Title Page

Title

A Systematic Review of Interoception in Substance Use Disorders

Authors

Jooyeon Jamie Im[1], Eunsol So[2], Kipyo Kim[3], Woo-Young Ahn[1,3,4,†]

Affiliations

[1] Department of Psychology, Seoul National University, Seoul, Republic of Korea

[2] Department of Psychology, Yonsei University, Seoul, Republic of Korea

[3] Department of Brain and Cognitive Sciences, Seoul National University, Seoul, Republic of Korea

[4] AI Institute, Seoul National University, Seoul, Republic of Korea

† Corresponding author. Email: wahn55@snu.ac.kr

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 records identified in APA PsycINFO, PubMed, CINAHL, and Embase using predefined search terms, 39 studies met eligibility criteria. Of these, 14 examined alcohol use disorder, 12 heterogeneous substance use, 6 opioid use disorder, 4 smokers, 2 cocaine use disorder, and 1 cannabis use. With respect to interoceptive domains (accuracy, sensibility, awareness), 12 studies assessed accuracy only, 19 assessed sensibility only, and 8 measured both; only one study additionally evaluated interoceptive awareness. Behavioral tasks (e.g., heartbeat counting) and self-report questionnaires (e.g., Multidimensional Assessment of Interoceptive Awareness; MAIA) were the most common measures of interoceptive accuracy and sensibility, respectively. Neuroimaging work was scarce, with only four studies examining neural correlates.

Summary

Across studies of interoception in SUDs, the most consistent pattern is reduced interoceptive accuracy relative to healthy controls, particularly in alcohol use disorder where impairments were most robust, though findings for other substances showed greater variability. Evidence for interoceptive sensibility is mixed, and work on interoceptive awareness remains sparse. The literature is constrained by a narrow emphasis on two dimensions and by heavy reliance on the heartbeat counting task, which has been widely criticized for validity concerns. Future research should assess multiple interoceptive dimensions across modalities, develop and validate more robust measures, and address potential confounders such as smoking status.

Keywords

Addiction, Substance use disorders, Interoception, Interoceptive accuracy, Interoceptive sensibility, Interoceptive awareness

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 closely linked to dysfunctional interoceptive processing, with evidence indicating alterations across multiple dimensions of interoception, including accuracy, sensibility, and awareness of internal bodily signals. These dysfunctions are thought to play a critical role in addiction-related mechanisms such as craving, relapse vulnerability, and impaired emotion regulation, all of which contribute to the development, maintenance, and recurrence of SUDs [5, 7, 8].

Several narrative and opinion reviews have addressed interoception in SUDs, but many are dated, and numerous new empirical studies have appeared in recent years [5, 8-15]. Despite this growing literature, a systematic review integrating findings on interoception in SUDs has not yet been conducted.

This paper reviews empirical work on interoception in SUDs, assesses evidence for deficits, highlights gaps, and proposes avenues for future research. The introduction covers interoceptive dimensions, measurement methods, and the theorized role of interoception in addiction.

Dimensions of Interoception

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 levels 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]. In response to these issues, more comprehensive frameworks have been proposed. Notably, a panel of experts in the interoception community [2] introduced the eight interoceptive dimensions, 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 proposals 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 paper, the original 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

Interoception measures vary across several dimensions and physiological domains including the cardiac, respiratory, and gastrointestinal domains. Among these, the cardiac domain is the 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 the number of heartbeats felt during varying specified time intervals (e.g., 25, 35, and 45 seconds) without manually feeling their pulse and 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 using the formula: (1 - |actual heartbeats – reported heartbeats|) / (actual heartbeats + reported heartbeats) / 2) for each trial, and then averaged over all trials to get a mean score [18]. Variants of the original heartbeat counting task exist, differing in interval durations, number of trials, rest periods between trials, and instructions (e.g., prohibiting guessing, using tapping instead of silent counting) [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]. Additionally, there are other cardiac tasks, such as the heartbeat discrimination task, where participants are asked to determine whether sequences of auditory tones are synchronized with or delayed relative to their heartbeats [30, 31], among others. 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 measures in interoceptive tasks. A systematic review by Desmedt et al. [20] identified the most frequently cited questionnaires on this dimension between 2015 and 2020, including 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 subscale of the Body Consciousness Questionnaire [36], and the Self-Awareness Questionnaire [37].

Less frequently cited measures included the Eating Disorder Inventory 1-3 [38-40], the Body Sensations Questionnaire [41], the Five Facet Mindfulness Questionnaire [42], the Emotional Susceptibility Scale [43], the Autonomic Perception Questionnaire [44], the Visceral Sensitivity Index [45], the Body Vigilance Scale [46], and the Interoceptive Awareness Questionnaire [47] (Bogaerts et al., 2018). Among these, the MAIA [34] has gained significant popularity in recent years due to its research applicability. It includes eight dimensions: noticing, not-distracting, not-worrying, attention regulation, emotional awareness, self-regulation, body-listening, and trusting. A second version (MAIA-2) [48] and a shorter version (Brief MAIA-2) [49] have since been developed.

Interoceptive awareness, a metacognitive measure reflecting the correspondence between behavioral and self-report measures, can be assessed through the correlation of accuracy and confidence scores from task-based measures. However, this method is biased by ceiling or floor task performance and violations of normality assumptions [50]. The Area Under the Receiver Operating Characteristic (AUROC) better quantifies the extent to which confidence ratings predict accuracy on a trial-by-trial basis but is similarly confounded by task performance [51]. The meta-d' approach addresses these issues by modeling the relationship between task performance and AUROC, yielding unbiased metacognitive estimates [52]. In this systematic review, we consider all measures discussed here, as well as additional measures identified in studies retrieved through our search strategy.

Role of Interoception in Addiction

Interoceptive dysfunctions have been increasingly recognized as important factors in the development, maintenance, and relapse of SUDs [5, 8, 11, 15]. One proposed mechanism is that individuals with SUDs often exhibit altered interoceptive accuracy, particularly in detecting bodily states related to craving, stress, and aversive stimuli. This altered sensitivity to bodily cues may exacerbate emotional dysregulation, impair decision-making, and fuel compulsive drug use as individuals may struggle to differentiate between internal signals of discomfort and the need for substance use [5]. Moreover, deficits in interoceptive sensibility may contribute to impaired emotion regulation, making it difficult for individuals to recognize and respond appropriately to emotional cues, which in turn increases vulnerability to addictive behaviors [8]. Interoceptive awareness may also be compromised in SUDs, leading to poor insight into the impact of substance use on one's physiological state, further reinforcing the cycle of addiction. Dysfunctional interoception is thought to interact with heightened stress reactivity, distorted reward processing, and maladaptive coping mechanisms, all of which are central to the pathophysiology of addiction. Despite the growing body of empirical research on interoception in SUDs, no systematic review has yet been conducted to synthesize these findings.

Aims

This paper aims to review empirical studies on interoception in individuals with SUDs, examine the evidence for potential interoceptive deficits, identify gaps in the current literature, and propose directions for future research.

Methods

This systematic review was conducted under the 2020 Preferred Reporting Items for Systematic Reviews (PRISMA) guidelines [53] 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

The screening and selection of studies were conducted independently by three authors using Rayyan, which is a web/mobile-based platform designed to optimize the process for systematic reviews [54]. Titles and abstracts screening of identified studies after duplication removal (n = 1544) was based on the inclusion/exclusion criteria as defined above. Disagreements or discrepancies regarding the eligibility of records were resolved by the authors through discussion, and a total of n = 45 studies were retrieved and assessed for eligibility. After full-text screening by each author and through consultation, 39 studies were ultimately included in the qualitative synthesis, with studies excluded for having no data reported on interoceptive dimension, a wrong population or publication type (n = 6). This data screening process is presented using the PRISMA flow diagram (**Figure 1**).

Data Extraction and Synthesis

Data were independently extracted by the authors and then cross-checked together to confirm the accuracy of all indices. The extracted data included the first author, publication year, population, sample size, interoception measures, non-interoception measures, and findings with relevant results (e.g., task scores with mean and standard deviation, correlation coefficient, and p-values). If numerical data were unavailable for interoception measures in the full-text paper, the supplementary materials were searched.

The extracted data are synthesized in the Results and Discussion sections. In **Table 3**, the key findings are summarized, with the extracted information from each study grouped by population (e.g., alcohol use, smoking, stimulant use). For the Samples (N) column, diagnostic criteria (e.g., DSM-5, ICD-10), duration of abstinence, and key participant characteristics (e.g., adolescents) were recorded. Interoception measures were categorized by interoceptive dimension and the type of task or self-report questionnaire used. For the heartbeat counting task, studies were classified based on whether the classical or adapted version was employed. Lastly, the findings were categorized as primary if they were direct results of the interoceptive dimensions, and as secondary if they involved indirect measures, such as correlations between interoception and other factors.

