] ($n=114$)<br>HC ($n=110$)<br>[a] Diagnosis based on ICD-10, MINI | **Alcohol Use**: AUDIT | **IA**: HCT (classic)<br>**IS**: PBCS | **Psychological Symptoms**: BSI<br>**Sleep problems**: AIS<br>**Impulsivity**: BIS-11 | (1) Lower HCT scores in AUD (0.46 ± 0.3) compared with HC (0.72 ± 0.1)<br>(2) Higher PBCS in AUD (17.42 ± 4.2) compared with HC (14.85 ± 4.1) | (1) No correlation between IA and all variables among both AUD and HC<br>(2) No correlation between IS and impulsivity, depressive symptoms among AUD<br>(3) Positive correlation between IS and sleep problems ($r=0.24$, $p=0.014$), anxiety symptoms ($r=0.27$, $p=0.005$) among AUD<br>(4) Higher impulsivity, sleep problems, depressive symptoms, anxiety symptoms found in AUD compared with HC |
| Jakubczyk et al. (2020) | AUD[a] ($n=165$)<br>HC ($n=110$)<br>[a] Diagnosis based on ICD-10, MINI | **Alcohol Use**: AUDIT | **IA**: HCT (classic)<br>**IS**: PBCS | **Emotion Regulation**: DERS<br>**Psychological Symptoms**: BSI<br>**Sleep Problems**: AIS | (1) Lower HCT scores in AUD (0.61 ± 0.16) compared with HC (0.72 ± 0.08)<br>(2) Higher PBCS in AUD (17.3 ± 4.1) compared with HC (14.8 ± 4.1) | (1) No correlation between IA and IS in AUD ($r=0.12$, $p=0.23$)<br>(2) Positive association between IS and difficulties controlling impulsive behavior when experiencing negative emotions in AUD |
| Jakubczyk et al. (2021) | AUD[a] ($n=165$)<br>HC ($n=110$)<br>[a] Diagnosis based on ICD-10, MINI | Not Assessed | **IA**: HCT (classic)<br>**IS**: PBCS | **Pain**: Pain Sensitivity Questionnaire (PSQ); VAS | (1) Lower HCT scores for AUD (0.61 ± 0.16) compared with HC (0.72 ± 0.08)<br>(2) Higher PBCS for AUD (17.3 ± 4.1) compared with HC (14.8 ± 4.1) | (1) Negative association between IA and PSQ among those with AUD ($\beta$ = -2.180, $p=0.019$)<br>(2) AUD status moderated association between IA and PSQ |

**Table 3** (continued)

| Authors (Year) | Samples ($n$) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Avcu Meric et al. (2022) | AUD[a] ($n = 52$)<br>HC ($n = 52$)<br>[a] Diagnosis based on DSM-5 | **Alcohol Use**: AUDIT<br>**Alcohol Craving**: PACS | **IA**: HCT (classic) | **Trait Mindfulness**: Mindfulness Attention Awareness Scale (MAAS)<br>**Decision-making**: IGT | Lower HCT scores for AUD (0.60 ± 0.13) compared with HC (0.72 ± 0.09) | (1) IA linked significantly to IGT performance ($p < 0.001$) and prediction ($\beta = 0.456$, $p < 0.001$)<br>(2) No correlation between trait mindfulness (MAAS score) and HBP and IGT in either group |
| Wisniewski et al. (2023) | AUD[a] ($n = 99$)<br>HC ($n = 103$)<br>[a] Diagnosis based on ICD-10, MINI | **Alcohol Use**: Short Inventory of Problems (SIP) + semi-structured interview; Substance Abuse Outcomes Module (SAOM) | **IA**: HCT (classic) | **Alexithymia**: TAS-20<br>**Psychological Symptoms**: BSI | Higher HCT scores for AUD (0.72 ± 0.08) compared with HC (0.49 ± 0.29) | (1) Negative association between IA and TAS-20 for AUD and HC<br>(2) Alexithymia as mediator between interoception and state anxiety was more pronounced in AUD |
| Gunawan et al. (2024) | AUD[a] ($n = 210$)<br>Non-AUD ($n = 89$)<br>[a] Diagnosis based on DSM-5 | **Alcohol Use**: AUDIT; OCDS; TLFB; Alcohol Dependence Scale (ADS)<br>**Alcohol Craving**: PACS; | **IS**: MAIA | **Alcohol Related Variables**: Addictions Neuroclinical Assessment battery (ANA)<br>[a] Multiple behavioral tasks and self-report measures organized into three neurofunctional domains (Incentive salience; negative emotionality; and executive function) | Lower MAIA in AUD compared with non-AUD[a]<br>[a] Exact value not reported | Not Applicable |
| Scigala et al. (2024) | Alcohol dependence[a] ($n = 160$)<br>[a] No diagnostic criteria was mentioned; All male inmates | **Alcohol Craving**: PACS | **IS**: MAIA | **Alexithymia**: TAS-20<br>**Emotional Regulation**: DERS | MAIA total score (22.13 ± 4.99) | (1) Negative correlation between IS and PACS ($r$ = -0.391, $p < 0.001$)<br>(2) Negative correlation between IS and TAS-20 ($r$ = -0.179, $p < 0.05$)<br>(3) Negative correlation between IS and DERS ($r$ = -0.261, $p < 0.001$)<br>(4) Alexithymia and emotional dysregulation significantly mediate the relationship between interoceptive sensibility and alcohol craving |

**Table 3** (continued)

| Authors (Year) | Samples ($n$) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| London et al. (2024) | AUD[b] ($n=50$)<br>- Inpatient ($n=24$)<br>- Outpatient ($n=26$)<br>GD[a] ($n=41$)<br>HC ($n=809$)<br>[a] GD=Gambling Disorder<br>[b] Diagnosis based on DSM-5 | **Alcohol Use**: AUDIT<br>**Gambling**: South Oaks Gambling Screen (SOGS) | **IS**: BPQ-VSF | Not assessed | Lower BPQ-VSF total score in AUD (21.84 ± 6.69) and GD (20.39 ± 5.41) compared with HC (27.28 ± 8.07) | Higher BPQ-VSF score in AUD (21.84 ± 6.69) compared with GD (20.39 ± 5.41), but both lower than HC) |
| Billaux et al. (2025) | AUD[b] ($n=48$)<br>HC-AUD ($n=41$)<br>BD[a] ($n=32$)<br>HC-BD ($n=32$)<br>[a] Defined using Maurage et al. (2020)'s criteria and binge drinking score (≥24) from Townshend & Duka (2005)<br>[b] Diagnosis based on DSM-5 for AUD (≥6 diagnosis criteria) | **Alcohol Use**: AUDIT; TLFB | **IA**: HCT (Classical task & Adapted task)<br>**IS**: PBCS<br>**Heartbeat**: ECG-based chest strap monitor | **Alexithymia**: TAS-20<br>**Anxiety**: STAI<br>**Trauma**: Childhood Trauma Questionnaire (CTQ)<br>**Depression**: BDI-13<br>**Dissociative Symptoms**: DES<br>**Emotion Regulation**: DERS<br>**Sleep**: AIS<br>**Time Estimation Task**[a]<br>[a] Measured for controlling confounding factor of HCT performance | (1) Lower HCT scores in AUD (0.50 ± 0.04) compared with matched HC (0.64 ± 0.04) on classical HCT<br>(2) Lower HCT scores in AUD (0.26 ± 0.04) compared with matched HC (0.35 ± 0.04) on adapted HCT<br>(3) No difference in HCT scores in BD (0.68 ± 0.04) compared with matched HC (0.69 ± 0.04) on classical HCT<br>(4) No difference in HCT scores in BD (0.36 ± 0.04) compared with matched HC (0.27 ± 0.04) on adapted HCT<br>(5) Higher HCT scores on the classical than adapted HCT in all groups<br>(6) No difference in PBCS between AUD vs. HC-AUD and BD vs. HC-BD | (1) Positive correlation between number of reported heartbeats during HCT and seconds reported during time estimation task for AUD ($r=0.31$, $p=0.03$) and matched HC ($r=0.35$, $p=0.02$)<br>(2) No correlation between IA scores and psychological constructs |
| De Groote et al. (2025) | AUD[a, b] ($n=37$)<br>HC[b] ($n=37$)<br>[a] Diagnosed with only AUD and didn't meet the criteria for other SUDs (excluding tobacco)<br>[b] Diagnosis based on DSM-5 | Not Assessed | **IS**: MAIA | **Memory Recall Experience**: Short-Form Memory Experiences Questionnaire (MEQ-SF)<br>**Anxiety and Depression**: Hospital Anxiety and Depression Scale (HADS-A and HADS-D)<br>**Emotion Regulation**: DERS-SF | (1) Lower MAIA for AUD ($M=2.77$) compared with HC ($M=3.08$)<br>(2) Lower MAIA subscales (Attention regulation and Trusting)[a] for AUD compared with HC<br>[a] Noticing (AUD = 3.53, HC = 3.68); Not distracting (AUD = 2.04, HC = 2.26); Not worrying (AUD = 2.12, HC = 2.29); Attention regulation (AUD = 2.91, HC = 3.59); Emotional awareness (AUD = 3.68, HC = 3.43); Self-regulation (AUD = 2.60, HC = 2.84); Body listening (AUD = 2.42, HC = 2.85); Trusting (AUD = 2.86, HC = 3.69) | Positive correlation between MEQ-SF and MAIA total score and subscales (Noticing, Emotional awareness, Listening)[a] in AUD<br>[a] MAIA total ($r=0.379$, $p=0.021$); Noticing ($r=0.425$, $p=0.009$); Emotional awareness ($r=0.332$, $p=0.045$); Listening ($r=0.383$, $p=0.019$) |
| Heterogeneous (8) | | | | | | |

