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The role of interoception in lifestyle factors: A systematic review

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ABSTRACT

Background: Interoception, the perception of the internal state of the body, offers an underrepresented and intriguing potential avenue for altering lifestyle-related behaviors. Interoception is intrinsically related to maintaining homeostasis and the flexible allostatic regulation of complex demands. Internal bodily states may also be influenced by lifestyle factors and related problems. This systematic review aimed to provide insight into the current state of evidence about the role of interoception in lifestyle factors.

Methods: Studies from three databases (PubMed, Embase, and Web of Science) were screened for eligibility based on two inclusion criteria: 1) at least one measure of interoception (e.g., interoceptive accuracy, attention, or awareness), and 2) at least one measure of a lifestyle factor (i.e., alcohol consumption, cognitive leisure and relaxation activities, eating behavior, exercise, sleep, or smoking). Risk of bias was assessed using an adjusted quality score checklist, consisting of five items related to study design, population size, exposure measurement, outcome measurement, and adjustment for confounders.

Results: The review included 73 studies. Out of the included studies, 51 measured interoceptive accuracy and 36 measured interoceptive attention. Six studies quantified interoceptive awareness. In terms of lifestyle factors, 26 studies on cognitive leisure and relaxation activities, 19 studies on eating behavior, 12 studies focused on alcohol consumption, 10 studies on exercise, five studies on smoking, and four studies on sleep were identified. Findings show positive relations between interoceptive domains and cognitive leisure and relaxation activities, eating behavior, and exercise. Conversely, the consumption of alcohol is negatively related to interoceptive domains. Studies in the smoking and sleep lifestyle factors were sparse and of varying methodological quality.

Discussion: The findings of this review show that interoceptive domains are associated with various lifestyle factors, but the quality of the evidence is limited. Future longitudinal studies with more objective measures of interoception are needed in order to better understand the interrelations between interoception and lifestyle factors.

1. Introduction

According to the World Health Organization (WHO), non-communicable diseases (NCDs), including cardiovascular diseases, cancers, diabetes, and chronic respiratory diseases, account for 74 % of global deaths. These NCDs are directly influenced by lifestyle factors (World Health Organization, 2023). Lifestyle factors can be defined as a set of modifiable behaviors and habits of individuals in their daily lives. As the WHO aims to reduce premature deaths from NCDs by one third before 2030, exploring new directions for prevention and treatment is

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crucial for figuring out the most effective strategies to support lifestyle changes. The adaptation of lifestyle behaviors can be challenging for many individuals, since many biosocial factors play a role in behavioral change (Harris and McDade, 2018). Biosocial factors are dynamic and bidirectional biological and sociological aspects, relationships, and contexts, which comprise the processes of human development. One of these aspects is interoception, which offers an underrepresented and intriguing potential avenue for altering lifestyle-related behaviors.

Interoception, the perception of the internal state of the body (e.g., heartrate, sweating, or hunger), is a field of research that has received increasing scientific interest over the years (Murphy et al., 2019). Research into interoception has demonstrated the importance of internal bodily signals for physical and mental well-being, as processing these signals helps maintain homeostasis (i.e., maintenance of physiological stability) (Farb et al., 2015). Additionally, interoception is intrinsically related to the predictive control of bodily signals, both in maintaining physiological balance and in the flexible allostatic regulation of complex demands (Quadt et al., 2018). For example, when the immune system communicates states of infection and inflammation to the brain, this happens via interoceptive pathways (Critchley and Harrison, 2013). The body responds to these states by activating cardiovascular and gastrointestinal reflexes, regulating peripheral immune reactions, and patterns of responses called sickness behaviors (i.e., fatigue, reduced food and water intake, social isolation, and fever) (Dantzer and Kelley, 2007; Tracey, 2009; Dantzer et al., 2008). This illustrates how changes in internal bodily states could affect behaviors, mediated by interoceptive pathways.

Interoceptive abilities influence lifestyle factors and related problems. An example is the role of interoception in exercise. If there is a mismatch between perceived fatigue communicated through interoceptive pathways (e.g., salience and sensitivity of visceral and peripheral signals, interoceptive attentional capacity, physiological changes in response to internal signals, and neuroplasticity), and the actual physiological state, this can result in hypoactivity (i.e., reduced participation in exercise, which may lead to problems related to sedentary behavior) or hyperactivity (i.e., continuation of physical exercise to the point of reaching dangerous physiological boundaries) (Wallman-Jones et al., 2021). Another example is the role of interoception in eating behavior. During eating, changes in hunger and satiety signals determine eating responses and maintain homeostasis. When hunger and satiety signals are not adequately perceived or acted on, this may lead to overeating and lifestyle-related diseases such as obesity (Farb et al., 2015). Lifestyle-related diseases and disorders shape variations in the response of the immune system (Bajpai and Nahrendorf, 2021), and a healthy lifestyle is regarded as an important factor in strengthening the immune system in the prevention and treatment of diseases (Monye and Adelowo, 2020). When an individual's physical and mental well-being is affected by lifestyle-related problems, infection, inflammation, and other immune reactions may occur, similar to reactions in other diseases (Dantzer and Kelley, 2007; Tracey, 2009; Dantzer et al., 2008). Research into the underlying mechanisms of interoception has yielded valuable insights in relation to lifestyle factors. Previous work concentrated mainly on the role of interoception in various conditions, such as alexithymia, sickness behaviors, fatigue, depression, eating disorders, autism spectrum disorders, and anxiety (Quadt et al., 2018; Garfinkel et al., 2016; Shah et al., 2016). However, to the best of our knowledge, the relationship between interoception and lifestyle factors has not yet been systematically evaluated, particularly with regard to the quality of the studies involved. Furthermore, measuring interoception is challenging due to differences between interoceptive domains, as well as the manner in which these interoceptive domains are measured. Therefore it is important to evaluate existing literature on interoception more systematically.