Studies primarily focused on treatment efficacy are summarized separately in **Table 4**. These studies differ in nature, as their primary purpose was not to assess the interoceptive dimension in SUDs, but rather to focus on treatment outcomes, with interoceptive measures serving a secondary role. As a result, some studies do not include HC groups, lack baseline data, and report only total means rather than subscale scores, making it difficult to draw conclusions. Therefore, the authors decided it would be more appropriate to address these studies separately.

Results

General Characteristics of the Included Studies

A total of thirty-nine studies investigating interoception in SUD populations were included in this review. **Table 3** summarizes 29 non-treatment empirical studies, and **Table 4** summarizes 10 treatment studies.

Of the thirty-nine studies, fourteen studies (n = 14/39, 35.9%) focused on individuals with alcohol use disorder (AUD), twelve studies (n = 12/39, 30.8%) on heterogeneous substance users, six studies (n = 6/39, 15.4%) on opioid use disorder (OUD), four studies (n = 4/39, 10.3%) studies on smokers, two studies (n = 2/39, 5.1%) on cocaine use disorder (CUD), and one study (n = 1/39, 2.6%) on cannabis users.

Across the thirty-nine studies, the median sample size was 120, with a mean of 173.5. The standard deviation exceeded 160, indicating considerable heterogeneity 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 the large-sample studies (n ≥ 300), three studies (n = 3/6, 50%) drew samples from the Tulsa 1000 Project [55-57], two (n = 2/6, 33.3%) utilized samples from MABT intervention studies [58, 59], and one (n = 1/6, 16.7%) included 809 healthy controls and 50 individuals with AUD and 41 with Gaming Disorder [60]. Most studies with fewer than 100 participants incorporated behavioral tasks or physiological assessments (e.g., MRI).

Interoception Measures

In terms of interoceptive dimensions, twelve studies (n = 12/39, 30.8%) assessed interoceptive accuracy only, nineteen studies (n = 19/39, 48.7%) assessed interoceptive sensibility only, and eight studies (n = 8/39, 20.5%) measured both accuracy and sensibility. Only one study additionally assessed interoceptive awareness [61].

Regarding methodological approaches for measuring interoception, twelve studies (n = 12/39, 30.8%) employed behavioral tasks only, seventeen studies (n = 17/39, 43.6%) utilized self-reported questionnaires only, and ten studies (n = 10/39, 25.6%) applied 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 [62] was utilized in four studies (n = 4/22, 18.2%) [55-57, 61], while the heartbeat discrimination task was used in two studies (n = 2/22, 9.1%) [63, 64]. Two studies (n = 2/22, 9.1%) [65, 66] employed the Interoceptive Breathing Load Task (IBLT; [67]), which measures interoceptive dimension through inspiratory breathing resistance. Among these two, one [66] assessed interoceptive accuracy under the breathing-load condition, while the other [65] collected only self-reported ratings of pleasantness and intensity of the breathing load. Therefore, the latter study was classified as measuring interoceptive sensibility only in this review.

Among the twenty-seven studies that measured interoceptive sensibility, the most frequently (n = 18/27, 66.7%) used questionnaire (n = 14/27, 51.9%) was MAIA. The second most common measure (n = 5/27, 18.5%) was the Freiburg Mindfulness Inventory [68], which was used in five studies by Price and colleagues [58, 59, 69-71]. The Private Body Consciousness Scale was used in four studies (n = 4/27, 14.8%) [72-75], the Body Perception Questionnaire in three studies (n = 3/27, 11.1%) [60, 66, 76], and the Five Facet Mindfulness Questionnaire in two studies (n = 2/27, 7.4%) [77, 78].

Apart from the three interoceptive dimensions (accuracy, sensibility, and awareness), three studies [55-57] have reported different interoceptive dimensions using the heartbeat tapping task. In addition to interoceptive accuracy, Smith and colleagues [56] 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 [55, 57] 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.

In summary, twelve studies (n = 12/39, 30.8%) employed behavioral tasks only, seventeen studies (n = 17/39, 43.6%) used self-report questionnaires only, and ten studies (n = 10/39, 25.6%) incorporated both behavioral and self-report measures to assess interoceptive dimensions. Notably, Stewart and colleagues [66] implemented a multimodal assessment by combining the IBLT to assess interoceptive accuracy, the BPQ to measure interoceptive sensibility, fMRI to record neural responses, and additional questionnaires to evaluate alcohol use and psychiatric symptoms. Similarly, De La Fuente et al. [63] employed the heartbeat discrimination task and Heart-Evoked Potentials (HEP) to assess interoceptive accuracy, and structural and functional MRI to examine neural correlates of interoception, providing a multimodal investigation of interoceptive processes in SUD populations.

Non-Interoception Measures

Across the thirty-nine studies included in this review, numerous measures not directly related to interoception were also used to characterize more details of the substance use populations.
To assess addiction-related characteristics in individuals with SUD, the most frequently used tool (n = 10/39, 25.6%) was the Timeline Follow-Back interview [79]. The Alcohol Use Disorders Identification Test (AUDIT; [80]) and the Penn Alcohol Craving Scale [81] were each used nine times (n = 9/39, 23.1%). The Obsessive Compulsive Drinking Scale [82] and the Addiction Profile Index [83] were each utilized three times, and the Fagerström Test for Nicotine Dependence [84] was used twice. In some cases, addiction severity was inferred based on diagnostic criteria or treatment status rather than specific addiction measures.

A variety of psychological assessments were utilized in addition to interoception and addiction-related measures. The most common assessments were questionnaires focused on psychiatric symptoms or trauma (n = 23/39, 59.0%). Measures of emotion regulation (e.g., Difficulties in Emotion Regulation Scale [85]) appeared in twelve studies (n = 12/39, 30.8%), followed by assessments of pain and physical symptoms (e.g., Brief Pain Inventory [86]) in six studies (n = 6/39, 15.4%), alexithymia (e.g., Toronto Alexithymia Scale–20 [87, 88]) in five studies (n = 5/39, 12.8%), and assessments of sleep (e.g., Athens Insomnia Scale [89]) and eating disorders (e.g., SCOFF Questionnaire [90]) in four studies each (n = 4/39, 10.3%). A noteworthy trend observed in six studies (n = 6/39, 15.4%) focusing on OUD is the use of a relatively large number of questionnaires [58, 59, 78, 91-93]. Together, these studies offer a multifaceted characterization of individuals with OUD by incorporating comprehensive assessments of psychiatric symptoms, pain and physical symptoms, emotion regulation, trauma, and other relevant domains.

Alcohol Use Disorder

Fourteen studies (n = 14/39, 35.9%) examined individuals with AUD [60, 72-76, 94-101]. 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%) [101] 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%) [72] found no significant difference between groups.

Five studies (n = 5/14, 35.7%) employed behavioral tasks that all used the heartbeat counting task. Five studies (n = 5/14, 35.7%) relied solely on self-reported questionnaires to assess interoceptive sensibility, while four studies (n = 4/14, 28.6%) combined behavioral tasks and self-report measures. Among addiction-related measures, the Alcohol Use Disorders Identification Test was the most frequently used (n = 9/14, 64.3%), followed by the Penn Alcohol Craving Scale (n = 5/14, 35.7%), the Obsessive Compulsive Drinking Scale (n = 3/14, 21.4%), and the Timeline Followback (n = 2/14, 14.3%).

Several correlations between interoceptive accuracy and non-interoceptive measures were reported. Ates Col et al. [94] identified significant negative correlations between interoceptive accuracy, alcohol usage, and craving. Positive associations between interoceptive accuracy and other measures were found for performance on the Iowa Gambling Task (IGT) [95, 100], while negative associations were observed with Addiction Profile Index (API) subscales (lack of assertiveness; impulsivity; anxiety) [101] and pain sensitivity [75]. For interoceptive sensibility, positive associations were reported with sleep problems and anxiety [73] and impulsivity while undergoing negative emotions [74]. Negative associations were found with alcohol craving, difficulties in emotion regulation, and alexithymia [99]. Overall, higher interoceptive dimensions (interoceptive accuracy and interoceptive sensibility) were generally associated with lower levels of alcohol-related risks.