**Table 3** (continued)

| Authors (Year) | Samples ($n$) | Addiction Measures(s) | Intero-ceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Stewart et al. (2015) | PSU[a, c] ($n=19$)<br>DSU[b, c] ($n=18$)<br>HC ($n=21$)<br>[a] PSU: current endorsement of 2 or more DSM-4 criteria for amphetamine or cocaine abuse during at least 6 months<br>[b] DSU: no endorsement of symptoms of stimulant abuse or dependence<br>[c] Diagnosis based on SSAGA-II | **Alcohol Use**: Semi-Structured Assessment for the Genetics of Alcoholism II (SSAGA-II) Lifetime history of substance dependence | **IA**, **IS**: IBLT[a]<br>**IS**: BPQ; VAS after task-based fMRI session<br>[a] Measured RT, CO2 level, accuracy during fMRI session | **Sensation Seeking**: Sensation Seeking Scale (SSS)<br>**Impulsivity**: BIS<br>**Depression**: BDI-II<br>**Anxiety**: STAI<br>**Neural Response**: fMRI | (1) No significant difference in IBLT (RT, accuracy, CO2 Level) across groups and conditions (Baseline, Anticipation, Breathing Load, Post-Anticipation)<br>(2) No significant difference in BPQ | (1) Higher percentage of drug use attributable to stimulants of PSU than DSU<br>(2) Lower activation for PSU in MFG/DLPFC, IFG, MedFG<br>(3) Lower activation for both PSU and DSU in left MFG/FP, right MFG/DLPFC, bilateral thalamus, left mINS, left lentiform nucleus, left PoCG<br>(4) Lower activation for PSU in right IFG, right aINS<br>(5) Lower activation for PSU as greater percentage of drug use due to stimulants in left MFG/DLPFC, left IFG, left mINS |
| Sonmez et al. (2017) | SUD[a, b] ($n=84$)<br>- Alcohol ($n=33$)<br>- Heroin ($n=29$)<br>- Synthetic Cannabinoids ($n=22$)<br>HC ($n=35$)<br>[a] All male abstinent inpatients<br>[b] Diagnosis based on DSM-4-TR | **Substance Use**: API | **IA**: HCT (classic) | **Alexithymia**: TAS-20 | (1) Lower HCT scores in SUD ($0.61 \pm 0.04$) compared with HC ($0.75 \pm 0.02$) | (1) Negative correlation between HCT scores and TAS-20 DIF ($r = -0.287$, $p=0.046$)<br>(2) Positive correlation between API scores and TAS-20 scores ($r=0.349$, $p=0.005$)<br>(3) 93.90%, 96.60%, 100%, 57.10% smoking rate for alcohol, heroin, SC, HC group respectively |
| Stewart et al. (2020) | SUD[a,b] ($n=40$)<br>OUD[a,b] ($n=20$)<br>HC ($n=30$)<br>[a] Endorsed greater than or equal to 50 uses within the past year<br>[b] Diagnosis based on DSM-4/DSM-5, MINI | **Drinking and Drug Use**: CDDR | **IS**: MAIA, Visceral Interoceptive Awareness (VIA) task[a] during fMRI<br>[a] Sensation intensity ranging 0~6 due to interoceptive cues were rated | **Anxiety**: ASI-3<br>**Depression**: PHQ-9<br>**Neural Response**: fMRI | (1) Lower MAIA subscales[a] for SUD, OUD compared with HC<br>(2) Higher VIA ($p<0.01$), but lower BOLD in dorsal dysgranular of SUD ($p=0.04$) compared with HC in heart cue condition<br>(3) Not different VIA, but lower BOLD in dorsal dysgranular of SUD ($p=0.02$) and OUD ($p=0.04$) compared with HC in stomach cue condition<br>(4) Higher VIA ($p=0.02$), but lower BOLD in hypergranular of SUD ($p=0.02$) compared with HC in heart cue condition<br>[a] Attention regulation; Not worrying; Self-regulation; Trusting | (1) Higher VIA of SUD ($p=0.02$) as more recent illicit drug use in heart cue condition<br>(2) Higher BOLD of SUD in dorsal dysgranular ($p<0.05$) as greater past-year stimulant uses in heart cue condition |

**Table 3** (continued)

| Authors (Year) | Samples ($n$) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Smith et al. (2020) | HC ($n = 52$)<br>Anxiety[a,b] ($n = 15$)<br>Depression[a,b] ($n = 69$)<br>Depression + Anxiety ($n = 153$) [a,b]<br>Eating Disorder[a,b] ($n = 14$)<br>SUD[a,b] ($n = 131$)<br>[a] Inclusion criteria of clinical groups based on PHQ-9, OASIS, DAST-10, SCOFF<br>[b] Diagnosis based on DSM-5, MINI | **Drug Use**: DAST-10 | **IA**[a]: HTT (adapted and classic)<br>**Heartbeat**: ECG<br>**Model parameters**: Interoceptive Precision (IP); Prior beliefs favoring the presence of a Heartbeat (pHB); Anticipatory or Reactive (AvR)<br>[a] Difficulty, Confidence, Heartbeat Intensity were directly asked after completion of each task condition. | **Depression**: PHQ-9<br>**Anxiety**: OASIS<br>**Eating Disorder**: SCOFF | (1) Lower IP in all clinical groups ($0.03 \pm 0.03$) than HCs ($0.07 \pm 0.07$) during breath-hold condition ($p < 0.001$)<br>(2) No significant difference between clinical groups and HCs in pHB during no-guessing or breath-hold conditions<br>(3) No significant difference in AvR across groups and conditions | (1) Positive correlation between IP and self-reported heartbeat intensity in no guessing ($r = 0.24$) and breath-hold conditions ($r = 0.29$) ($p < 0.001$)<br>(2) Positive correlation between pHB estimates and self-reported confidence in no guessing ($r = 0.16$) and breath-hold conditions ($r = 0.21$) ($p < 0.001$)<br>(2) Positive correlation between pHB estimates and self-reported heartbeat intensity in no guessing ($r = 0.71$) and breath-hold conditions ($r = 0.67$) ($p < 0.001$) |

**Table 3** (continued)

| Authors (Year) | Samples ($n$) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| May et al. (2020) | CAN+ALC-EXP[a,b] ($n$=16)<br>CAN+ALC-SUD[a,c] ($n$=13)<br>HC ($n$=18)<br>[a] All adolescent participants (ages 15–17)<br>[b] CAN+ALC-SUD: current endorsement of 2 or more DSM-5 criteria for cannabis or alcohol<br>[c] CAN+ALC-EXP: no substance use history other than nicotine/alcohol/cannabis and no current endorsement of DSM-5 | **Drug Dependence and Alcoholism**: Semi-structured Assessment for Drug Dependence and Alcoholism (SSADDA)<br>**Substance Reinforcement**: Michigan Nicotine Reinforcement Questionnaire (MNRQ)<br>**Drinking and Drug Use**: CDDR | **IS**: MAIA, IBLT[a] (with VAS evaluation)<br>[a] Rated the breathing load for pleasantness and intensity | **Impulsivity**: UPPS Impulsive Behavior Scale<br>**Neural Response**: fMRI | (1) Total MAIA scores[a] were reported (Noticing, Not Distracting, Not Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, Trusting)<br>(2) No significant difference in MAIA between conditions<br>[a] CAN+ALC-SUD=Noticing (2.83±1.52); Not distracting (2.14±0.50); Not worrying (2.89±1.43); Attention regulation (3.17±0.95); Emotional awareness (3.18±1.43); Self-regulation (3.10±1.05); Body listening (1.36±1.156); Trusting (3.47±1.40)<br>CAN+ALC-EXP=Noticing (2.75±1.03); Not distracting (2.37±1.12); Not worrying (2.81±1.42); Attention regulation (3.45±0.74); Emotional awareness (3.04±1.31); Self-regulation (3.23±0.90); Body listening (1.96±1.44); Trusting (3.73±1.08)<br>HC=Noticing (2.78±1.19); Not distracting (2.52±1.30); Not worrying (2.70±1.05); Attention regulation (3.14±1.15); Emotional awareness (3.07±0.93); Self-regulation (3.01±1.05); Body listening (1.79±1.05); Trusting (3.72±0.92) | (1) CAN+ALC-SUD experience aversive breathing load differently compared with HC and CAN+ALC-EXP in neural regions related to interoception and emotion regulation<br>(2) No significant findings within insular cortex despite role in interoception |