We aim to provide insight into the current state of evidence about the role of interoception in lifestyle factors by conducting a systematic review. The overall goal is to synthesize findings and identify general patterns in the relation between interoception and lifestyle factors. Insights into the association between interoception and a healthy lifestyle can be used to promote a healthy lifestyle through the development and improvement of lifestyle interventions focusing on interoception.

2. Methods

2.1. Eligibility criteria and search strategy

A protocol for this systematic review was developed in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) for protocols guidelines, and registered prospectively within PROSPERO with registration number CRD42023465957. This systematic review of literature was performed according to the PRISMA statement (Page et al., 2021). The review included peer-reviewed papers written in English, with no limitations on publication date. Only quantitative studies were included. Evidence syntheses (e.g., reviews) or non-original research articles (e.g., commentaries) were excluded. This review included adults as population of interest (i.e., $\geq$ 18 years of age). However, if results for both adults and children were presented separately, the study was included and only the results for the group of adults were extracted. Studies were screened on titles and abstracts for eligibility based on two inclusion criteria: 1) the study had to include at least one measure of interoception (e.g., interoceptive accuracy, attention, or awareness), and 2) at least one measure of a lifestyle factor (i.e., alcohol consumption, cognitive leisure and relaxation activities, eating behavior, exercise, sleep, or smoking). Studies were excluded based on full-text assessment when 1) the study focused on alexithymia, emotion, or autism spectrum disorders, 2) eating disorders such as anorexia nervosa, bulimia nervosa, binge eating disorder, and emotional eating (a recent review already covered the relation between interoception and eating disorders) (Martin et al., 2019), and 3) when the population consisted exclusively of individuals with impaired cognitive function, hypertension, obesity, or other non-lifestyle related disorders.

A systematic literature search was conducted from the date of inception to the 21st of September 2023 (date of last search) in three databases (PubMed, Embase, and Web of Science). The search strategy was developed using medical subheadings and free-text words in the title or abstract and enhanced by a medical librarian with expertise in systematic reviews. Search strategies were adapted to fit each database. The search strategy included terms such as interoception (accuracy, attention, awareness, sensitivity, or sensibility), as well as lifestyle factors (alcohol consumption, cognitive leisure and relaxation activities, eating behavior, exercise, sleep, or smoking). The complete search string can be found in Appendix A. Additionally, reference lists of included articles were screened by hand.

2.2. Selection and data extraction

Records were imported into EndNote (The EndNote Team, 2013) to check for duplicates. Titles and abstracts were independently screened for eligibility by at least two authors, and by using the automation tool ASReview (van de Schoot et al., 2021). ASReview uses an active researcher-in-the-loop machine learning algorithm to rank articles from high to low relevancy for inclusion by text mining. The algorithm is able to detect 95 % of the final included studies within the first 20 % of studies that are presented to the reviewer, significantly reducing the time spent screening titles and abstracts while maintaining quality (Ferdinands, 2021). To provide relevant terms to the automation tool, a few systematic reviews and meta-analyses were entered at the beginning of the screening process. These review articles were not included in the eligibility assessment phase. One-fourth (25 %) of the records imported into ASReview were screened by the authors. Data were independently extracted by at least two authors using a manually created data extraction form (Appendix B), after which full-texts were assessed based on the exclusion criteria. Extracted information included study

characteristics (e.g., title, first author, year, and study design), participant demographics (e.g., number of participants, sex, ethnicity, country, setting, and other population characteristics), outcome measures of interoception and lifestyle factors (e.g., interoception domain and measure according to the 2 ×2 factorial structure for interoception shown in Fig. 1, and lifestyle factor and measure), results of the measurements (e.g., statistical analyses, confounders, interoception results, lifestyle factor results, and correlations), and main findings reported in the article. A list of the most frequently used objective and self-reported interoceptive measures was provided to the authors screening records, to aid in determining whether reported measures could be considered interoceptive and to determine the interoceptive domains each measure falls under. This list was discussed beforehand with the authors assigned to screening records, where additionally definitions of what was to be considered interoceptive were discussed. In cases of discrepancies between authors on the in- or exclusion of studies, whether a measure was interoceptive, or the domain in which measures reported in studies were placed, issues were resolved by group discussion until consensus was reached. The inter-rater reliability was assessed using Fleiss' Kappa due to multiple reviewers, resulting in a Kappa score of 0.42, indicating a moderate level of agreement.

2.3. Synthesis methods

To categorize interoceptive domains and measures, the 2 × 2 factorial structure for interoception developed by Murphy and colleagues was adopted (Fig. 1) (Murphy et al., 2019). The first factor in this model makes the distinction between interoceptive accuracy (i.e., an individual's ability to perceive interoceptive signals accurately) and attention (i.e., the degree to which interoceptive signals are objects of attention). The second factor distinguishes between the way interoceptive accuracy or attention is measured: an objective performance measure or a self-report measure. Subsequently, interoceptive awareness can be quantified by assessing the correlation between self-reported beliefs and objective measures.