Smokers

Four studies (n = 4/39, 10.3%) examined populations of smokers [61, 64, 102, 103]. Of the four studies, two included only smoker participants without a comparison group [61, 102], whereas the remaining two studies that compared smokers with healthy controls reported inconsistent findings regarding interoceptive measures [64, 103]. Kim et al. [102] assessed interoception exclusively using the MAIA questionnaire, while the other three studies employed behavioral tasks (heartbeat counting task, heartbeat detection task, heartbeat tapping task) to measure interoceptive accuracy. Addiction-related measures included the Fagerström Test for Nicotine Dependence (FTND) and the Questionnaire of Smoking Urge (QSU), with two studies utilizing the FTND and another two using the QSU.

Among the studies comparing smokers and non-smokers, Veilleux et al. [103] reported no significant group differences in interoceptive accuracy. Hina and Aspell [64] 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. [102] classified the participants into ‘neglect’ and ‘amplification’ groups based on MAIA subscale scores (not-distracting, noticing, not-worrying) and their smoking status. Although total MAIA scores did not differ significantly between smokers and non-smokers, a significant difference was found in MAIA scores between the neglect and amplification bias groups.

Interestingly, Mattioni et al. [61] was the only study among the 39 reviewed studies that explicitly measured interoceptive awareness. The authors found no significant group differences in interoceptive awareness but reported that individuals with lower interoceptive awareness smoked more cigarettes per day when experiencing higher smoking desire. On the other hand, nicotine dependence assessed by the FTND revealed no significant correlation with either interoceptive accuracy or interoceptive sensibility [64].

Opioid Use Disorder

Six studies (n = 6/39, 15.4%) investigated OUD populations [58, 59, 78, 91-93]. All studies explicitly stated buprenorphine or methadone medication-assisted treatment as part of their inclusion criteria. Furthermore, all studies assessed interoceptive sensibility only, with MAIA administered in all six studies and the Freiburg Mindfulness Inventory used in two studies.

Three studies (n = 3/6, 50%) [58, 59, 92] included the Timeline Followback to assess addiction-related measures, whereas the remaining three (n = 3/6, 50%) did not include any direct assessments of substance use quantity or craving. Notably, all six studies incorporated a wide range of non-interoceptive measures, including assessments of psychiatric symptoms, pain and physical symptoms, trauma, and emotion regulation.

Marcus et al. [91] reported no significant difference in MAIA scores between low versus high early life stress subgroups within the OUD population. Conversely, White et al. [93] found that OUD participants with greater insomnia symptoms exhibited higher MAIA ‘noticing’ subscale scores and elevated inflammatory phenotypes compared to those with fewer insomnia symptoms.

Cocaine Use Disorder

Two studies (n = 2/39, 5.1%) focused on cocaine use disorder populations [63, 104]. De La Fuente et al. [63] assessed interoceptive accuracy using the heartbeat discrimination task and Heart-Evoked Potentials (HEP), while Pérez de los Cobos et al. [104] employed the heartbeat counting task. In de la Fuente et al. [63], 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. [104], which did not include a healthy control group, found no significant differences in task scores between craver and non-craver participants.

Cannabis Users

Although two studies included cannabis users as part of mixed or comparative samples [65, 105], Bloomer et al. [105] was the only study to examine cannabis users as an independent group compared to healthy controls. This study assessed interoceptive sensibility only 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.

Heterogeneous Substance Users

Twelve studies (n = 12/39, 30.8%) included heterogeneous substance use samples, defined as either (1) groups consisting of distinct substance use disorder populations or (2) groups of participants who use multiple substances [55-57, 65, 66, 69-71, 77, 106-108]. Among these, eight studies (n = 8/12, 66.7%) incorporated behavioral tasks, while four studies (n = 4/12, 33.3%) employed self-report questionnaires only. Across this category, 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 [55, 66].

Unlike studies dealing with other substance populations, a variety of methodological approaches have been employed to assess interoceptive measures across heterogeneous substance user groups. Two studies [55, 57] utilized Bayesian computational modeling to estimate latent interoceptive variables, including interoceptive precision (IP) and prior beliefs (pHB). Additionally, two studies [65, 66] employed the Interoceptive Breathing Load Task (IBLT) to assess interoception through respiratory sensations rather than cardiac signals. Three studies [65, 66, 107] 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) [56]. One study [66] found no group difference in interoceptive sensibility, whereas another [107] 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. In addition, two studies employing computational modeling [55, 57] observed reduced interoceptive precision in clinical groups relative to controls, particularly under the perturbation condition.

All 12 studies involving heterogeneous substance users included drug use-related measures, most frequently the Timeline Followback (n = 4/12, 33.3%) and Drug Abuse Screening Test (n = 3/12, 25%). Regarding non-interoceptive measures, psychiatric symptom questionnaires including assessments of trauma, depression, and anxiety were administered in nine studies (n = 9/12, 75%), representing the most frequently evaluated domain.

Positive associations with interoceptive accuracy were observed for Iowa Gambling Task performance [108], while negative associations were found with impulsivity [108] and alexithymia [106]. One study [107] further reported that interoceptive sensibility, as assessed by the Visceral Interoceptive Awareness task, was positively correlated with recent illicit drug use under the heart cue condition in the SUD group.

In summary, higher interoceptive dimensions were associated with more adaptive cognitive and emotional functioning, whereas differences between SUD and HC groups in interoceptive measures appeared less robust than those observed in studies focusing specifically on AUD populations.

Studies on Intervention and Clinical Outcomes

Among the 39 studies included in this review, nine longitudinal studies (n = 9/39, 23.1%) and one cross-sectional study (n = 1/39, 2.6%) evaluated the effectiveness of interventions for addiction treatment. Sönmez et al. [100] followed AUD patients who underwent inpatient detoxification treatment, comparing high interoceptive accuracy and low interoceptive accuracy subgroups over a one-year relapse follow-up period, and also examined differences between the AUD and healthy control groups. Shimohara et al., [76] compared baseline and 3-month follow-up data on interoceptive measures and liver function biomarkers (via blood testing) between inpatient and outpatient AUD groups. Schuman-Olivier [78] investigated the effects of Mindful Recovery Opioid Care Continuum (M-ROCC), a mindfulness-based adjunctive program implemented in OUD patients receiving buprenorphine medication treatment.

Of the 10 intervention-based studies, the remaining seven studies (n = 7/39, 17.9%) were conducted by Price and colleagues [58, 59, 69-71, 77, 92]. Price et al. [77] was the first to examine Mindful Awareness in Body-oriented Therapy (MABT) among SUD patients. Subsequent studies [69-71] used the same SUD sample (n = 217) but implemented randomized controlled trial (RCT) designs when assigning participants to different treatment conditions and follow-up periods to track changes in mindfulness, interoceptive sensibility, emotion regulation, and psychological distress. Price et al. [92] extended MABT to OUD populations, conducting a pilot test to evaluate feasibility. Later, Price et al. [58, 59] examined the effects of MABT as an adjunctive intervention in outpatient individuals with OUD (n = 303) receiving medication-assisted treatment employing RCT designs.

Among the 10 intervention-based studies, Sönmez et al. [100] was the only study to measure interoceptive accuracy using the heartbeat counting task, reporting that AUD patients showed lower IA compared to healthy controls. The remaining nine studies (n = 9/10, 90%) assessed interoceptive sensibility using self-report questionnaires.

In the study by Shimohara [76], the inpatient group exhibited higher interoceptive sensibility at baseline compared to the outpatient group, but at the 3-month follow-up, interoceptive sensibility decreased significantly in the inpatient group while no significant changes were observed in the outpatient group. In contrast, with the exception of Price et al. [69], which reported only baseline data, all seven mindfulness-based intervention studies observed increases in both interoceptive sensibility and mindfulness, although a few did not reach statistical significance. In two papers by Price et al. [58, 59], which involved OUD patients already demonstrating a high proportion of abstinence (86–90%), MABT did not further extend abstinence duration. However, three studies from Price and colleagues which focused on heterogenous SUD populations [70, 71, 77] found consistently higher proportions of abstinence following MABT treatment.

Taken together, findings from these intervention-based studies suggest that enhancing interoceptive dimensions may contribute to reductions in substance use behaviors, underscoring the potential therapeutic role of interoceptive training in addiction recovery.

Evidence from Neuroimaging Data

While behavioral tasks and self-report questionnaires are commonly used to investigate the interoceptive dimensions of individuals with SUD, neuroimaging studies using MRI remain relatively scarce, despite their potential to provide deeper insights into the underlying neural mechanisms. Four studies (n = 4/39, 10.3%) incorporated magnetic resonance imaging (MRI) to examine the neural correlates of interoceptive dimensions in individuals with SUD [63, 65, 66, 107].