**Table 3** (continued)

| Authors (Year) | Samples ($n$) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Smith et al. (2021) | MDD/co-morbid anxiety disorders[b] ($n$=221)<br>SUD[a,b] ($n$=136)<br>HC ($n$=53)<br>[a] Were not included in SUD if only alcohol or nicotine dependence<br>[b] Diagnosis based on DSM-4/DSM-5, MINI | **Drug Use**: DAST-10 | **IA**: HTT (classic AND adapted[a])<br>**Others**: Beat-to-tap consistency (variability between individual's taps and each heartbeat/tone)<br>[a] 3 conditions: (1) guess, (2) no guessing, (3) breath-hold, (4) exteroceptive control task (tone-tapping)<br>**Heartbeat**: ECG | **Anxiety**: OASIS<br>**Depression**: PHQ-9<br>**Eating Disorder**: SCOFF | (1) No significant difference of beat-to-tap consistency in breath-hold condition in patient groups (SUD = 0.68 ± 1.17)<br>(2) Higher beat-to-tap consistency in breath-hold condition in HC (1.58 ± 2.46)<br>(3) Significant reduction of difficulty in HC from guessing (57.53 ± 22.86) to breath-hold conditions (49.17 ± 26.49)<br>(4) Higher IA in SUD (0.47 ± 0.31) compared with HC (0.36 ± 0.28) in No-guessing condition | (1) Psychiatric patients have less flexible range of interoceptive processing than HC<br>(2) Higher beat-to-tap consistency in guessing condition for clinical group (SUD = 0.52 ± 1.47) compared with HC (0.01 ± 1.11) |
| Subay & Sonmez et al. (2021) | AUD[a,b] ($n$=40)<br>OUD[a,b] ($n$=40)<br>HC[a] ($n$=40)<br>[a] All male participants who were abstinent at least for 3 weeks<br>[b] Diagnosis based on DSM- | **Substance Use**: API<br>**Craving**: PACS; Substance Craving Scale (SCS) | **IA**: HCT (classic) | **Decision-making**: IGT<br>**Impulsiveness**: BIS-11 | Lower HCT scores for AUD (0.64 ± 0.15) and OUD (0.60 ± 0.19) compared to HC (0.73 ± 0.16). | (1) Positive correlation between IA and IGT scores ($r$ = 0.226, $p$ = 0.013)<br>(2) Negative correlation between IA and BIS-11 ($r$ = -0.292, $p$ = 0.001)<br>(3) No correlation between HCT scores and PACS/CSC |
| Lavalley et al. (2024) | Substance Users[a,b] ($n$=84)<br>HC ($n$=59)<br>[a] Consists of single and multiple SUDs of alcohol, cannabis, stimulant, sedative, and/or hallucinogen<br>[b] Diagnosis based on DSM-4/DSM-5, MINI | **Drug Use**: DAST-10 | **IA**: HTT<br>**Heartbeat**: ECG<br>**Model parameters**: Interoceptive Precision (IP); Prior beliefs favoring the presence of a Heartbeat (pHB); Anticipatory or Reactive (AvR)<br>**IS**: MAIA | **Depression**: PHQ-9<br>**Anxiety**: OASIS; ASI-3<br>**Eating Disorder**: SCOFF<br>**Alexithymia**: TAS-20 | (1) Lower IP in SUDs (0.04 ± 0.04) than HCs (0.06 ± 0.06) during breath-hold condition<br>(2) Higher pHB in SUDs than HCs during no-guessing or breath-hold conditions<br>(3) No difference in IA between SUDs and HCs | (1) Positive correlations between IP in no-guessing condition and two MAIA subscales ('attention regulation' $r$ = 0.16, $p$ = 0.006 and 'emotional awareness' $r$ = 0.12, $p$ = 0.0.36)<br>(2) Negative correlation between AvR in guessing-condition and two MAIA subscales ('emotional awareness' $r$ = -0.16, $p$ = 0.007 and 'not distracting' $r$ = -0.21, $p$ < 0.001)<br>[a] Data added from supplementary material<br>[b] Result is from across multiple psychiatric disorders including SUD |
| Smoking/Nicotine (4) | | | | | | |

**Table 3** (continued)

| Authors (Year) | Samples (*n*) | Addiction Measures(s) | Intero-ceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Veilleux et al. (2018) | Smokers[a, b] (*n*=14)<br>Nonsmokers[b] (*n*=14)<br>[a] Smokers who had smoked at least one pack per week for at least 4 years<br>[b] All male participants | **Nicotine Dependence**: FTND<br>**Smoking Craving**: QSU-B | **IA**: HCT (classic) | **Self-control**: Breath holding task<br>**Emotion and craving**[a]: Anxiety; Irritation; Body Discomfort; Happiness; Craving<br>[a] Self-reported via verbal analogue, scaling from 0 (none at all) to 100 (the worst) | (1) No significant difference in HCT scores between smokers and nonsmokers | (1) Positive correlation between HCT scores and breath holding length under heat<br>(2) Higher anxiety, irritability, body discomfort and lower happiness in smokers under heat<br>(3) Decreased breath holding length under heat for both smokers and nonsmokers<br>(4) No significant difference in cigarette craving under heat |
| Hina and Aspell (2019) | Smokers[a](*n*=49)<br>Non-smokers (*n*=51)<br>[a] Smokers who had smoked cigarettes daily for at least one year based on self-report | **Nicotine Dependence**: FTND (smokers only) | **IA**: HCT (classic); HDT<br>**IS**: MAIA | **Time Estimation Task**[a]<br>[a] Measured for controlling confounding factor of HCT performance | (1) Lower HCT scores in smokers (0.65±0.18) compared with non-smokers (0.74±0.15)<br>(2) No significant difference in IA (HDT) and IS (MAIA) between non-smokers and smokers | (1) No correlation between IA (HCT, HDT) and FTND-R scores<br>(2) No correlation between IA (HCT) and time estimation task performance<br>(3) No correlation between MAIA and FTND-R scores |
| Kim et al. (2020) | Smoker[a]<br>- Amplification (*n*=17)<br>- Neglect (*n*=17)<br>Non-smokers[a]<br>- Amplification (*n*=19)<br>- Neglect (*n*=19)<br>[a] Classified based on MAIA subscale scores (not-distracting, noticing, not-worrying) and their smoking status | **Smoking Craving**: QSU-Brief | **IS**: MAIA | **Arousal Level**: Galvanic stimulus response (GSR)<br>**Anxiety**: STAI<br>**Positive and Negative Affect**: PANAS<br>**Subjective Measures**[a]: VAS<br>[a] Rated differences in valence, arousal and craving before and after watching video clips | Significant difference in MAIA scores[a] for neglect and amplification bias groups<br>[a] Smokers: Amp (30.05±8.52); Neglect (20.58±2.74); Non-smokers: Amp (32.84±5.64); Neglect (22.56±6.01) | No difference in level of subjective arousal according to interoceptive bias (Amp vs. Neglect) in response to negative emotions |
| Mattioni et al. (2024) | Smokers (*n*=49)<br>- Experimental (*n*=26)<br>- Control (*n*=23) | **Smoking Desire**: Desire Thinking Questionnaire (DTQ)<br>**Cigarette Use**: Self-reported number of cigarettes smoked per day | **IA**: HTT<br>**IS**: Self-reported performance confidence<br>**IAw**: Calculated from IA and IS measures<br>**Heartbeat**: ECG | Not Assessed | (1) IAw level was reported (0.78±0.14)<br>(2) IAw level moderated the relationship between desire thinking–induced physiological changes and cigarette consumption, suggesting that desire thinking about smoking leads to greater cigarette use among individuals with lower interoceptive awareness<br>[a] Exact values for IA and IS are not reported | Not Applicable |
| Opioid (2) | | | | | | |

**Table 3** (continued)

| Authors (Year) | Samples ($n$) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| White et al. (2024) | OUD[a] ($n=129$)<br>- Minimal insomnia[b] ($n=53$)<br>- Insomnia[c] ($n=76$)<br>[a] No diagnostic criteria was mentioned; Had been receiving buprenorphine at least 6 weeks<br>[b] ISI$\leq$10<br>[c] ISI$\geq$11 | Not Assessed | **IS**: MAIA | **Sleep Problems**: Insomnia Severity Index (ISI)<br>**Negative Emotionality**: Distress Tolerance Scale (DTS)<br>**Depression**: PHQ-9<br>**Anxiety**: GAD-7<br>**Mental Health**: PROMIS-10 Global Mental Health Scale<br>**Trauma**: PCL-5<br>**Aggression**: Buss-Perry Aggression Scale (BPAS)<br>**Pleasure**: Snaith-Hamilton Pleasure Scale (SHPS)<br>**Metacognition**: Metacognition Questionnaire (MCQ-30)<br>**Cognition**: 5-Trial Adjusting Delay Discounting Task (5-DD)<br>**Impulsivity**: Short Impulsive Behavior Scale (SUPPS-P) | (1) Baseline MAIA was reported for all subscales[a]<br>(2) Higher MAIA subscale[b] in OUD with insomnia symptoms compared to OUD without symptoms($p=0.01$)<br>[a] Noticing (3.26 ± 1.3); Not distracting (2.47 ± 1.1); Not worrying (2.50 ± 0.9); Attention regulation (2.65 ± 1.2); Emotional awareness (3.23 ± 1.3); Self-regulation (2.45 ± 1.3); Body listening (2.31 ± 1.2); Body trusting (2.97 ± 1.4)<br>[b] Noticing for insomnia symptoms (3.55 ± 1.2); without insomnia symptoms (2.86 ± 1.4) | Not Applicable |
| Marcus et al. (2025) | OUD[a] ($n=21$)<br>[a] Diagnosis based on DSM-5, MINI; Maintenance on 8-24 mg buprenorphine-naloxone | Not Assessed | **IS**: MAIA | **Trauma**: Trauma History Questionnaire (THQ)<br>**Inflammation**: 10 Inflammatory markers; LBP; CRP; MCP-1<br>**Neurofunctional Measures**: NIDA Phenotyping Assessment Battery (PhAB) 5 domains (Reward; Cognition; Negative Emotionality; Metacognition; Sleep) | (1) Total MAIA score[a] was reported<br>(2) No subscale differences between high- and low-ELS OUD patients<br>[a] Noticing (3.69 ± 1.11); Not distracting (1.92 ± 0.88); Not worrying (3.06 ± 0.93); Attention regulation (3.25 ± 1.20); Emotional awareness (3.63 ± 1.17); Self-regulation (3.15 ± 1.32); Body listening (2.40 ± 1.33); Trusting (3.84 ± 1.22) | (1) High inflammatory phenotype in high ELS compared to low ELS OUD patients<br>(2) No neurofunctional differences between high- and low-ELS OUD patients |
| Stimulant (2) | | | | | | |