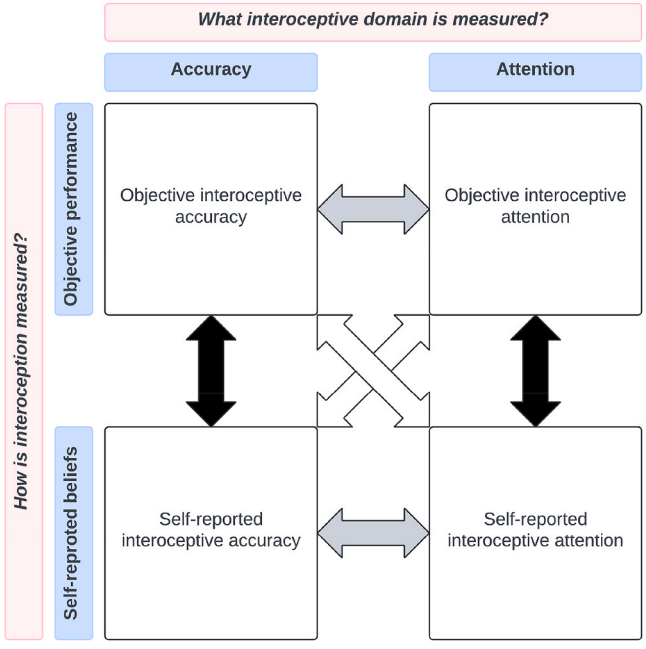

Fig. 1. Simplified version of the 2 × 2 factorial structure for interoception developed by Murphy et al. 2019 (Murphy et al., 2019). The quadrants represent interoceptive accuracy assessed with objective performance tasks (top left), interoceptive attention measured with objective performance tasks (top right), interoceptive accuracy assessed with self-report measures (bottom left), and interoceptive attention assessed with self-report measures (bottom right). The arrows represent the interaction between objective and self-report measures (i.e., interoceptive awareness; black arrows), interoceptive accuracy and attention (grey arrows), and across different interoceptive domains and measures (white arrows).

We operationalized lifestyle factors based on the following definitions: 1) alcohol consumption, which included all behavior related to the consumption of alcoholic beverages (Collins and Kirouac, 2013); 2) cognitive leisure and relaxation activities, which included leisure activities such as reading, writing, playing games like cards, checkers, crosswords or other puzzles, participating in groups or clubs, attending movies, plays, lectures or public meetings, or playing music, and stress or anxiety reducing activities such as mindfulness, meditation, yoga, and tai-chi (Malinowski and Shalamanova, 2017; Saczynski et al., 2008; Verghese et al., 2006; Wilson et al., 2010); 3) eating behavior, which included food choice and motives, feeding practices, and problems related to eating (LaCaille et al., 2013); 4) exercise was defined as regular physical activity with the intention of improving physical fitness or health, which ranges from low intensity exercise a few times a week to participating in daily high intensity exercise (Caspersen et al., 1985); 5) sleep included aspects related to sleep such as sleep duration, quality, latency, and stages (Baranwal et al., 2023); and finally, 6) smoking behavior, which is the action or habit of inhaling and exhaling smoke from burning substances (Baker and Webb Hooper, 2013). For each of these lifestyle factors, the 2 × 2 factorial structure for interoception was used to create harvest plots.

2.4. Study risk of bias and quality of evidence assessment

Risk of bias was assessed using an adjusted quality score checklist, based on three other checklists, to align with the objectives of the current systematic review and to accommodate both interventional and observational study designs (Stroup et al., 2000; von Elm et al., 2014; Wong et al., 2008). The quality score consists of five items related to study design, population size, exposure measurement, outcome measurement, and adjustment for confounders (see Appendix C). Each item was scored 0, 1, or 2, allowing for a total score between 0 and 10, with 10 representing the highest quality (Stroup et al., 2000; von Elm et al., 2014; Wong et al., 2008). Quality scores were assigned to all included articles by at least two authors. In case of discrepancies in quality score assessments between the two authors, the studies were discussed until consensus was reached, or a third author was consulted. Studies were considered of low, moderate, or high methodological quality when the quality score was ≤ 3, 4 – 6, or ≥ 7, respectively. Information on the quality and findings of the studies were combined to rate the level of evidence, based on the rating system shown in Table 1. The level of evidence was categorized as strong (i.e., three studies of high OR five studies of moderate quality with/without statistically significant effects), moderate (i.e., two studies of high OR three studies of moderate quality with/without statistically significant effects), limited (i.e., one study of high OR two studies of moderate quality with/without statistically significant effects), or conflicting (i.e., < 2:1 ratio between studies with and without statistically significant effects).

Table 1
Level of evidence ratings.

Level of evidence	Definition
Conflicting	Conflicting results (< 2:1 ratio) between studies finding (no) discriminatory, explanatory and/or predictive effects
Limited	One study of high OR two studies of moderate quality finding (no) discriminatory, explanatory and/or predictive effects
Moderate	Two studies of high OR three studies of moderate quality finding (no) discriminatory, explanatory and/or predictive effects
Strong	At least three studies of high OR at least five studies of moderate quality finding (no) discriminatory, explanatory and/or predictive effects

3. Results

A total of 4609 studies were identified. After removing duplicate records (n = 1603) and excluding studies based on title and abstract by the automation tool (n = 2564), 442 studies remained for full-text screening. Five additional studies were identified through reference list screening. Assessment of full-text studies and identification of studies via other methods resulted in 73 studies included in the review (see Fig. 2 for the selection process).