Two of these studies [65, 66] employed the Interoceptive Breathing Load Task (IBLT), which induces breathing resistance, during fMRI experiment to elicit aversive interoceptive sensations. Additionally, Stewart et al. [107] used the Visceral Interoceptive Awareness (VIA) task, where participants were instructed to focus their attention on bodily sensations associated with specific cue words (e.g., heart, stomach, external) displayed on the screen. All three studies assessed interoceptive sensibility. In contrast, De la Fuente et al. [63] uniquely measured interoceptive accuracy by combining the heartbeat discrimination task with high-density EEG recordings to derive heart-evoked potentials (HEPs), apart from MRI task. Stewart et al. [66] also assessed interoceptive accuracy within the IBLT paradigm.

The relationship between activation pattern of insula, a brain region considered as the core hub of interoceptive information processing, and drug use has shown inconsistent results across studies. Stewart et al. [66] reported that during the breathing load condition, greater lifetime drug use was associated with lower insular activation. In contrast, Stewart et al. [107] found that within the SUD group, greater past-year stimulant use was linked to higher BOLD activation in the dorsal dysgranular insula. de la Fuente et al. [63] further observed that, only in the smoked cocaine dependence (SCD) group, higher interoceptive accuracy was associated with lower gray matter volume in the left insula and dorsolateral prefrontal regions, as well as reduced functional connectivity between the anterior insula and somatosensory–temporal cortices. Given that the SCD group also demonstrated higher IA compared to both the crack cocaine dependence (CCD) and healthy control groups, the authors suggested that heterogeneous interoceptive profiles across addiction subtypes show structural and functional adaptations of the insula may be substance- or administration route-specific. In contrast, May et al. [65] found no significant results within the insular cortex. This finding contradicts previous studies of adolescent SUD populations and may indicate developmental or age-related variability in interoceptive neural processing.

Despite these inconsistencies, a convergent pattern emerged across studies: during breathing load, which is considered an aversive interoceptive challenge, greater lifetime drug use was consistently associated with lower activation in the left inferior frontal gyrus, dorsolateral prefrontal cortex, and parahippocampal gyrus. This pattern may be interpreted as evidence that chronic substance use impairs neural systems involved in emotional regulation and contextual processing.

Summary across SUD studies

Among the twenty studies that measured interoceptive accuracy, eighteen adopted a case-control design, whereas two did not include control groups. Three studies [55-57] employed a heartbeat tapping task consisting of four conditions (Guessing, No-Guessing, Breath-Hold, and Tone). These studies assessed interoceptive dimensions using distinct methodological approaches, making direct comparisons with other studies employing traditional interoceptive accuracy tasks inappropriate. Of the remaining fifteen studies that compared interoceptive accuracy between individuals with SUD and healthy controls, nine (n = 9/15, 60%) reported lower interoceptive accuracy in the SUD group. In contrast, two studies (n = 2/15, 13.3%) involving AUD and cocaine users (specifically smoked cocaine) found higher interoceptive accuracy. Three studies (n = 3/15, 20.0%) found no significant group differences. One study reported mixed findings: interoceptive accuracy was lower in smokers in the heartbeat counting task, but no significant difference was found between smokers and non-smokers in the heartbeat discrimination task [64]. Furthermore, three studies employing the heartbeat tapping task reported lower interoceptive precision [55, 57], and reduced beat-to-tap consistency during the breath-hold condition [56] in individuals with SUDs.

Findings for interoceptive sensibility were more variable. Among sixteen studies comparing interoceptive sensibility between individuals with SUDs and healthy controls, two studies lacked healthy control groups, preventing direct comparison. Of fourteen studies with comparison groups, six (n = 6/14, 42.9%) reported no significant differences. Four studies (n = 4/14, 28.6%) found lower interoceptive sensibility in SUD, while another four (n = 4/14, 28.6%) found higher sensibility.

Discussion

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

Summary of Our Results

Among the thirty-nine studies that met our eligibility criteria, twelve studies (n = 12/39, 30.8%) assessed interoceptive accuracy only, nineteen studies (n = 19/39, 48.7%) assessed interoceptive sensibility only, and eight studies (n = 8/39, 20.5%) measured both accuracy and sensibility. Only one study additionally assessed interoceptive awareness [61].

Overall, interoceptive accuracy was consistently reduced in individuals with substance use disorders, particularly in those with alcohol use disorder, though this pattern was less pronounced across other substance use populations. This finding suggests impaired objective interoceptive performance compared to healthy controls. In contrast, interoceptive sensibility showed highly heterogeneous results across studies, with no consistent pattern of alteration emerging. Due to the limited number of studies on interoceptive awareness, no clear conclusions can be drawn at this point.

However, caution is needed when interpreting these findings, as the methodologies used across studies limit the ability to draw definitive conclusions. The following section outlines the limitations of the studies reviewed.

Limitations in the Current Literature

This review raises several concerns in the current interoception research on individuals with SUDs. First, most studies (n = 35/39, 89.7%) are heavily focused on measuring just two interoceptive dimensions including accuracy and sensibility, with limited exploration of other dimensions. However, interoception is a complex, multidimensional construct, and the narrow focus of just two dimensions risks providing an incomplete understanding of interoception, potentially overlooking other critical interoceptive processes. Notable exceptions include studies examining interoceptive awareness [61], beat-to-tap consistency [56], and the use of computational methods to estimate parameters related to interoceptive processes, such as interoceptive precision and interoceptive prior [55, 57].

This issue is further compounded by discrepancies between conceptualization and measurement [21]. For example, a meta-analysis revealed that the heartbeat counting and heartbeat discrimination tasks, both assumed to measure interoceptive accuracy, shared only 4.4% of the variance, calling into question whether these tasks truly assess the same construct [109]. Furthermore, although interoceptive sensibility is often treated as a single dimension in self-report measures, these scales actually capture a broad range of different aspects, such as self-perceived capacity to detect internal sensations, capacity to regulate emotion distress through interoceptive attention, and trust in bodily signals [20]. These discrepancies between conceptualization and operationalization make it challenging to draw reliable conclusions and replicate findings, highlighting the need for more precise definitions and better alignment between conceptualizations and measurement tools. One such attempt to address this gap is the increasing use of computational modeling methods [55, 57]. These models offer the advantage of breaking down latent processes within interoceptive dimensions, allowing for a more nuanced understanding and quantification of complex interoceptive phenomena.

Building on these concerns, another critical issue in the field is that most studies (n = 14/22, 63.6%) have relied on the heartbeat counting task as a performance-based measure of interoceptive accuracy, despite substantial criticism regarding its reliability and validity [27]. The primary issue with the HCT is that participants can achieve high scores by guessing their heart rate rather than relying on their actual felt heartbeats, a limitation that has been repeatedly demonstrated [25, 27, 29, 110-114]. Billaux and colleagues [72] echoed these concerns and investigated the validity of the HCT in both clinical (severe AUD) and subclinical (binge drinkers) populations. They tested both the classical and adapted versions of the HCT, which differ in instructions, and found that performance was lower in the adapted version. This supports the idea that the classical HCT is influenced by non-interoceptive strategies, such as guessing. Additionally, their findings showed no significant correlation between HCT performance and psychological constructs like emotion regulation or anxiety, further questioning the HCT's validity as a measure of interoception in AUD. Future research should explore more reliable cardiac measures [19].

Second, another concern in current research is the predominant focus (n = 17/20, 85.0%) on the cardiac domain, with other interoceptive domains (e.g., respiratory, gastric) remaining understudied. This reliance on a single bodily system is particularly problematic, as previous studies have found no significant correlations across different interoceptive domains [115-119]. Findings from these studies suggest that performance in one domain (e.g., high accuracy in cardiac tasks) cannot be generalized to other domains (e.g., respiratory tasks). Therefore, broadening the scope beyond the cardiac focus, or better yet, examining multiple interoceptive domains within a single study, would facilitate a more comprehensive understanding of interoceptive processes.

Third, a limitation concerns the lack of control and insufficient reporting on various substance use factors in many studies. This is particularly important because the relationships between interoception and addiction-related elements such as substance type, duration of use, addiction severity, abstinence duration, craving, and withdrawal symptoms are still poorly understood. Many studies fail to report these details and explore the relationship with interoception, and when they do, they often examine only one or two variables instead of systematically exploring these factors. Similarly, another significant concern is the inclusion of smokers in studies on SUDs, with some studies explicitly mentioning a high proportion of smokers in their population (e.g., more than 80% of participants in [91]), while many others do not specify whether smokers were excluded. As a result, it becomes difficult to rule out the confounding effect of smoking in their results.

Building on this issue, there is substantial evidence suggesting that smokers may perform differently on interoceptive tasks when in a deprived state compared to when satiated. For instance, smoking deprivation can impact various physiological and cognitive functions, including cardiac, emotional, motivational, and brain states [120-124]. Resting heart rate can decrease by an average of 8.5

beats per minute after just 11-15 hours of abstinence [124], and insula activity is higher in abstinent smokers compared to satiated smokers [120, 125]. Additionally, smokers may show poorer time estimation abilities during periods of abstinence [126-128].