**Table 3** (continued)

| Authors (Year) | Samples (*n*) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| de La Fuente et al. (2019) | SUD[a] ($n=47$)<br>- Smoked Cocaine Dependent (SCD; $n=25$)<br>- Chlorhydrate Cocaine Dependents (CCD; $n=22$)<br>HC ($n=25$)<br>[a] Diagnosis based on DSM-4 | **History of Drug Consumption**: Alcohol, Smoking, and Substance Involvement Screening Test (ASSIST)<br>**Craving**: Current Craving Questionnaire (CQC) | **IA**: HDT; HEP<br>[a] HDT were conducted in 3 conditions (Awareness, Feedback, Learning) | **Neural Response**: sMRI, fMRI | (1) Higher HDT scores in SCD (0.73 ± 0.14) compared with CCD (0.54 ± 0.28) and HC (0.59 ± 0.21)<br>(2) More negative deflections of HEP modulation of SCD compared with HC ($p=0.05$) during IA over the frontal ROI | (1) Positive correlation between better IA and reduced gray-matter volume in LINS and dorsolateral prefrontal regions in SCD<br>(2) Positive correlation between better IA and increased gray-matter volume in PINS and cingulate areas in HC<br>(3) Positive correlation between better IA and decreased connectivity between AINS nodes and somatosensory-temporal cortices in SCD<br>(4) Positive correlation between better IA and enhanced connectivity between bilateral INS postcentral and temporal regions in HC |
| Perez de los Cobos et al. (2020) | Cocaine Use Disorder[b] ($n=87$)<br>- Cravers ($n=58$)<br>- Non-cravers[a] ($n=29$)<br>[a] Craving absence: daily score of 0 across two craving VAS<br>[b] Diagnosis based on DSM-4; | **Cocaine Craving**: VAS from Cocaine Selective Severity Assessment (CSSA) + ad hoc survey<br>**Cocaine Dependence**: Severity of Dependence Scale (SDS)[a]<br>[a] Measure cocaine dependence for last 6 months | **IA**: HCT (classic) | **Anxiety**: STAI<br>**Depression**: BDI<br>**Readiness to change (cocaine use)**: University of Rhode Island Change Assessment Scale (URICA)<br>**Premorbid IQ**: Word Accentuation Test<br>**Cognitive Flexibility**: Trail Making Test<br>**Working Memory**: Wechsler Adult Intelligence Scale<br>**Response Inhibition**: Stroop Color Test<br>**Decision-making**: IGT<br>**Social Desirability**: Marlowe-Crowne Social Desirability Scale | No significant difference in HCT scores between cravers (48.54 ± 24.55) and non-cravers (38.88 ± 26.65) ($p=0.110$) | Not Applicable |

**Table 3** (continued)

| Authors (Year) | Samples (*n*) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Cannabis (1) | | | | | | |
| Bloomer et al. (2024) | Cannabis Users[a] ($n=72$)<br>HC ($n=78$)<br>[a] Used cannabis at least two times per week for a minimum of 6 consecutive months | **Cannabis Use**: Cannabis Use Disorders Identification Test-Revised (CUDIT-R); TLFB | **IS**: MAIA-2 | **Sensory**: Sensory Gating Inventory (SGI) | Higher MAIA subscale scores[a] in cannabis use than HC<br>[a] Noticing ($p<0.001$), Emotional awareness ($p<0.05$) subscales; No data on MAIA was reported | (1) No correlation between MAIA-2 and severity/frequency of cannabis use<br>(2) No correlation between MAIA-2 and SGI total score |

*AIS* Athens Insomnia Scale, *AIS-3* Anxiety Sensitivity Index, *API* Addiction Profile Index, *AUDIT-C* Alcohol Use Disorders Identification Test-Consumption, *AUD* Alcohol Use Disorder, *BD* Binge Drinker, *BDI-13* Beck Depression Inventory, *BIS* Body Investment Scale, *BIS-11* Barratt Impulsiveness Scale, *BPQ-VSF* Body Perception Questionnaire-Very Short Form, *BSI* Brief Symptom Inventory, *CDDR* Customary Drinking and Drug Use Record, *DAST-10* Drug Abuse Screening Test, *DERS-SF* Difficulties with Emotion Regulation Scale-Short Form, *DES* Dissociation Experiences Scale, *FFMQ* Five Facet Mindfulness Questionnaire, *FMI* Freiburg Mindfulness Inventory, *FTND* Fagerström Test of Nicotine Dependence, *HC* Healthy Controls, *HCT* Heartbeat Counting Task, *HDT* Heartbeat Discrimination Task, *HTT* Heartbeat Tapping Task, *IA* Interoceptive Accuracy, *IAw* Interoceptive Awareness, *IBLT* Interoceptive Breathing Load Task, *ICD-10* International Classification of Diseases, 10th Revision, *IGD* Iowa Gambling Task, *IS* Interoceptive Sensibility, *MABT* Mindful Awareness in Body-oriented Therapy, *MAIA* Multidimensional Assessment of Interoceptive Awareness, *MINI* Mini-International Neuropsychiatric Interview, *MSC* Medical Symptoms Checklist, *OASIS* Overall Anxiety Severity and Impairment Scale, *OCDS* Obsessive-Compulsive Drinking Scale, *OUD* Opioid Use Disorder, *PACS* Penn Alcohol Craving Scale, *PANAS* Positive and Negative Affect Scale, *PBCS* Private Body Consciousness Scale, *PCL-5* Post-traumatic Stress Disorder Checklist for DSM-5, *PHQ-9* Patient Health Questionnaire-9, *PSS* Perceived Stress Scale, *PSS-SR* PTSD Symptom Scale–Self Report, *QSU-B* Questionnaire of Smoking Urges–Brief, *RCT* Randomized Clinical Trial, *RSA* Respiratory Sinus Arrhythmia, *STAI* State and Trait Anxiety Inventory, *TAS-20* 20-item Toronto Alexithymia Scale, *TAU* Treatment As Usual, *TLEQ* Trauma Life Events Questionnaire, *TLFB* Timeline Follow-Back, *VAS* Visual Analog Scale, *WHE* Women's Health Education

62], while the heartbeat discrimination task was used in two studies ($n$ = 2/22, 9.1%) [64, 65]. Two studies ($n$ = 2/22, 9.1%) [66, 67] employed the Interoceptive Breathing Load Task (IBLT) [68]. One of them [67] assessed interoceptive accuracy and sensibility under the breathing-load condition, while the other [66] collected only self-reported ratings of pleasantness and intensity of the breathing load. The latter was therefore classified as measuring interoceptive sensibility only.

Among the twenty-seven studies that measured interoceptive sensibility, the most frequently used questionnaire ($n$ = 18/27, 66.6%) was MAIA. The second most common measure ($n$ = 5/27, 18.5%) was the Freiburg Mindfulness Inventory [69], which was used in five studies by Price and colleagues [59, 60, 70–72]. The Private Body Consciousness Scale was used in four studies ($n$ = 4/27, 14.8%) [51, 73–75], the Body Perception Questionnaire in three studies ($n$ = 3/27, 11.1%) [61, 67, 76], and the Five Facet Mindfulness Questionnaire in two studies ($n$ = 2/27, 7.4%) [77, 78].

Beyond the three key interoceptive dimensions (accuracy, sensibility, and awareness), three studies [56–58] examined additional constructs using the heartbeat tapping task. In addition to interoceptive accuracy, Smith and colleagues [57] reported beat-to-tap consistency, which is a measure of the reliability in the timing between an individual's perceived heartbeats and the taps they make in response to those heartbeats during a task. Essentially, it measures the consistency with which a person can tap to their heartbeat, with lower variability in the timing of taps suggesting greater interoceptive awareness. Furthermore, using Bayesian computational modeling, two studies [56, 58] estimated interoceptive precision and prior beliefs favoring the presence of a heartbeat. Across three studies, these parameters consistently demonstrated that patients exhibit perceptual insensitivity to the modulation of interoceptive signals under physiological perturbation.