Table 2 provides an overview of the study characteristics of the included studies. The included studies involved 10,695 participants, ranging from seven to 1447 participants per study. Our review covered a total of 33 observational studies (Arora et al., 2021; Ates Col et al., 2016; Avery et al., 2017a,b; Billeci et al., 2021; Daubenmier et al., 2013; de la Fuente et al., 2019; Ewing et al., 2017; Hanley et al., 2017; Herbert et al., 2013; Herbert and Pollatos, 2014; Hina and Aspell, 2019; Iatridi et al., 2021; Jakubczyk et al., 2019; Khalsa et al., 2008, 2019; Kiken et al., 2018; Lovan et al., 2022; Mailloux et al., 2014; Melloni et al., 2013; Meric and Sonmez, 2022; Nishimura et al., 2020; Oswald et al., 2017; Price et al., 2019a; Robinson et al., 2021; Schmidt et al., 2013; Sönmez et al., 2017; Stevenson et al., 2023; Sübay and Sönmez, 2021; Tylka, 2006; Vabba et al., 2023; van Strien, 2000; Wallman-Jones et al., 2023), 20 randomized controlled trials (Abrams et al., 2018; Almarcha et al., 2022; Amaya et al., 2021; de Lima-Araujo et al., 2022; Eusebio et al., 2022; Farb et al., 2013; Fazia et al., 2021; Haase et al., 2016; Leganes-Fonteneau et al., 2019, 2022; Loucks et al., 2021; Palazzo et al., 2022; Price et al., 2019b,c; Roberts et al., 2021; Schillings et al., 2021; Teng et al., 2018; Thomas et al., 2019; Wu et al., 2021; Young et al., 2019), and 20 quasi-experimental studies (Betka et al., 2018; Bornemann et al., 2015; Chen et al., 2021; D'Antoni et al., 2022; Fairclough and Goodwin, 2007; Fischer et al., 2017; Flasbeck et al., 2021; Floyd et al., 2022; Haase et al., 2015; Herbert et al., 2007, 2012; Kosa et al., 2021; Koteles et al., 2020; Machado et al., 2019; Palascha et al., 2021; Parkin et al., 2014; Rominger et al., 2021; Schulz et al., 2015; Shen et al., 2023; Wallman-Jones et al., 2022).

Harvest plots to visualize the distribution of included studies over interoceptive domains and lifestyle factors are shown in Fig. 3. Out of the included studies, 51 measured interoceptive accuracy, with 49 instances of objective performance measures (Abrams et al., 2018; Amaya et al., 2021; Ates Col et al., 2016; Avery et al., 2017a,b; Betka et al., 2018; Billeci et al., 2021; Daubenmier et al., 2013; de la Fuente et al., 2019; de Lima-Araujo et al., 2022; Ewing et al., 2017; Fairclough and Goodwin, 2007; Farb et al., 2013; Fischer et al., 2017; Flasbeck et al., 2021; Haase et al., 2015, 2016, Herbert et al., 2007, 2012, 2013; Herbert and Pollatos, 2014; Hina and Aspell, 2019; Iatridi et al., 2021; Jakubczyk et al., 2019; Khalsa et al., 2008, 2019; Kosa et al., 2021; Koteles et al., 2020; Leganes-Fonteneau et al., 2019, 2022; Machado et al., 2019; Melloni et al., 2013; Meric and Sonmez, 2022; Nishimura et al., 2020; Palascha et al., 2021; Palazzo et al., 2022; Parkin et al., 2014; Rominger et al., 2021; Schillings et al., 2021; Schmidt et al., 2013; Schulz et al., 2015; Shen et al., 2023; Sönmez et al., 2017; Sübay and Sönmez, 2021; Vabba et al., 2023; Wallman-Jones et al., 2022, 2023; Wu et al., 2021; Young et al., 2019) and 17 self-report measures (Avery et al., 2017b; Daubenmier et al., 2013; Ewing et al., 2017; Iatridi et al., 2021; Khalsa et al., 2008, 2019; Kiken et al., 2018; Robinson et al., 2021; Wallman-Jones et al., 2023; Abrams et al., 2018; Leganes-Fonteneau et al., 2022, 2019; Fischer et al., 2017; Koteles et al., 2020; Parkin et al., 2014; Shen et al., 2023; Wallman-Jones et al., 2022). Interoceptive attention was assessed in 36 studies, all of which used self-report measures (Almarcha et al., 2022; Arora et al., 2021; Billeci et al., 2021; Bornemann et al., 2015; Chen et al., 2021; D'Antoni et al., 2022; Daubenmier et al., 2013; de Lima-Araujo et al., 2022; Eusebio et al.,