However, no study has yet evaluated interoceptive dimensions in smokers under both deprived and satiated states. Of the four smoking studies reviewed in this paper, one required 1-hour abstinence (presumably to induce a satiated state) [64], another instructed overnight abstinence (to induce a deprived state) [61], and the smoking status of participants in other studies remains unclear [102, 103]. Taken together, future SUD studies should clearly report whether smokers are included and control for the effects of smoking. For studies involving smokers, researchers should aim to standardize the smoking state and explore potential differences in interoception between abstinent and satiated conditions.

Conclusions

In conclusion, this systematic review synthesizes existing research on interoception in SUDs, with a focus on the three interoceptive dimensions: accuracy, sensibility, and awareness. Overall, individuals with SUDs demonstrated consistently lower interoceptive accuracy than healthy controls, with this impairment being most evident in AUD and attenuating across other substance use populations. However, findings regarding interoceptive sensibility are highly inconsistent, with some studies reporting lower sensibility in SUD populations, while others report higher or no significant differences. Furthermore, the limited research on interoceptive awareness prevents any firm conclusions from being drawn regarding its role in SUDs. The relationship between interoceptive accuracy and addiction-related behaviors remains inconclusive, highlighting the need for further studies to explore and clarify these associations.

The review also identifies several critical concerns in the current literature, including the predominant focus on only two interoceptive dimensions, the overemphasis on the cardiac domain, and the widespread use of the heartbeat counting task, which has faced significant criticism regarding its validity. Future research should aim to assess multiple interoceptive dimensions across various physiological domains simultaneously, develop more reliable measurement tasks, and explore how these dimensions interrelate and influence substance use behaviors. Additionally, studies should carefully consider and report whether their populations include or exclude smokers to account for confounding factors. Lastly, further investigation into the potential therapeutic role of enhancing interoceptive abilities in addiction recovery is needed to better understand its clinical implications.

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Statements and Declarations

The authors have no financial interests to disclose.

Tables

Table 1. Summary of interoceptive 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)

Table 2. Inclusion and Exclusion Criteria

Inclusion criteria	• Published in English • 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. • 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 (Garfinkel et al., 2015).
Exclusion criteria	• Animal study • Wrong publication type (e.g., case studies, book chapters, reviews, conference abstracts, dissertations, study protocols, clinical trials without results, letters, opinion papers) • Wrong population (e.g., studies restricted to subclinical samples or clinical populations with comorbid psychiatric disorders) • Wrong outcome (e.g., studies on SUD populations that did not assess any interoceptive dimension) • No reported data (studies that did not report data on the measured interoceptive dimension).

Table 3

Authors (Year)	Samples (N)	Addiction Measures(s)	Interoceptive Measure(s)	Non-interoceptive Measure(s)	Primary Findings	Secondary Findings
Alcohol Users (12)						
Schmidt et al. (2013)	Alcohol Dependence[a] (n=89) [a] Diagnosis based on ICD-10	**Alcohol Use:** OCDS **Alcohol Expectancy:** Tension Reduction Expectancies (TRE)	**IA:** HCT (classic)	Not Assessed	(1) HCT scores were reported (0.70 ± 0.19) (2) No correlation between HCT, OCDS-G, and TRE (3) Negative correlation between IA and OCDS-G only when participants have high TRE (β=-0.31)	(1) No independent effect of IA on OCDS-Q (2) Independent effect of TRE on OCDS-Q
Ates Col et al. (2016)	AUD[a] (n=55) HC (n=52) [a] Diagnosis based on DSM-4-TR	**Alcohol Use:** AUDIT; OCDS **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 (β=-0.216, -0.330, -0.216)
Jakubczyk et al. (2019)	AUD[a] (n=114) HC (n=110) [a] Diagnosis based on ICD-10, MINI	**Alcohol Use:** AUDIT	**IA:** HCT (classic) **IS:** PBCS	**Psychological Symptoms:** BSI **Sleep problems:** AIS **Impulsivity:** BIS-11	(1) Lower HCT scores in AUD (0.46 ± 0.3) compared with HC (0.72 ± 0.1) (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 (2) No correlation between IS and impulsivity, depressive symptoms among AUD (3) Positive correlation between IS and sleep problems (r=0.24, p=0.014), anxiety symptoms (r=0.27, p=0.005) among AUD (4) Higher impulsivity, sleep problems, depressive symptoms, anxiety symptoms found in AUD compared with HC
Jakubczyk et al. (2020)	AUD[a] (N=165) HC (N= 110) [a] Diagnosis based on ICD-10, MINI	**Alcohol Use:** AUDIT	**IA:** HCT (classic) **IS:** PBCS	**Emotion Regulation:** DERS **Psychological Symptoms:** BSI **Sleep Problems:** AIS	(1) Lower HCT scores in AUD (0.61 ± 0.16) compared with HC (0.72 ± 0.08) (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) (2) Positive association between IS and difficulties controlling impulsive behavior when experiencing negative emotions in AUD
Jakubczyk et al. (2021)	AUD[a] (n=165) HC (n=110) [a] Diagnosis based on ICD-10, MINI	Not Assessed	**IA:** HCT (classic) **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) (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 (β =-2.180, p=0.019) (2) AUD status moderated association between IA and PSQ
Avcu Meric et al. (2022)	AUD[a] (n=52) HC (n=52) [a] Diagnosis based on DSM-5	**Alcohol Use:** AUDIT **Alcohol Craving:** PACS	**IA:** HCT (classic)	**Trait Mindfulness:** Mindfulness Attention Awareness Scale (MAAS) **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 (β=0.456, p<0.001) (2) No correlation between trait mindfulness (MAAS score) and HBP and IGT in either group
Wisniewski et al. (2023)	AUD[a] (n= 99) HC (n= 103) [a] Diagnosis based on ICD-10, MINI	**Alcohol Use:** Short Inventory of Problems (SIP) + semi-structured interview; Substance Abuse	**IA:** HCT (classic)	**Alexithymia:** TAS-20 **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 (2) Alexithymia as mediator between interoception and state anxiety was more pronounced in AUD

		Outcomes Module (SAOM)				
Gunawan et al. (2024)	AUD[a] (n=210) Non-AUD (n=89) [a] Diagnosis based on DSM-5	**Alcohol Use:** AUDIT; OCDS; TLFB; Alcohol Dependence Scale (ADS) **Alcohol Craving:** PACS;	**IS:** MAIA	**Alcohol Related Variables:** Addictions Neuroclinical Assessment battery (ANA) [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] [a] Exact value not reported	Not Applicable
Scigala et al. (2024)	Alcohol dependence[a] (n=160) [a] No diagnostic criteria was mentioned; All male inmates	**Alcohol Craving:** PACS	**IS:** MAIA	**Alexithymia:** TAS-20 **Emotional Regulation:** DERS	MAIA total score (22.13±4.99)	(1) Negative correlation between IS and PACS (*p*<0.001) (2) Negative correlation between IS and TAS-20 (*p*<0.05) (3) Negative correlation between IS and DERS (*p*<0.001) (4) Alexithymia and emotional dysregulation significantly mediate the relationship between interoceptive sensibility and alcohol craving
London et al. (2024)	AUD[b] (n=50) - Inpatient (n=24) - Outpatient (n=26) GD[a] (n=41) HC (n=809) [a] GD=Gambling Disorder [b] Diagnosis based on DSM-5	**Alcohol Use:** AUDIT **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 IS in AUD (21.84 ± 6.69) compared with GD (20.39 ± 5.41)
Billaux et al. (2025)	AUD[b] (n=48) HC-AUD (n=41) BD[a] (n=32) HC-BD (n=32) [a] Defined using Maurage et al. (2020)'s criteria and binge drinking score (≥ 24) from Townshend & Duka (2005) [b] Diagnosis based on DSM-5 for AUD (≥ 6 diagnosis criteria)	**Alcohol Use:** AUDIT; TLFB	**IA:** HCT (Classical task & Adapted task) **IS:** PBCS **Heartbeat:** ECG-based chest strap monitor	**Alexithymia:** TAS-20 **Anxiety:** STAI **Trauma:** Childhood Trauma Questionnaire (CTQ) **Depression:** BDI-13 **Dissociative Symptoms:** DES **Emotion Regulation:** DERS **Sleep:** AIS **Time Estimation Task**[a] [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 (2) Lower HCT scores in AUD (0.26 ± 0.04) compared with matched HC (0.35 ± 0.04) on adapted HCT (3) No difference in HCT scores in BD (0.68 ± 0.04) compared with matched HC (0.69 ± 0.04) on classical HCT (4) No difference in HCT scores in BD (0.36 ± 0.04) compared with matched HC (0.27 ± 0.04) on adapted HCT (5) Higher HCT scores on the classical than adapted HCT in all groups (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) (2) No correlation between IA scores and psychological constructs
De Groote et al. (2025)	AUD[a,b] (n= 37) HC[b] (n=37) [a] Diagnosed with only AUD and didn't meet the criteria for other SUDs (excluding tobacco) [b] Diagnosis based on DSM-5	Not Assessed	**IS:** MAIA	**Memory Recall Experience:** Short-Form Memory Experiences Questionnaire (MEQ-SF) **Anxiety and Depression:** Hospital Anxiety and Depression Scale (HADS-A and HADS-D) **Emotion Regulation:** DERS-SF	(1) Lower MAIA for AUD (M=2.77) compared with HC (M=3.08) (2) Lower MAIA subscales (Attention regulation and Trusting)[a] for AUD compared with HC [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	Positive correlation between MEQ-SF and MAIA total score and subscales (Noticing, Emotional awareness, Listening)[a] in AUD [a] MAIA total (*r*=0.379, *p*=0.021); Noticing (*r*=0.425, *p*=0.009); Emotional awareness (*r*=0.332,