## Non-Interoception Measures

In addition to interoceptive assessments, various measures were employed to characterize substance use populations. The most frequently used addiction-related tools were the Timeline Follow-Back Interview [79] ($n$ = 10/39, 25.6%), followed by the Alcohol Use Disorders Identification Test (AUDIT) [80] and the Penn Alcohol Craving Scale [81] (each $n$ = 9/39, 23.1%). Among psychological assessments, questionnaires focused on psychiatric symptoms or trauma were most common ($n$ = 23/39, 59.0%), followed by measures of emotion regulation (e.g., Difficulties in Emotion Regulation Scale) [82] ($n$ = 12/39, 30.8%), pain and physical symptoms (e.g., Brief Pain Inventory) [83] ($n$ = 6/39, 15.4%), and alexithymia [84, 85] ($n$ = 5/39, 12.8%).

**Table 4** Summary of treatment studies with interoceptive measures in SUDs

| Authors (Year) | Samples (*N*) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Alcohol (2) | | | | | | |
| Sonmez et al. (2022) | AUD [a, b,c] ($n$=85)<br>HC [a] ($n$=87)<br>[a] All male participants were abstinent at least for 3 weeks<br>[b] Diagnosed with only AUD and didn't meet the criteria for other SUDs (excluding tobacco)<br>[c] Diagnosis based on DSM-5 | **Alcohol Use**: API; AUDIT<br>**Alcohol Craving**: PACS | **IA**: HCT (classic) | **Decision-making**: IGT | Lower HCT scores for AUD (0.63 ± 0.14) compared with HC (0.74 ± 0.12) | (1) Positive correlation between IA and IGT scores ($r$=0.271, $p$=0.012)<br>(2) Negative correlation between IA and three API subscales[a]<br>(3) No different proportion of abstinence between low IA group and high IA group after 3, 6, 12 months treatment<br>[a] Lack of assertiveness ($r$=0.221, $p$=0.042); Impulsivity ($r$=0.274, $p$=0.011); Anxiety ($r$=0.287, $p$=0.008) |
| Shimohara et al. (2024) | AUD[a] ($n$=50)<br>- Inpatient ($n$=27)<br>- Outpatient ($n$=23)<br>[a] Diagnosis based on DSM-5 | **Alcohol Use**: AUDIT; AUDIT-C | **IS**: BPQ-VSF | **Blood biomarkers**: Aspartate Amoinotransferase (AST); Alanine Aminotransferage (ALT); Gamma-glutamyl transpeptidase (γ-GTP); Mean red blood cell volume (MCV); Platelets; Fib-4 Index; Blood Pressure | (1) Higher BPQ-VSF total score for inpatient group (23.9 ± 5.8) compared to outpatient group (20.0 ± 6.0) at baseline<br>(2) Decrease in BPQ-VSF total score from admission (24.5 ± 5.6) to before discharge (19.6 ± 6.9) in inpatient group<br>(3) No significant change in BPQ-VSF total score in outpatient group | (1) Positive correlation between IS and both Fib-4 index ($r$=0.30, $p$=0.038) and AST (aspartate aminotransferase) levels ($r$=0.28, $p$=0.046) at admission<br>(2) No correlation between changes in IS and changes in various indicators of liver function |
| Heterogenous (4) | | | | | | |
| Price et al. (2012) | SUD[a, b] ($n$=46)<br>- TAU ($n$=15)<br>- TAU+MABT ($n$=31)<br>[a] Patients who enrolled SUD treatment<br>[b] All female participants | **Substance Use**: TLFB<br>**Relapse**: Reasons for Drinking Questionnaire (RFDQ) | **Mindfulness**: FFMQ<br>**Body Awareness**: Scale of Body Connection (SBC)<br>**Attitude toward the body**: Body Investment Scale (BIS) | **Psychological Symptoms**: BSI<br>**PTSD**: Modified Post-traumatic Stress Disorder Scale (MPSS)<br>**Eating Disorder**: Eating Disorder Examination Questionnaire (EDE-Q)<br>**Physical Symptoms**: Medical Symptoms Checklist (MSC)<br>**Stress and Coping**: PSS; DES; PANAS; DERS | (1) Baseline scores for SBC subscales[a], BIS (7.5 ± 1.0), FFMQ (116 ± 23.98) were reported<br>(2) Lower SBC subscale (Bodily dissociation) for MABT (0.88 ± 0.39) compared with TAU (1.4 ± 0.61) at 9 months<br>(3) Higher BIS for MABT (8.0 ± 1.1) compared with TAU (7.3 ± 1.1) at 9 months<br>[a] Bodily dissociation (1.6 ± 0.68); Body awareness (2.4 ± 0.60) | (1) Higher proportion of days abstinent for MABT ($M$=98.2) compared with TAU ($M$=82.7) at 3 months ($p$=0.02)<br>(2) Lower craving and social pressure as reasons for relapse for MABT (3.29, 1.31) compared with TAU (6.06, 5.1) ($p$=0.03, 0.007) |

**Table 4** (continued)

| Authors (Year) | Samples ($N$) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Price et al. (2019a) | SUD[a, b] ($n=217$)<br>[a] All female participants<br>[b] SUD patients who enrolled Intensive Outpatient Program (IOP) | **Substance Use**: TLFB | **IS**: MAIA<br>**Mindfulness**: FMI | **Trauma**: TLEQ; PSS-SR<br>**Depression**: BDI-II<br>**Emotion regulation**: RSA task, DERS | (1) Baseline MAIA (2.5 ± 0.86) and FMI (35.96 ± 9.16) were reported<br>(2) Positive correlation between MAIA and resting RSA after adjusting age and BMI ($\beta=0.28$, $p=0.03$)<br>(3) No significant relation between psychophysiological measures (PSS-SR, DERS, BDI, MAIA, FMI) and substance use | (1) No correlation between resting RSA and trauma (PSS-SR), depression (BDI), mindfulness (FMI), substance use (TFLB) and emotion regulation (DERS)<br>(2) All SUD reported at least one interpersonal traumatic event and 68% scored above the screening cutoff of PTSD |
| Price et al. (2019b) | SUD[a, b] ($n=217$)<br>- TAU only ($n=67$)<br>- TAU + WHE ($n=46$)<br>- TAU+MABT ($n=76$)<br>[a] All female participants<br>[b] SUD patients who enrolled Intensive Outpatient Program (IOP) | **Substance Use**: TLFB<br>**Craving**: PACS[a]<br>[a] Modified to address both alcohol and other drugs | **IS**: MAIA<br>**Mindfulness**: FMI | **Trauma**: TLEQ; PSS-SR<br>**Depression**: BDI-II<br>**Emotion regulation**: RSA task, DERS | Higher FMI ($p=0.002$) and MAIA subscales[a] ($p<0.002$) for MABT vs. WHE and MABT vs. TAU<br>[a] Noticing; Attention regulation; Emotional awareness; Self-regulation; Body listening; Trusting | (1) Higher proportion of abstinence for MABT vs. TAU and WHE vs. TAU ($p<0.001$)<br>(2) Lower craving (PACS) for MABT vs. TAU ($p=0.053$)<br>(3) Higher RSA ($p=0.04$) and lower DERS ($p=0.01$) for MABT vs. WHE and MABT vs. TAU |
| Price et al. (2019c) | SUD[a, b] ($n=217$)<br>- TAU only ($n=67$)<br>- TAU + WHE ($n=46$)<br>- TAU+MABT ($n=76$)<br>[a] All female participants<br>[b] SUD patients who enrolled Intensive Outpatient Program (IOP) | **Substance Use**: TLFB<br>**Craving**: PACS[a]<br>[a] Modified to address both alcohol and other drugs | **IS**: MAIA<br>**Mindfulness**: FMI | **Trauma**: TLEQ; PSS-SR<br>**Depression**: BDI-II<br>**Emotion regulation**: RSA task, DERS | Baseline: MAIA (2.6 ± 0.9), FMI (36.5 ± 9.5)<br>(1) Higher MAIA for MABT vs. TAU at 3,6 months ($M=0.8$, 0.4) and MABT vs. WHE at 3,6,12 months ($M=1.0$, 0.8, 0.5)<br>(2) Higher FMI for MABT vs. TAU at 3,6 months ($M=4.9$, 5.0) and MABT vs. WHE at 3,6,12 months ($M=7.6$, 6.9, 6.3),<br>(3) Higher RSA scores for MABT vs. TAU at 3,6,12 months ($M=0.53$, 0.29, 0.44) and MABT vs. WHE at 3,12 months ($M=0.57$, 0.72)<br>[a] $M$ = Mean difference | (1) More days abstinent in MABT (11.6%) and WHE (10.6%) compared to TAU at 6 months, however only MABT (22.4%) showed more days abstinent at 12 months<br>(2) Lower DERS from baseline to 3 months for MABT vs. TAU (M=-14.2) and MABT vs. WHE (M=-13.8)<br>(3) Consistent MABT skill use during past 3 months at 6-month follow-up (75.5%) and 12-month follow-up (78.4%) |
| Opioid (4) | | | | | | |