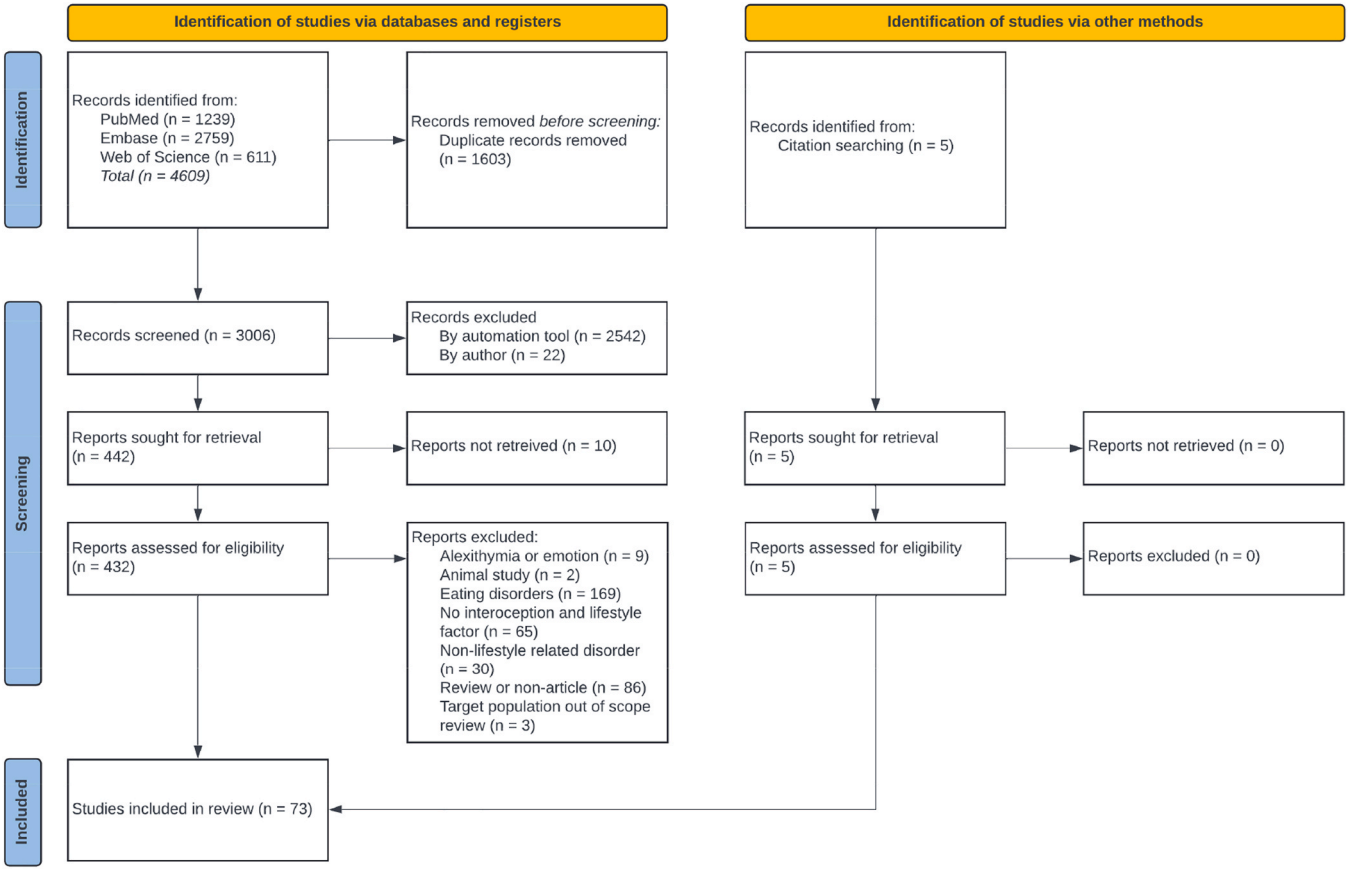

Fig. 2. Flow-chart showing the study selection process.

Table 2
Summary table of included studies per lifestyle factor (A-F), including reference ID, first author (year of publication), study design, number, age, sex, and ethnicity of participants, study setting, interoceptive domain and measure, main findings, and study quality score (grade). M = Mean, SD = Standard Deviation, Mdn = Median, NR = Not Reported.

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
A. Cognitive leisure and relaxation activities											
86	Bornemann (2015)	Quasi-Experimental	232 total 152 training group 80 control group	Training group: M = 41.6 (SD = 9.4, range = 20–55) Control group: M = 42.5 (SD = 8.6, range = 23–55)	Training group: 73 male Control group: 32 male	NR	NR	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	We observed training-related changes on five out of eight aspects of self-reported IA, when tested in comparison to a retest control group that underwent the same assessment but did not receive any training.	6 (Moderate)
87	Chen (2021)	Quasi-Experimental	56 total 26 Tai Chi Chuan group 30 control group	Tai-Chi Chuan group: M = 22.65 (SD = 3.92) Control group: M = 20.60 (SD = 4.8)	Tai-Chi Chuan group: 7 male Control group: 6 male	NR	Laboratory	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness-Chinese Version questionnaire	This study showed that 8-week Tai-Chi Chuan (TCC) practice can significantly improve mindfulness and marginally increase self-reported interoceptive attention. In addition, at the end of week 24, the TCC-induced benefits on three dimensions of mindfulness (describing, acting with awareness, and nonjudging) and the trusting dimension of self-reported interoceptive attention still remained.	8 (High)
88	D'Antoni (2022)	Quasi-Experimental	219 total 113 mindfulness group 106 control group	Mindfulness group: M = 23.46 (SD = 3.3) Control group: M = 22.33 (SD = 3.19)	Mindfulness group: 99 female, 14 male Control group: 97 female, 9 male	Caucasian	University Laboratory	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	The data showed a specific effect of Mindfulness Oriented Meditation (MOM) in enhancing mindfulness skills and specific self-reported interoceptive attention components, and in reducing dissociative functioning. Moreover, we found that MOM participants' global changes in mindfulness skills, self-reported interoceptive attention and dissociation tended to be correlated.	6 (Moderate)
68	de Lima-Araujo (2022)	Randomized-Controlled Trial	40 total 20 control group 20 participants	Control: M = 24.25 (SD = 3.55) Mindfulness: M	Control: 10 male, 10 female Mindfulness: 10 male, 10 female	NR	University Laboratory	Accuracy - Performance Attention - Beliefs Awareness	Heartbeat tracking task Multidimensional Assessment of Interoceptive	Although objective interoceptive accuracy did not change after the mindfulness training, an important increase in	6 (Moderate)