					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)	*p*=0.045); Listening (*r*=0.383, *p*=0.019)
Smokers (4)						
Veilleux et al. (2018)	Smokers[a,b] (n=14) Nonsmokers[b] (n=14) [a] Smokers who had smoked at least one pack per week for at least 4 years [b] All male participants	**Nicotine Dependence:** FTND **Smoking Craving:** QSU-B	**IA:** HCT (classic)	**Self-control:** Breath holding task **Emotion and craving[a]:** Anxiety; Irritation; Body Discomfort; Happiness; Craving [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 (2) Higher anxiety, irritability, body discomfort and lower happiness in smokers under heat (3) Decreased breath holding length under heat for both smokers and nonsmokers (4) No significant difference in cigarette craving under heat
Hina and Aspell (2019)	Smokers[a](n=49) Non-smokers (n=51) [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 **IS:** MAIA	**Time Estimation Task[a]** [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) (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 (2) No correlation between IA (HCT) and time estimation task performance (3) No correlation between MAIA and FTND-R scores
Kim et al. (2020)	Smoker[a] - Amplification (n=17) - Neglect (n= 17) Non-smokers[a] - Amplification (n=19) - Neglect (n=19) [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) **Anxiety:** STAI **Positive and Negative Affect:** PANAS **Subjective Measures[a]:** VAS [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 [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) - Experimental (n=26) - Control (n=23)	**Smoking Desire:** Desire Thinking Questionnaire (DTQ) **Cigarette Use:** Self-reported number of cigarettes smoked per day	**IA:** HTT **IS:** Self-reported performance confidence **IAw:** Calculated from IA and IS measures **Heartbeat:** ECG	Not Assessed	(1) IAw level was reported (0.78 ± 0.14) (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 [a] Exact values for IA and IS are not reported	Not Applicable
Opioids (2)						
White et al. (2024)	OUD[a] (n=129) - Minimal insomnia[b] (n=53) - Insomnia[c] (n=76) [a] No diagnostic criteria was mentioned; Had been receiving buprenorphine at least 6 weeks [b] ISI ≤ 10 [c] ISI ≥ 11	Not Assessed	**IS:** MAIA	**Sleep Problems:** Insomnia Severity Index (ISI) **Negative Emotionality:** Distress Tolerance Scale (DTS) **Depression:** PHQ-9 **Anxiety:** GAD-7 **Mental Health:** PROMIS-10 Global Mental Health Scale **Trauma:** PCL-5 **Aggression:** Buss-Perry Aggression Scale (BPAS)	(1) Baseline MAIA was reported for all subscales[a] (2) Higher MAIA subscale[b] in OUD with insomnia symptoms compared to OUD without symptoms [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)	Not Applicable

				Pleasure: Snaith-Hamilton Pleasure Scale (SHPS) **Metacognition:** Metacognition Questionnaire (MCQ-30) **Cognition:** 5-Trial Adjusting Delay Discounting Task (5-DD) **Impulsivity:** Short Impulsive Behavior Scale (SUPPS-P)	[b] Noticing for insomnia symptoms (3.55 ± 1.2); without insomnia symptoms (2.86 ± 1.4)	
Marcus et al. (2025)	OUD[a] (n=21) [a] Diagnosis based on DSM-5, MINI; Maintenance on 8-24mg buprenorphine-naloxone	Not Assessed	**IS:** MAIA	**Trauma:** Trauma History Questionnaire (THQ) **Inflammation:** 10 Inflammatory markers; LBP; CRP; MCP-1 **Neurofunctional Measures:** NIDA Phenotyping Assessment Battery (PhAB) 5 domains (Reward; Cognition; Negative Emotionality; Metacognition; Sleep)	(1) Total MAIA score[a] was reported (2) No subscale differences between high- and low-ELS OUD patients [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 (2) No neurofunctional differences between high- and low-ELS OUD patients
Stimulants (2)						
de La Fuente et al. (2019)	SUD[a] (n=47) - Smoked Cocaine Dependent (SCD; n=25) - Chlorhydrate Cocaine Dependents (CCD; n=22) HC (n=25) [a] Diagnosis based on DSM-4	**History of Drug Consumption:** Alcohol, Smoking, and Substance Involvement Screening Test (ASSIST) **Craving:** Current Craving Questionnaire (CQC)	**IA:** HDT; HEP [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) (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 (2) Positive correlation between better IA and increased gray-matter volume in PINS and cingulate areas in HC (3) Positive correlation between better IA and decreased connectivity between AINS nodes and somatosensory-temporal cortices in SCD (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) - Cravers (n=58) - Non-cravers[a] (n= 29) [a] Craving absence: daily score of 0 across two craving VAS [b] Diagnosis based on DSM-4;	**Cocaine Craving:** VAS from Cocaine Selective Severity Assessment (CSSA) + ad hoc survey **Cocaine Dependence:** Severity of Dependence Scale (SDS)[a] [a] Measure cocaine dependence for last 6 months	**IA:** HCT (classic)	**Anxiety:** STAI **Depression:** BDI **Readiness to change(cocaine use):** : University of Rhode Island Change Assessment Scale (URICA) **Premorbid IQ:** Word Accentuation Test **Cognitive Flexibility:** Trail Making Test **Working Memory:** Wechsler Adult Intelligence Scale **Response Inhibition:** Stroop Color Test **Decision-making:** IGT **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
Cannabis (1)						

Bloomer et al. (2024)	Cannabis Users[a] (n=72) HC (n=78) [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 [a] Noticing, Emotional awareness subscales; No data on MAIA was reported	(1) No correlation between MAIA-2 and severity/frequency of cannabis use (2) No correlation between MAIA-2 and SGI total score
Heterogenous Drug Users (8)						
Stewart et al. (2015)	PSU[a,c] (n=19) DSU[b,c] (n=18) HC (n=21) [a] PSU: current endorsement of 2 or more DSM-4 criteria for amphetamine or cocaine abuse during at least 6 months [b] DSU: no endorsement of symptoms of stimulant abuse or dependence [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] **IS:** BPQ; VAS after task-based fMRI session [a] Measured RT, CO2 level, accuracy during fMRI session	**Sensation Seeking:** Sensation Seeking Scale (SSS) **Impulsivity:** BIS **Depression:** BDI-II **Anxiety:** STAI **Neural Response:** fMRI	(1) No significant difference in IBLT (RT, accuracy, CO2 Level) across groups and conditions (Baseline, Anticipation, Breathing Load, Post-Anticipation) (2) No significant difference in BPQ	(1) Higher percentage of drug use attributable to stimulants of PSU than DSU (2) Lower activation for PSU in MFG/DLPFC, IFG, MedFG (3) Lower activation for both PSU and DSU in left MFG/FP, right MFG/DLPFC, bilateral thalamus, left mINS, left lentiform nucleus, left PoCG (4) Lower activation for PSU in right IFG, right aINS (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) - Alcohol (n=33) - Heroin (n=29) - Synthetic Cannabinoids (n=22) HC (n=35) [a] All male abstinent participants [b] Diagnosis based on DSM-4-TR	**Substance Use:** API	**IA:** HCT (classic)	**Alexithymia:** TAS-20	(1) Lower HCT scores in SUD (0.61 ± 0.04) compared with HC (0.75 ± 0.02)	(1) Negative correlation between HCT scores and TAS-20 DIF (r=-0.287, p=0.046) (2) Positive correlation between API scores and TAS-20 scores (r=0.349, p=0.005) (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) OUD[a,b] (n=20) HC (n=30) [a] Endorsed greater than or equal to 50 uses within the past year [b] Diagnosis based on DSM-4/DSM-5, MINI	**Drinking and Drug Use:** CDDR	**IS:** MAIA, Visceral Interoceptive Awareness (VIA) task[a] during fMRI [a] Sensation intensity ranging 0~6 due to interoceptive cues were rated	**Anxiety:** ASI-3 **Depression:** PHQ-9 **Neural Response:** fMRI	(1) Lower MAIA subscales[a] for SUD, OUD compared with HC (2) Higher VIA (p<0.01), but lower BOLD in dorsal dysgranular of SUD (p=0.04) compared with HC in heart cue condition (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 (4) Higher VIA (p=0.02), but lower BOLD in hypergranular of SUD (p=0.02) compared with HC in heart cue condition [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 (2) Higher BOLD of SUD in dorsal dysgranular (p<0.05) as greater past-year stimulant uses in heart cue condition
Smith et al. (2020)	HC (n=52) Anxiety[a,b] (n=15) Depression[a,b] (n=69) Depression + Anxiety (n=153) [a,b] Eating Disorder[a,b] (n=14) SUD[a,b] (n=131)	**Drug Use:** DAST-10	**IA**[a]: HTT (adapted and classic) **Heartbeat:** ECG **Model parameters:** Interoceptive Precision(IP); Prior beliefs favoring the	**Depression:** PHQ-9 **Anxiety:** OASIS **Eating Disorder:** SCOFF	(1) Lower IP in all clinical groups (0.03 ± 0.03) than HCs (0.07 ± 0.07) during breath-hold condition (p<0.001) (2) No significant difference between clinical groups and HCs in pHB during no-guessing or breath-hold 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) (2) Positive correlation between pHB estimates and self-reported confidence in no guessing (r=0.16)