**Table 4** (continued)

| Authors (Year) | Samples (*N*) | Addiction Measures(s) | Intero-ceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Price et al. (2020) | OUD[a] ($n=10$)<br>- TAU ($n=5$)<br>- TAU+MABT ($n=5$)<br>[a] Participants who enrolled buprenorphine program for at least four weeks | Substance Use: TLFB<br>**Craving**: PACS[a]<br>[a] Modified to address both alcohol and other drugs | **IS**: MAIA | **Depression**: PHQ-9<br>**Anxiety**: GAD-7<br>**Emotion regulation**: DERS-SF<br>**Pain**: BPI<br>**PTSD**: PCL-5<br>**Physical symptoms**: MSC<br>**Subjective Measure**[a]: Intervention acceptability; Intervention satisfaction<br>[a] Rated on a four-point scale (0 = dissatisfied, 3 = extremely satisfied) | Improved MAIA in TAU+MABT from baseline (2.09 ± 0.96) to post treatment (3.47 ± 0.33) | TAU only showed no difference from baseline (2.84 ± 0.88) to post treatment (2.82 ± 0.82) |
| Schuman-Olivier et al. (2023) | OUD[a, b] ($n=18$)<br>[a] Prescribed sublingual buprenorphine for at least 30 days<br>[b] Diagnosis with DSM-5 | Not Assessed | **IS**: MAIA<br>**Mindfulness**: FFMQ | **Anxiety**, **Pain**, **Depression**: Patient Reported Outcomes Measurement Information System (PROMIS-ASF; PROMIS-PISF; PROMIS-DSF)<br>**Trauma**: Adverse childhood experiences (ACE)<br>**Experiential Avoidance**: Brief Experiential Avoidance Questionnaire (BEAQ)<br>**Emotional regulation**: DERS<br>**Self-compassion**: Self-Compassion Scale Short Form (SCS-SF)<br>**Stress**: Perceived Stress Scale (PSS-14) | (1) Significantly increased MAIA at 24 weeks of M-ROCC treatment (2.96 ± 0.60) compared to baseline (2.42 ± 0.72)<br>(2) Significantly increased FFMQ at 24 weeks of M-ROCC treatment (4.42 ± 0.38) compared to baseline (4.58 ± 0.32) | Not Applicable |

**Table 4** (continued)

| Authors (Year) | Samples (*N*) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Price et al. (2024) | OUD[a, b] (*n*=303)<br>- TAU (*n*=148)<br>- TAU+MABT (*n*=155)<br>[a] Enrolled in a medication (either buprenorphine or methadone) treatment program for OUD and stabilized on medication dose<br>[b] No specific criteria for OUD was directly mentioned | **Substance Use**: TLFB<br>**Craving**: a single item on an 11-point numeric scale (0~10) | **IS**: MAIA-2<br>**Mindfulness**: FMI | **PTSD**: PCL-5<br>**Depression**: PHQ-9<br>**Anxiety**: GAD-7<br>**Emotion regulation**: DERS-SF<br>**Pain**: BPI<br>**Physical Symptoms**: MSC | (1) Baseline MAIA-2 subscales[a] were reported for TAU+MABT group<br>(2) Baseline MAIA-2 subscales[b] were reported for TAU group<br>(3) Improved MAIA-2 subscales[c] for TAU+MBAT group compared with TAU group from baseline to 3 months<br>[a] Noticing (3.0 ± 1.0); Not distracting (1.9 ± 0.1); Not worrying (2.8 ± 0.1); Attention regulation (2.4 ± 0.1); Emotional awareness (3.1 ± 0.1); Self-regulation (2.4 ± 0.1); Body listening (1.7 ± 0.1); Trusting (2.7 ± 0.1)<br>[b] Noticing (3.0 ± 1.0); Not distracting (1.8 ± 0.1), Not worrying (2.7 ± 0.1); Attention regulation (2.5 ± 0.1); Emotional awareness (3.3 ± 0.1); Self-regulation (2.6 ± 0.1); Body listening (1.9 ± 0.1); Trusting (2.9 ± 0.1)<br>[c]Interoceptive awareness; Noticing; Attention regulation; Emotional awareness; Self-regulation; Body listening; Body trusting | |

**Table 4** (continued)

| Authors (Year) | Samples (*N*) | Addiction Measures(s) | Interoceptive Measure(s) | Non-interoceptive Measure(s) | Primary Findings | Secondary Findings |
|---|---|---|---|---|---|---|
| Price et al. (2025) | OUD[a, b] (*n* = 303)<br>- TAU (*n* = 148)<br>- TAU+MABT (*n* = 155)<br>[a] Enrolled in a medication (either buprenorphine or methadone) treatment program for OUD and stabilized on medication dose<br>[b] No specific criteria for OUD was directly mentioned | **Substance Use**: TLFB<br>**Craving**: a single item on an 11-point numeric scale (0 ~ 10) | **IS**: MAIA-2<br>**Mindfulness**: FMI | **PTSD**: PCL-5<br>**Depression**: PHQ-9<br>**Anxiety**: GAD-7<br>**Emotion regulation**: DERS-SF<br>**Pain**: BPI<br>**Physical Symptoms**: MSC | (1) Baseline MAIA-2 for TAU+MBAT (2.5 ± 0.1) and TAU (2.6 ± 0.1) were reported<br>(2) Baseline FMI score for TAU+MABT (34.4 ± 0.7) and TAU (35.1 ± 0.8) were reported<br>(3) Improved total scores of MAIA-2 (M[a]=0.38) and FMI (M = 2.18) for TAU+MABT compared with TAU from baseline to 12 months<br>[a] M=Mean group difference | (1) No group difference in abstinent days between adjunctive mindfulness-based therapy and standard treatment<br>(2) Improved physical symptom frequency in mindfulness-based therapy adjunct to standard treatment |

*API* Addiction Profile Index, *AUD* Alcohol Use Disorder, *AUDIT-C* Alcohol Use Disorders Identification Test-Consumption, *BDI-13* Beck Depression Inventory, *BIS* Body Investment Scale, *BPQ-VSF* Body Perception Questionnaire-Very Short Form, *BSI* Brief Symptom Inventory, *DERS-SF* Difficulties with Emotion Regulation Scale-Short Form, *DES* Dissociation Experiences Scale, *FFMQ* Five Facet Mindfulness Questionnaire, *FMI* Freiburg Mindfulness Inventory, *HC* Healthy Controls, *HCT* Heartbeat Counting Task, *IA* Interoceptive Accuracy, *IS* Interoceptive Sensibility, *MABT* Mindful Awareness in Body-oriented Therapy, *MAIA* Multidimensional Assessment of Interoceptive Awareness, *MSC* Medical Symptoms Checklist, *OUD* Opioid Use Disorder, *PACS* Penn Alcohol Craving Scale, *PANAS* Positive and Negative Affect Scale, *PCL-5* Post-traumatic Stress Disorder Checklist for DSM-5, *PHQ-9* Patient Health Questionnaire-9, *PSS* Perceived Stress Scale, *PSS-SR* PTSD Symptom Scale–Self Report, *RCT* Randomized Clinical Trial, *RSA* Respiratory Sinus Arrhythmia, *TAS-20* 20-item Toronto Alexithymia Scale, *TAU* Treatment As Usual, *TLEQ* Trauma Life Events Questionnaire, *TLFB* Timeline Follow-Back, *WHE* Women's Health Education

## Results by Substance Type

### Alcohol Use Disorder

Fourteen studies (*n* = 14/39, 35.9%) examined individuals with AUD [51, 52, 61, 73–76, 86–92]. Among the studies that compared interoceptive accuracy between individuals with AUD and healthy controls, most (*n* = 7/8, 87.5%) reported lower interoceptive accuracy in the AUD group, whereas one study (*n* = 1/8, 12.5%) [52] found higher interoceptive accuracy in individuals with AUD. Regarding interoceptive sensibility, results were more heterogeneous. Of the seven studies comparing interoceptive sensibility between AUD and HC groups, three (*n* = 3/7, 42.9%) reported lower interoceptive sensibility in the AUD group, three (*n* = 3/7, 42.9%) reported higher interoceptive sensibility, and one study (*n* = 1/7, 14.3%) [73] found no significant difference between groups.

Several correlations between interoceptive measures and addiction-related measures were reported, though the evidence showed limited convergence across studies. Ates Col and colleagues [86] identified negative correlations between interoceptive accuracy and both alcohol usage and craving. However, Schmidt et al. [90] found no independent effect of interoceptive accuracy on craving when controlling for other variables, and several other studies, including Jakubczyk et al. [51, 74] and Hina and Aspell [65] found no correlation between interoceptive accuracy and substance use or dependence. For interoceptive sensibility, Scigala et al. [91] reported negative associations with alcohol craving, suggesting that higher sensibility was related to lower craving. However, several studies reported null findings: Jakubczyk et al. [51] found no correlation between interoceptive sensibility and addiction severity, and Bloomer et al. [93] found no correlation between interoceptive sensibility and cannabis use severity or frequency. Overall, while some studies suggest that higher interoceptive dimensions may be associated with lower levels of substance use and craving, the evidence remains mixed and requires cautious interpretation.