(*continued on next page*)

Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
			mindfulness group	= 24.05 (SD = 3.76)					Awareness questionnaire	self-reported interoceptive attention was observed along with a mediation of lower anxiety state scores.	
37	Daubenmier (2013)	Observational	18 meditators 16 nonmeditators	Meditators: 41.9 (SD = 11.0) Nonmeditators: 35.4 (SD = 11.4)	Meditators: 61 % male Nonmeditators: 50 % male	NR	Laboratory	Accuracy - Performance Accuracy - Beliefs Attention - Beliefs	Respiratory load detection, discrimination, and tracking tasks, with confidence ratings Body Awareness sub-scale from Body Connection Scale, Body Responsiveness Questionnaire, and Breath Awareness Scale	Contrary to prediction, groups did not differ in overall performance on the tasks; however, meditators were more accurate than nonmeditators on two of the three tasks under specific task conditions.	4 (Moderate)
69	Eusebio (2022)	Randomized-Controlled Trial	16 interoceptive focus yoga 18 movement focus yoga	M = 28.6 (SD = 6.5)	83 % female	NR	Clinic or hospital	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	Both Movement- and Interoception-Focused Yoga interventions reduced depressive symptoms and improved self-reported interoceptive attention.	7 (High)
89	Fairclough (2007)	Quasi-Experimental	40	Male: M = 25.3 (SD = 6.3) Female: M = 25.8 (SD = 4.9)	20 male 20 female	NR	NR	Accuracy - Performance	Heartbeat tracking task	The study provided evidence that transient states of stress may degrade objective interoceptive accuracy for female participants during laboratory testing. This effect was not created by any change of cardiovascular rate or rhythm or any gender-based differences in subjective mood.	5 (Moderate)
70	Farb (2013)	Randomized-Controlled Trial	16 untrained 20 mindfulness	Untrained: M = 42.00 (SD = 9.24) Mindfulness training: M = 45.55 (SD = 13.38)	Untrained: 12 female, 4 male Mindfulness training: 15 female, 5 male	NR	Clinic or hospital	Accuracy - Performance	Functional MRI during breath monitoring	Relative to untrained, waitlisted control participants, individuals completing an 8 week mindfulness course demonstrated objective interoceptive accuracy specific functional plasticity in the middle and anterior insula, regions theorized to support present moment awareness, commensurate with the goals of the mindfulness intervention.	6 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
71	Fazia (2021)	Randomized-Controlled Trial	42 total 19 controls 23 treated	Controls: M = 33.53 (SD = 8.15) Treated: M = 34.65 (SD = 12.56)	Controls: 5 (26 %) male, 14 (74 %) female Treated: 8 (35 %) male, 15 (65 %) female	NR	Workplace	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	The results relative to self-reported interoceptive attention indicate that our mindfulness intervention helped the participants to gain a better interoceptive awareness relatively to emotional awareness, self-regulation, body listening and trusting subscales.	6 (Moderate)
90	Fischer (2017)	Quasi-Experimental	Study 1: 49 total, 25 intervention, 24 control Study 2: 36 total, 18 intervention, 18 control	Study 1: intervention 22.4 (SD = 3.4), control 22.6 (SD = 4.2) Study 2: intervention 22.2 (SD = 2.8), control 22.8 (SD = 3.3)	Study 1: intervention 6 male, control 4 male Study 2: female	NR	Laboratory	Accuracy - Performance Accuracy - Beliefs	Heartbeat tracking task, with confidence rating Interoceptive Awareness subscale from Eating Disorder Inventory−2 questionnaire	Our data provide consistent evidence for the influence of a body scan intervention over 8 weeks on interoceptive processes.	7 (High)
92	Floyd (2022)	Quasi-Experimental	76	M = 40.8 (SD = 9.6, range = 25–63)	70 (92 %) male 6 (8 %) female	NR	NR	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	Participation in the 10-class FireFlex yoga program designed for firefighters appeared to improve their observed movement function and self-reported interoceptive attention.	6 (Moderate)
93	Haase (2015)	Quasi-Experimental	7	M = 21.86 (SD = 3.67)	NR	NR	NR	Accuracy - Performance Attention - Beliefs	Functional MRI inspiratory breathing load task Multidimensional Assessment of Interoceptive Awareness questionnaire	First, following Mindful Performance Enhancement, Awareness and Knowledge (mPEAK) training, elite athletes reported greater levels of objective interoceptive accuracy, self-reported interoceptive attention, mindfulness, and lower levels of alexithymia. Second, mPEAK training resulted in increased insula and ACC activation during the anticipation and post-breathing load conditions during an interoceptive challenge.	4 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
72	Haase (2016)	Randomized-Controlled Trial	19 mindfulness group 16 control group	Mindfulness: M = 22.53 (SD = 3.30) Control: M = 20.81 (SD = 1.10)	NR	NR	Army base	Accuracy - Performance	Functional MRI inspiratory breathing load task	Although we did not find a significant effect of mindfulness-based mind fitness training (MMFT) on objective interoceptive accuracy during aversive interoception, we did find a significant attenuation in neural systems that are important for interoceptive processing. Specifically, marines after MMFT showed significant attenuation of right anterior insula and ACC, in contrast to those in the training as usual condition who showed a trend for increased brain activation during loaded breathing.	6 (Moderate)
40	Hanley (2017)	Observational	232	M = 36.44 (SD = 12.17)	57 % female	1 % American Indian or Alaskan native 6 % Asian or South Asian 6 % African American 0 % native Hawaiian or Pacific Islander 6 % Latino or Hispanic 77 % Caucasian 9 % multiracial	Online survey	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	Our findings demonstrate that self-reported interoceptive attention (IA) and dispositional mindfulness (DM) are tightly interwoven, partly overlapping constructs. Indeed, greater DM is strongly linked with greater IA. Additionally, both IA and DM appear to be independently associated with enhanced psychological well-being, defined as "the striving for perfection that represents the realization of one's true potential".	3 (Low)
46	Khalsa (2008)	Observational	17 nonmeditators 17 Kundalini meditators 13 Tibetan Buddhist meditators	Nonmeditators: M = 50.6 (SD = 9.6) Kundalini: M = 52.1 (SD = 8.6) Tibetan: M	Nonmeditators: 4 male, 13 female Kundalini: 5 male, 12 female Tibetan: 7 male, 6 female	NR	NR	Accuracy - Performance Accuracy - Beliefs	Pulse detection familiarization task and heartbeat detection task, with confidence ratings	The current findings do not support the hypothesis that experienced meditators would display increased objective and self-reported interoceptive	4 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
				= 48.8 (SD = 10.1)						accuracy, as meditators did not differ from nonmeditators in heartbeat detection accuracy.	