	[a] Inclusion criteria of clinical groups based on PHQ-9, OASIS, DAST-10, SCOFF [b] Diagnosis based on DSM-5, MINI		presence of a Heartbeat(pHB); Anticipatory or Reactive (AvR) [a] Difficulty, Confidence, Heartbeat Intensity were directly asked after completion of each task condition.		(3) No significant difference in AvR across groups and conditions	and breath-hold conditions (*r*=0.21) (*p*<0.001) (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)
May et al. (2020)	CAN+ALC-EXP[a,b] (n=16) CAN+ALC-SUD[a,c] (N = 13) HC (N = 18) [a] All adolescent participants (ages 15-17) [b] CAN+ALC-SUD: current endorsement of 2 or more DSM-5 criteria for cannabis or alcohol [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) **Substance Reinforcement:** Michigan Nicotine Reinforcement Questionnaire (MNRQ) **Drinking and Drug Use:** CDDR	**IS:** MAIA, IBLT[a] (with VAS evaluation) [a] Rated the breathing load for pleasantness and intensity	**Impulsivity:** UPPS Impulsive Behavior Scale **Neural Response:** fMRI	(1) Total MAIA scores[a] were reported (Noticing, Not Distracting, Not Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, Trusting) (2) No significant difference in MAIA between conditions [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) 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) 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 (2) No significant findings within insular cortex despite role in interoception
Smith et al. (2021)	MDD/co-morbid anxiety disorders[b] (n=221) SUD[a,b] (n=136) HC (n=53) [a] Were not included in SUD if only alcohol or nicotine dependence [b] Diagnosis based on DSM-4/DSM-5, MINI	**Drug Use:** DAST-10	**IA:** HTT (classic AND adapted[a]) **Others:** Beat-to-tap consistency (variability between individual's taps and each heartbeat/tone) [a] 3 conditions: (1) guess, (2) no guessing, (3) breath-hold, (4) exteroceptive control task (tone-tapping) **Heartbeat:** ECG	**Anxiety:** OASIS **Depression:** PHQ-9 **Eating Disorder:** SCOFF	(1) No significant difference of beat-to-tap consistency in breath-hold condition in patient groups (SUD=0.68 ± 1.17) (2) Higher beat-to-tap consistency in breath-hold condition in HC (1.58 ± 2.46) (3) Significant reduction of difficulty in HC from guessing (57.53 ± 22.86) to breath-hold conditions (49.17 ± 26.49) (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 (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) OUD[a,b] (n=40) HC[a] (n=40) [a] All male participants who were abstinent at	**Substance Use:** API **Craving:** PACS; Substance Craving Scale (SCS)	**IA:** HCT (classic)	**Decision-making:** IGT **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) (2) Negative correlation between IA and BIS-11 (*r*=-0.292, *p*=0.001) (3) No correlation between HCT scores and PACS/CSC

	least for 3 weeks [b] Diagnosis based on DSM-					
Lavalley et al. (2024)	Substance Users[a,b] (n=215) HC (n=111) [a] Consists of single and multiple SUDs of alcohol, cannabis, stimulant, sedative, and/or hallucinogen [b] Diagnosis based on DSM-4/DSM-5, MINI;	**Drug Use:** DAST-10	**IA:** HTT **Heartbeat:** ECG **Model parameters:** Interoceptive Precision(IP); Prior beliefs favoring the presence of a Heartbeat(pHB); Anticipatory or Reactive (AvR) **IS:** MAIA	**Depression:** PHQ-9 **Anxiety:** OASIS; ASI-3 **Eating Disorder:** SCOFF **Alexithymia:** TAS-20	(1) Lower IP in SUDs (0.04 ± 0.04) than HCs (0.06 ± 0.06) during breath-hold condition (2) Higher pHB in SUDs than HCs during no-guessing or breath-hold conditions (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) (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) [a] Data added from supplementary material [b] Result is from across multiple psychiatric disorders including SUD