#### Heterogeneous Substance Use

Twelve studies (*n* = 12/39, 30.8%) included heterogeneous substance use samples, which included either groups with different SUD diagnoses or individuals with polysubstance use [56–58, 66, 67, 70–72, 77, 94–96]. Among these, four studies (*n* = 4/12, 33.3%) measured interoceptive accuracy only, six (*n* = 6/12, 50.0%) assessed interoceptive sensibility only, and two (*n* = 2/12, 16.7%) measured both [56, 67]. Methodologically, these studies extended beyond commonly used cardiac tasks and self-report measures. Two studies [56, 58] utilized Bayesian computational modeling to estimate latent interoceptive variables, including interoceptive precision and prior beliefs. Two studies [66, 67] employed the Interoceptive Breathing Load Task (IBLT) to assess respiratory interoception using respiratory perturbation. In addition, three studies [66, 67, 95] used MRI to investigate neural correlates of interoceptive processing.

Of the five studies (*n* = 5/12, 41.7%) comparing interoceptive accuracy between SUD and healthy control groups, two reported lower IA in the SUD group, two found no group difference, and one reported higher IA in the SUD group (but only under the 'no-guessing' condition of the heartbeat tapping task) [57]. Regarding IS, one study [67] found no group differences, whereas a different study [95] reported that SUD and OUD groups scored lower than controls on MAIA subscales, including 'attention regulation', 'not worrying', 'self-regulation', and 'trusting'. Other studies assessing IS either did not report baseline data or did not include HC comparisons. Two studies employing computational modeling [56, 58] observed reduced interoceptive precision in SUD relative to control groups, particularly under the perturbation condition. Higher interoceptive accuracy was associated with better decision-making [96], and lower impulsivity [96] and alexithymia [94], though these findings are based on limited correlational evidence. Group differences between SUD and healthy controls in interoceptive measures were less consistent than those observed in AUD-specific studies.

#### Opioid Use Disorder

Six studies (*n* = 6/39, 15.4%) investigated individuals with OUD [59, 60, 78, 97–99]. All studies assessed IS only using the MAIA, with two also administering the Freiburg Mindfulness Inventory. Notably, none of the six studies included healthy control comparisons, precluding conclusions about whether IS differs between OUD populations and healthy individuals. The two non-treatment studies [97, 99] compared subgroups within OUD samples, while the four treatment studies [59, 60, 78, 98] examined pre-post changes following mindfulness-based interventions. Of the two non-treatment studies, Marcus et al. [97] reported no significant differences in MAIA scores between high and low early life stress subgroups, whereas White et al. [99] found that OUD participants with insomnia symptoms exhibited higher scores on the MAIA 'noticing' subscale. The four treatment studies [59, 60, 78, 98] all reported increases in IS following mindfulness-based interventions, with improvements maintained up to 12 months post-treatment.

#### Nicotine Use

Four studies (*n* = 4/39, 10.3%) examined smokers [62, 65, 100, 101]. Among the studies comparing smokers and non-smokers, Veilleux et al. [101] reported no significant group differences in IA. However, Hina and Aspell [65] found that smokers exhibited lower scores in the heartbeat counting task, while the heartbeat detection task and MAIA scores did not differ significantly between groups. Kim et al. [100] also found no difference in total MAIA scores between smokers and non-smokers, though scores differed between participants classified as having 'neglect' versus 'amplification' interoceptive styles. Notably, Mattioni et al. [62] was the only study among the 39 reviewed to measure interoceptive awareness. The authors reported no significant group differences in interoceptive awareness; however, individuals with lower interoceptive awareness smoked more cigarettes per day when experiencing higher smoking desire. Nicotine dependence showed no significant correlations with IA or IS [65].

#### Cocaine Use Disorder

Two studies (*n* = 2/39, 5.1%) focused on cocaine use disorder populations [64, 102]. De La Fuente et al. [64] assessed interoceptive accuracy using the heartbeat discrimination task and heart-evoked potential, while Pérez de los Cobos et al. [102] employed the heartbeat counting task. In de la Fuente et al. [64], participants were divided into Smoked Cocaine Dependence (SCD), Chlorhydrate Cocaine Dependence (CCD), and control groups. The SCD group exhibited higher heartbeat detection task scores than both the CCD and control groups. Pérez de los Cobos et al. [102], which did not include a healthy control group, found no significant differences in task scores between craver and non-craver participants.

### Cannabis Use

Although two studies included cannabis users as part of mixed or comparative samples [66, 93], Bloomer et al. [93] was the only study to examine cannabis users as an independent group compared to healthy controls. This study assessed IS using the MAIA-2. Cannabis users demonstrated higher scores on the 'noticing' and 'emotional awareness' subscales, although exact numerical values were not reported. Moreover, MAIA scores showed no significant correlations with cannabis use severity, frequency, and sensory gating performance.

## Studies on Intervention

Ten studies ($n$ = 10/39, 25.6%) evaluated interventions for addiction treatment. Sönmez et al. [92] followed AUD patients undergoing inpatient detoxification treatment, comparing high and low IA subgroups over a one-year relapse follow-up. Shimohara et al. [76] compared interoceptive measures and liver function biomarkers between inpatient and outpatient AUD groups at baseline and 3-month follow-up. Schuman-Olivier [78] investigated a mindfulness-based program for OUD patients receiving buprenorphine treatment. The remaining seven studies were conducted by Price and colleagues [59, 60, 70–72, 77, 98], examining Mindful Awareness in Body-oriented Therapy (MABT). Three studies [70–72] used the same SUD sample ($n$ = 217) with RCT designs to track changes in mindfulness, interoceptive sensibility, and emotion regulation. Later studies extended MABT to OUD populations, including a pilot study [98] and a larger RCT ($n$ = 303) [59, 60].

Among the ten studies, only Sönmez et al. [92] measured IA, reporting lower scores in AUD patients compared to healthy controls. The remaining nine studies assessed IS using self-report questionnaires. Shimohara et al. [76] found that IS decreased in inpatient AUD patients, while no significant changes were observed in outpatient patients at 3-month follow-up. In contrast, with the exception of Price et al. [70] which reported only baseline data, all seven mindfulness-based intervention studies observed increases in IS and mindfulness, although not all reached statistical significance.

Regarding substance use outcomes, MABT did not further extend abstinence duration in OUD patients who already demonstrated high abstinence rates (86–90%) [59, 60]. However, studies in heterogeneous SUD populations [71, 72, 77] found consistently higher abstinence rates following MABT. Taken together, these findings raise the possibility that targeting specific aspects of interoceptive processing may contribute to improvements in some addiction-related outcomes, although the evidence remains preliminary.

## Evidence from Neuroimaging Data

Four studies ($n$ = 4/39, 10.3%) used MRI to examine neural correlates of interoception in SUDs [64, 66, 67, 95]. Two employed the Interoceptive Breathing Load Task during fMRI [66, 67], one used the Visceral Interoceptive Awareness task during fMRI [95], and one combined structural and functional MRI with the heartbeat discrimination task and EEG-derived heart-evoked potentials [64]. The relationship between insular activation and drug use showed inconsistent results. Stewart et al. [67, 95] reported that greater lifetime drug use was associated with lower insular activation during breathing load, whereas Stewart et al. [95] found greater stimulant use linked to higher insular activation. De la Fuente et al. [64] observed that in smoked cocaine users, higher IA was associated with lower gray matter volume and reduced connectivity in the left insula, suggesting substance- or route-specific neural adaptations. May et al. [66] found no significant insular results in adolescents, possibly reflecting developmental differences in interoceptive processing. Despite these inconsistencies, a convergent pattern emerged: greater lifetime drug use was consistently associated with lower activation in the left inferior frontal gyrus, dorsolateral prefrontal cortex, and parahippocampal gyrus during aversive interoceptive challenge, consistent with potential alterations in neural systems involved in emotional regulation and contextual processing.

### Summary Across SUD Studies

Among the twenty studies that measured interoceptive accuracy, two did not include control groups and three [56–58] employed a heartbeat tapping task with distinct methodological approaches, precluding direct comparisons with traditional accuracy tasks. Of the remaining fifteen studies comparing SUD and healthy controls, nine ($n$ = 9/15, 60%) reported lower IA in the SUD group, two ($n$ = 2/15, 13.3%) found higher IA (in AUD and smoked cocaine users), three ($n$ = 3/15, 20.0%) found no significant differences, and one reported mixed findings across tasks [65]. Additionally, the three heartbeat tapping task studies reported lower interoceptive precision [56, 58] and reduced beat-to-tap consistency [46] in individuals with SUDs. Findings for interoceptive sensibility were more variable. Of fourteen studies with healthy control comparisons, six ($n$ = 6/14, 42.9%) reported no significant differences, four studies ($n$ = 4/14, 28.6%) found lower IS, and four ($n$ = 4/14, 28.6%) found higher IS.

## Discussion

This is the first systematic review to synthesize the existing evidence on interoception in individuals with SUDs. The review includes peer-reviewed studies with human participants that assessed at least one interoceptive dimension (accuracy, sensibility, or awareness) using behavioral tasks, self-report questionnaires, or both.

### Overview of the Findings

Among the thirty-nine studies that met the eligibility criteria, twelve studies ($n$ = 12/39, 30.8%) assessed IA only, nineteen ($n$ = 19/39, 48.7%) assessed IS only, and eight ($n$ = 8/39, 20.5%) measured both IA and IS. Only one study additionally assessed interoceptive awareness [62]. Overall, IA was frequently, though not uniformly, reduced in individuals with SUDs compared to healthy controls, particularly in those with alcohol use disorder. This pattern is suggestive of altered objective interoceptive performance in SUDs. In contrast, IS showed highly heterogeneous results, with no consistent pattern of alteration emerging across studies. Due to the limited number of studies on interoceptive awareness, firm conclusions regarding this dimension cannot be drawn at this time. However, caution is needed when interpreting these findings due to several methodological limitations in the current literature, which are outlined below.