47	Khalsa (2019)	Observational	15 meditators 15 nonmeditators	Meditators: M = 44.7 (SD = 13.2) Nonmeditators: M = 44.0 (SD = 13.7)	Meditators: 10 male, 5 female Nonmeditators: 10 male, 5 female	Meditators: 15 Caucasian Nonmeditators: 14 Caucasian, 1 Asian	NR	Accuracy - Performance Accuracy - Beliefs	Rating of internal body sensations both during and immediately after receiving bolus infusions of isoproterenol, with confidence ratings	Our findings do not support the hypothesis that the practice of meditation is associated with increased objective and self-reported interoceptive accuracy for the heartbeat.	8 (High)
48	Kiken (2018)	Observational	28	M = 55.05 (SD = 10.42)	67 % female	57 % African American/Black 29 % White/ Caucasian 5 % Asian 9 % other races	Clinic or hospital	Accuracy - Beliefs	Estimation of blood glucose levels	A measure of mindfulness in general daily life was unrelated to blood glucose estimate accuracy (self-reported interoceptive accuracy). However, a context-specific measure of mindfulness, in terms of a balanced and clear perspective on difficult present-moment experiences, was positively associated with blood glucose estimate accuracy (self-reported interoceptive accuracy).	3 (Low)
75	Loucks (2021)	Randomized-Controlled Trial	96	M = 20 (range = 18–26)	68 % female 2 % nonbinary	62.5 % White 14.6 % Asian 8.3 % Black 14.6 % other	NR	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	Findings suggest that the MB-College program improved overall health of young adults during the college school term; evidence suggested that MB College may provide resilience in the face of mounting stressors. Mechanistically, MB-College improved the self-regulation pathways including attention control, self-reported interoceptive attention, and emotion regulation, compared with control.	7 (High)
51	Melloni (2013)	Observational	10 controls 9 short-term meditators 10 long-term meditators	Control: M = 37.30 (SD = 9.12, range = 22–49) Short-term: M	Control: 2 male, 8 female Short-term: 4 male, 4 female	NR	NR	Accuracy - Performance	Heartbeat tracking task	No influence of meditation practice in cardiac interoception (objective interoceptive accuracy) and related	4 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
				= 41.12 (SD = 12.15, range = 25–55) Long-term: M = 43.80 (SD = 10.55, range = 29–56)	Long-term: 7 male, 3 female					social cognition measures was observed.	
100	Parkin (2014)	Quasi-Experimental	Study 1 and 2: 60 total, 20 body group, 20 sound group, 20 control group Study 3: 19 Study 4: 166	Study 1 and 2: body group 45.67 (SD = 16.49), sound group 42.36 (SD = 16.94), control group 43.34 (SD = 18.17) Study 3: 46.94 (SD = 13.97) Study 4: 41.28 (SD = 15.74)	Study 1 and 2: body group 70 % female, sound group 70 % female, control group 75 % female Study 3: 15 female, 4 male Study 4: 120 female, 47 male	United Kingdom	NR	Accuracy - Performance Accuracy - Beliefs	Heartbeat tracking task, with confidence ratings	In the three training studies, meditation practice did not significantly alter cardiac perception accuracy following week long or 8 week mindfulness practice. Eight-week (but not 1 week) meditation practice led to an increase in confidence in cardiac perception judgements. Meditation practice did not alter the coherence between accuracy and confidence judgements.	8 (High)
55	Price (2019a)	Observational	217	Mdn = 35 (range = 20–61)	Female	Ethnicity: 20 (10 %) Hispanic Race: 9 (4.1 %) African American 3 (1.4 %) Asian 1 (0.5 %) Native Hawaiian 9 (4.1 %) Native American 164 (75.6 %) White 22 (10.1 %) Mixed race 9 (4.1 %) other	Clinic or hospital Online survey	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	Findings provide the first evidence of a positive significant relationship between self-reported interoceptive attention and respiratory sinus arrythmia (RSA) among women in substance use disorder treatment. Psychological symptoms and mindfulness skills were not associated with RSA in this sample. Self-reported interoceptive attention was significantly related with mindfulness skills.	4 (Moderate)
79	Roberts (2021)	Randomized-Controlled Trial	95 total 50 intervention 45 control	Intervention: M = 55.9 (SD = 11.5) Control: M = 57.6 (SD = 12.0)	Intervention: 27 (54 %) female Control: 36 (80 %) female	Majority White	Clinic or hospital	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	Our first hypothesis, that self-reported interoceptive attention mediates the effect of Mindfulness-Oriented Recovery Enhancement (MORE) on reappraisal, was supported. The MORE group had greater improvements in self-reported interoceptive	8 (High)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										attention than the support group. Beyond testing the mindfulness-to-meaning theory, this is the first study to show that MORE can enhance multiple facets of self-reported interoceptive attention.	
80	Schillings (2021)	Randomized-Controlled Trial	137 total 47 yoga 46 endurance 44 control	Yoga: M = 24.11 (SD = 4.44) Endurance: M = 23.89 (SD = 4.02) Control: M = 23.09 (SD = 3.32)	Yoga: 17 male, 30 female Endurance: 17 male, 29 female Control: 10 male, 34 female	NR	NR	Accuracy - Performance	Heartbeat tracking task	We could not find any effects of a single yoga session on objective interoceptive accuracy, or positive and negative affect. Nevertheless, objective interoceptive accuracy at baseline as well as the change in positive affect predicted objective interoceptive accuracy after the yoga session. Sex, BMI, physical activity, level, negative affect at baseline, and the change in negative affect did not predict objective interoceptive accuracy after the yoga session.	8 (High)
103	Shen (2023)	Quasi-Experimental	86 total 50 intervention 36 control	Intervention: M = 21.56 (SD = 5.10) Control: M = 21.61 (SD = 2.25)	Intervention: 9 male, 41 female Control: 5 male, 31 female	NR	NR	Accuracy - Performance Accuracy - Beliefs Attention - Beliefs	Heartbeat tracking task, with confidence ratings Multidimensional Assessment of Interoceptive Awareness questionnaire	As predicted, the 12-week Tai-Chi Chuan practice increased objective and self-reported interoceptive accuracy, and self-reported interoceptive attention, but decreased anxiety levels.	6 (Moderate)
82	Thomas (2019)	Randomized-Controlled Trial	26 MORE POWER group (intervention) 25 POWER group (comparison)	M = 57.92 (SD = 7.39, range = 29–76)	Female	96 % White/ Caucasian 1 Black/African American 1 Hispanic/ Latino	NR	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	In the present trial, Mindfulness-Oriented Recovery Enhancement (MORE) was associated with significant improvements in self-reported interoceptive attention.	8 (High)
83	Wu (2021)	Randomized-Controlled Trial	26 mindfulness training group 25 control group	Training: M = 29.73 (SD = 1.67) Control: M = 30.12 (SD = 1.78)	Training: 23 female Control: 20 female	NR	NR	Accuracy - Performance	Breath-delay detection task	Mindfulness training increased the objective interoceptive accuracy of the participants.	8 (High)