Table 4

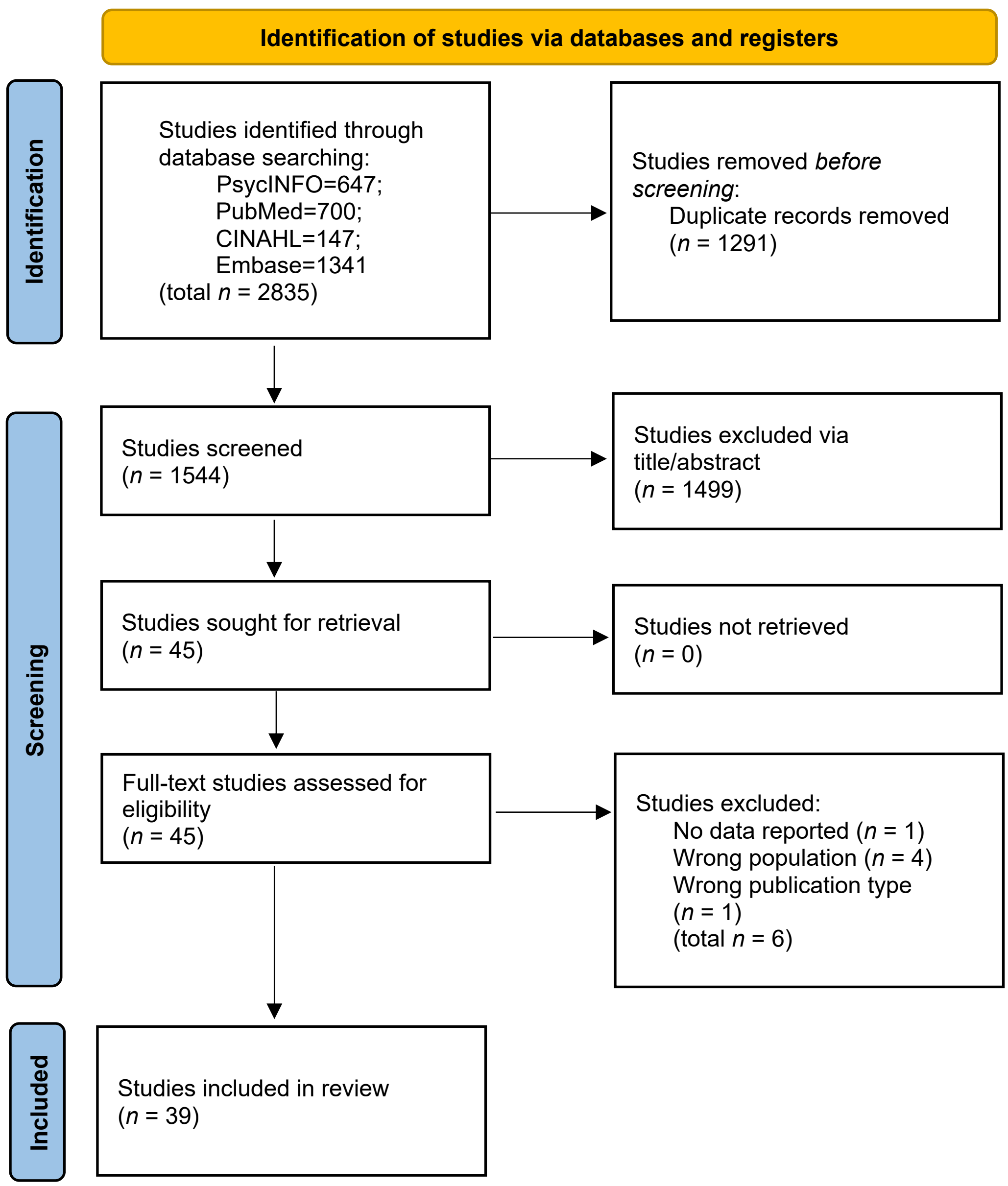
Authors (Year)	Samples (N)	Addiction Measures(s)	Interoceptive Measure(s)	Non-interoceptive Measure(s)	Primary Findings	Secondary Findings
Alcohol Users (2)						
Sonmez et al. (2022)	AUD [a,b,c] (n= 85) HC [a] (n= 87) [a] All male participants were abstinent at least for 3 weeks [b] Diagnosed with only AUD and didn't meet the criteria for other SUDs (excluding tobacco) [c] Diagnosis based on DSM-5	**Alcohol Use:** API; AUDIT **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) (2) Negative correlation between IA and three API subscales[a] (3) No different proportion of abstinence between low IA group and high IA group after 3, 6, 12 months treatment [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) - Inpatient (n=27) - Outpatient (n=23) [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 (2) Decrease in BPQ-VSF total score from admission (24.5 ± 5.6) to before discharge (19.6 ± 6.9) in inpatient group (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 (2) No correlation between changes in IS and changes in various indicators of liver function
Opioids (4)						
Price et al. (2020)	OUD[a] (n= 10) - TAU (n=5) - TAU+MABT (n=5) [a] Participants who enrolled buprenorphine program for at least four weeks	Substance Use: TLFB **Craving:** PACS[a] [a] Modified to address both alcohol and other drugs	**IS:** MAIA	**Depression:** PHQ-9 **Anxiety:** GAD-7 **Emotion regulation:** DERS-SF **Pain:** BPI **PTSD:** PCL-5 **Physical symptoms:** MSC **Subjective Measure[a]:** Intervention acceptability; Intervention satisfaction [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) [a] Prescribed sublingual buprenorphine for at least 30 days [b] Diagnosis with DSM-5	Not Assessed	**IS:** MAIA **Mindfulness:** FFMQ	**Anxiety, Pain, Depression:** Patient Reported Outcomes Measurement Information System (PROMIS-ASF; PROMIS-PISF; PROMIS-DSF) **Trauma:** Adverse childhood experiences (ACE) **Experiential Avoidance:** Brief Experiential Avoidance Questionnaire (BEAQ) **Emotional regulation:** DERS **Self-compassion:** Self-Compassion Scale Short Form (SCS-SF) **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) (2) Significantly increased FFMQ at 24 weeks of M-ROCC treatment (4.42 ± 0.38) compared to baseline (4.58 ± 0.32)	Not Applicable

Price et al. (2024)	OUD[a,b] (n=303) - TAU (n=148) - TAU+MABT (n=155) [a] Enrolled in a medication (either buprenorphine or methadone) treatment program for OUD and stabilized on medication dose [b] No specific criteria for OUD was directly mentioned	**Substance Use:** TLFB **Craving:** a single item on an 11-point numeric scale (0~10)	**IS:** MAIA-2 **Mindfulness:** FMI	**PTSD:** PCL-5 **Depression:** PHQ-9 **Anxiety:** GAD-7 **Emotion regulation:** DERS-SF **Pain:** BPI **Physical Symptoms:** MSC	(1) Baseline MAIA-2 subscales[a] were reported for TAU+MABT group (2) Baseline MAIA-2 subscales[b] were reported for TAU group (3) Improved MAIA-2 subscales[c] for TAU+MBAT group compared with TAU group from baseline to 3 months [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) [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) [c]Interoceptive awareness; Noticing; Attention regulation; Emotional awareness; Self-regulation; Body listening; Trusting	
Price et al. (2025)	OUD[a,b] (n=303) - TAU (n=148) - TAU+MABT (n=155) [a] Enrolled in a medication (either buprenorphine or methadone) treatment program for OUD and stabilized on medication dose [b] No specific criteria for OUD was directly mentioned	**Substance Use:** TLFB **Craving:** a single item on an 11-point numeric scale (0~10)	**IS:** MAIA-2 **Mindfulness:** FMI	**PTSD:** PCL-5 **Depression:** PHQ-9 **Anxiety:** GAD-7 **Emotion regulation:** DERS-SF **Pain:** BPI **Physical Symptoms:** MSC	(1) Baseline MAIA-2 for TAU+MBAT (2.5±0.1) and TAU (2.6 ± 0.1) were reported (2) Baseline FMI score for TAU+MABT (34.4 ± 0.7) and TAU (35.1 ± 0.8) were reported (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 [a] M=Mean group difference	(1) No group difference in abstinent days between adjunctive mindfulness-based therapy and standard treatment (2) Improved physical symptom frequency in mindfulness-based therapy adjunct to standard treatment
Heterogeneous Drug Users (4)						
Price et al. (2012)	SUD[a,b] (n=46) - TAU (n=15) - TAU+MABT (n=31) [a] Patients who enrolled SUD treatment [b] All female participants	**Substance Use:** TLFB **Relapse:** Reasons for Drinking Questionnaire (RFDQ)	**Mindfulness:** FFMQ **Body Awareness:** Scale of Body Connection (SBC) **Attitude toward the body:** Body Investment Scale (BIS)	**Psychological Symptoms:** BSI **PTSD:** Modified Post-traumatic Stress Disorder Scale (MPSS) **Eating Disorder:** Eating Disorder Examination Questionnaire (EDE-Q) **Physical Symptoms:** Medical Symptoms Checklist (MSC) **Stress and Coping:** PSS; DES; PANAS; DERS	(1) Baseline scores for SBC subscales[a], BIS (7.5 ± 1.0), FFMQ (116 ± 23.40) were reported (2) Lower SBC subscale (Bodily dissociation) for MABT (0.88 ± 0.39) compared with TAU (1.4 ± 0.61) at 9 months (3) Higher BIS for MABT (8.0 ± 1.1) compared with TAU (7.3 ± 1.1) at 9 months [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) (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)
Price et al. (2019a)	SUD[a,b] (n=217) [a] All female participants [b] SUD patients who enrolled Intensive Outpatient Program (IOP)	**Substance Use:** TLFB	**IS:** MAIA **Mindfulness:** FMI	**Trauma:** TLEQ; PSS-SR **Depression:** BDI-II **Emotion regulation:** RSA task, DERS	(1) Baseline MAIA (2.5 ± 0.86) and FMI (35.96 ± 9.16) were reported (2) Positive correlation between MAIA and resting RSA after adjusting age and BMI (β=0.28, *p*=0.03) (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) (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) - TAU only (n=67) - TAU+WHE (n=46) - TAU+MABT (n=76) [a] All female participants [b] SUD patients who enrolled Intensive Outpatient Program (IOP)	**Substance Use:** TLFB **Craving:** PACS[a] [a] Modified to address both alcohol and other drugs	**IS:** MAIA **Mindfulness:** FMI	**Trauma:** TLEQ; PSS-SR **Depression:** BDI-II **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 [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) (2) Lower craving (PACS) for MABT vs. TAU (p=0.053) (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) - TAU only (n=67) - TAU+WHE (n=46) - TAU+MABT (n=76) [a] All female participants [b] SUD patients who enrolled Intensive Outpatient Program (IOP)	**Substance Use:** TLFB **Craving:** PACS[a] [a] Modified to address both alcohol and other drugs	**IS:** MAIA **Mindfulness:** FMI	**Trauma:** TLEQ; PSS-SR **Depression:** BDI-II **Emotion regulation:** RSA task, DERS	Baseline: MAIA (2.6 ± 0.9), FMI (36.5± 9.5) (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) (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), (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) [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 (2) Lower DERS from baseline to 3 months for MABT vs. TAU (M=-14.2) and MABT vs. WHE (M=-13.8) (3) Consistent MABT skill use during past 3 months at 6-month follow-up (75.5%) and 12-month follow-up (78.4%)

Figures

Figure 1. PRISMA flow diagram



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