### Limitations in the Current Literature

This review identified several concerns regarding interoception research in SUDs. First, most studies ($n$ = 35/39, 89.7%) focused on only two interoceptive dimensions (accuracy and sensibility) with minimal exploration of other dimensions. However, interoception is a complex, multidimensional construct, and this narrow focus risks providing an incomplete understanding and potentially overlooking other critical interoceptive processes. Notable exceptions include studies examining interoceptive awareness [62], beat-to-tap consistency [57], and computational approaches to estimating interoceptive precision and prior beliefs [56, 58].

Adding another layer of complexity to this limited dimensional approach, discrepancies exist between conceptualization and measurement of interoception [21]. For example, a meta-analysis revealed that the heartbeat counting and heartbeat discrimination tasks, both assumed to measure IA, shared only 4.4% of variance, raising questions about whether these tasks assess the same construct [103]. Furthermore, although IS is often treated as a single dimension, self-report questionnaires actually capture a broad range of aspects, including self-perceived capacity to detect internal sensations, emotional regulation through interoceptive attention, and trust in bodily signals [20]. These discrepancies make it challenging to draw reliable conclusions and replicate findings, underscoring the need for more precise definitions and better alignment between theory and assessment methods. Computational modeling methods [56, 58] represent one attempt to address this gap by decomposing latent processes within interoceptive dimensions.

A second limitation concerns the predominant focus on the cardiac domain ($n$ = 17/20, 85.0%), with other interoceptive domains (e.g., respiratory, gastric) remaining understudied. This reliance on a single bodily system is problematic, as previous studies have found no significant correlations across different interoceptive domains [104–108], suggesting that performance in one domain cannot be generalized to others. Therefore, broadening the scope beyond the cardiac domain or examining multiple domains within a single study would facilitate a more comprehensive understanding of interoceptive processes. Compounding this cardiac-centric focus, many studies ($n$ = 14/22, 63.6%) assessing cardiac interoceptive accuracy relied on the heartbeat counting task as their sole performance-based measure, despite substantial criticism regarding its validity [27]. The primary concern is that participants can achieve high scores by guessing their heart rate rather than relying on actual felt sensations [25, 27, 29, 109–113]. Billaux and colleagues [73] directly addressed these concerns by comparing classical and adapted versions of the HCT in both clinical (severe AUD) and subclinical (binge drinkers) populations. Performance was lower in the adapted version, supporting the notion that the classical HCT is influenced by non-interoceptive strategies such as guessing. Additionally, HCT performance showed no significant correlation with psychological constructs like emotion regulation or anxiety, further questioning its validity as a measure of interoception. Future research should employ more reliable cardiac measures [19].

A third limitation involves inadequate control and reporting of substance use characteristics. This is particularly important because the relationships between interoception and addiction-related factors, including substance type, duration of use, addiction severity, abstinence duration, craving, and withdrawal symptoms, remain poorly understood. Many studies fail to report these details or examine their relationship with interoception, and when they do, they typically examine only one or two variables rather than a full range of potentially relevant factors. A notable example is the inconsistent treatment of smoking as a confounding variable. Some studies report a high proportion of smokers in their samples (e.g., more than 80% of participants in [97]), while others do not specify whether smokers were included or report their smoking state. As a result, the confounding effect of smoking cannot be ruled out. This concern is particularly salient given evidence that smoking deprivation impacts physiological and cognitive functions relevant to interoceptive tasks, including cardiac function, insula activity, and time estimation [114–122]. However, no study has evaluated interoceptive dimensions in smokers under both deprived and satiated states, and the four smoking studies reviewed used varied abstinence protocols or did not report them [62, 65, 100, 101]. Future research should clearly report smoking status, control for its effects, and standardize smoking state in study protocols.

### Limitations of the Systematic Review

The systematic review has several limitations that should be acknowledged. First, the heterogeneity of included studies, varying in sample characteristics, substance types, abstinence durations, assessment methods, and control procedures, made quantitative meta-analysis difficult. The narrative synthesis approach, while comprehensive, does not provide the statistical power of meta-analytic techniques to detect small effects or moderators. Second, the review relied on published literature, which may be subject to publication bias favoring significant findings. Studies finding null results for interoception in substance use populations may be underrepresented. Third, using "interoception" as the primary search term may have excluded studies using alternative terminology (e.g., body awareness, visceral perception). Future systematic reviews should consider broader search strategies with multiple related terms, though at the risk of reduced specificity and increased heterogeneity in constructs examined.

## Conclusions

In conclusion, this systematic review synthesizes the existing evidence on interoception in SUDs, focusing on three interoceptive dimensions: accuracy, sensibility, and awareness. IA was consistently reduced in individuals with SUDs compared to healthy controls, with this reduction being most pronounced in AUD and less consistent across other substance use populations. In contrast, findings regarding IS were highly heterogeneous, with studies reporting lower, higher, or comparable levels relative to healthy controls. Furthermore, the limited research on interoceptive awareness prevents any firm conclusions from being drawn regarding its role in SUDs. The relationship between interoceptive functioning and addiction-related behaviors remains poorly understood, highlighting the need for research to better characterize these associations.

This review also identified several critical methodological limitations in the current literature, including the predominant focus on only two interoceptive dimensions, overreliance on the cardiac domain, and widespread use of the heartbeat counting task despite substantial concerns about its validity. Additionally, the inconsistent treatment of smoking as a confounding variable and the lack of standardized protocols for assessing smokers in different physiological states represent significant gaps in the literature. Future research should simultaneously assess multiple interoceptive dimensions across various physiological domains, employ more reliable measurement methods, and utilize computational modeling approaches to better understand the latent processes underlying interoceptive performance. For studies involving smokers, it is essential to systematically examine interoceptive functioning under both satiated and deprived conditions to account for the physiological and cognitive changes associated with nicotine withdrawal. Finally, investigating the potential therapeutic benefits of enhancing interoceptive abilities in addiction recovery represents an important avenue for future research with direct clinical implications.

## Key References


- Billaux P, Desmedt O, Corneille O, et al. Validity concerns about the heartbeat counting task extend to alcohol use disorder: Evidence from subclinical and clinical samples. Addiction Biology. 2025;30(5).
  - Directly tests the validity of the heartbeat counting task in AUD populations, demonstrating that non-interoceptive strategies contaminate performance and calling for alternative measurement approaches.
- Desmedt O, Luminet O, Maurage P, Corneille O. Discrepancies in the definition and measurement of human interoception: A comprehensive discussion and suggested ways forward. Perspectives on Psychological Science. 2025;20(1):76-98.
  - A comprehensive examination of conceptual and methodological discrepancies in interoception research, proposing consensus definitions and measurement standards critical for advancing the field.
- Desmedt O, Luminet O, Walentynowicz M, Corneille O. The new measures of interoceptive accuracy: A systematic review and assessment. Neuroscience & Biobehavioral Reviews. 2023;153.

  - A systematic review evaluating recently developed interoceptive accuracy measures, providing crucial guidance for selecting valid assessment methods in clinical and experimental research.

- Garfinkel SN, Seth AK, Barrett AB, Suzuki K, Critchley HD. Knowing your own heart: Distinguishing interoceptive accuracy from interoceptive awareness. Biological Psychology. 2015;104:65-74.

  - Proposes the influential three-dimensional model distinguishing interoceptive accuracy, sensibility, and awareness, providing the theoretical framework adopted throughout this systematic review.

- Paulus MP, Stewart JL. Interoception and drug addiction. Neuropharmacology. 2014;76:342-50.

  - Influential review proposing that interoception contributes to addiction, integrating evidence on insula dysfunction with arousal, conditioning, and reward processing.

- Smith R, Kuplicki R, Feinstein J, et al. A Bayesian computational model reveals a failure to adapt interoceptive precision estimates across depression, anxiety, eating, and substance use disorders. PLoS Computational Biology. 2020;16(12).

  - Introduces innovative Bayesian computational modeling approaches to quantify latent interoceptive processes, revealing transdiagnostic perceptual insensitivity patterns across clinical populations including SUDs.

- Suksasilp C, Garfinkel SN. Towards a comprehensive assessment of interoception in a multi-dimensional framework. Biological Psychology. 2022;168.

  - Updates the influential three-dimensional interoception model to include eight dimensions, providing a more comprehensive theoretical framework for assessing interoceptive functioning in clinical populations.

- Verdejo-Garcia A, Clark L, Dunn BD. The role of interoception in addiction: A critical review. Neuroscience & Biobehavioral Reviews. 2012;36(8):1857-69.

  - Comprehensive critical review establishing the role of interoceptive deficits in addiction-related mechanisms, including insula dysfunction and physiology-emotion decoupling.

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**Data Availability** No datasets were generated or analyzed during the current study.

## Declarations

**Human and Animal Rights and Informed Consent** This article is a systematic review of previously published studies. No animal or human subjects were used by the authors in this study.

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