B. Eating behavior

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
35	Avery (2017)	Observational	52 obese participants 18 healthy weight participants	Obese: M = 37.3 (SD = 8) Healthy weight: M = 35.1 (SD = 10.5)	Obese: 33 female Healthy weight: 14 female	NR	NR	Accuracy - Performance Accuracy - Beliefs	Functional MRI pre- and post-meal, with confidence ratings	Given previous findings, as well as the findings of the present study, it seems likely that strategies that improve individuals' objective and self-reported interoceptive accuracy may promote eating behaviors that more closely track the body's energy needs.	2 (Low)
91	Flasbeck (2021)	Quasi-Experimental	37	M = 25.81 (SD = 3.67)	Male	NR	NR	Accuracy - Performance	Heartbeat evoked potentials	We found higher heartbeat evoked potential (HEP) amplitudes during the satiety condition compared to the fasting condition over right central and parietal electrodes, whereas in the initial analyses, no effect of the type of nutrition occurred. This is the first study showing that fasting and intake of carbohydrates and proteins affect HEP amplitudes, whereas this effect was more prominent during the carbohydrate testing days, as shown by exploratory analyses.	6 (Moderate)
94	Herbert (2012)	Quasi-Experimental	20	M = 24.4 (SD = 24.4, range = 21–31)	Female	NR	Clinic or hospital	Accuracy - Performance	Heartbeat tracking task	Our data demonstrate that short-term fasting increased the perceptibility of one's cardiac signals as a marker of objective interoceptive accuracy. The results confirm that the improvement of heartbeat perception induced by fasting was substantially associated with changes of cardiodynamic parameters that have been demonstrated to causally improve cardiac objective interoceptive accuracy during	4 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										experimental manipulations of autonomic and cardiodynamic changes.	
41	Herbert (2013)	Observational	111	M = 25.4 (SD = 4.8)	Female	NR	NR	Accuracy - Performance	Heartbeat tracking task	Objective interoceptive accuracy was not only positively related to total Intuitive Eating Scale (IES) score and reliance on internal hunger and satiety cues (RIH) and eating for physical rather than emotional reasons (EPR), and negatively predicted BMI, but also proved to fully mediate the negative relationship between RIH, as well as EPR and BMI. Additionally, the subjective appraisal of one's interoceptive signals independently predicted EPR and BMI.	3 (Low)
42	Herbert (2014)	Observational	75 overweight and obese individuals Number of controls not reported	Overweight and obese: female 25.1 (SD = 4.5), male 25.6 (SD = 4.6) Normal weight controls: female 23.0 (SD = 4.6), male 25.8 (SD = 5.1)	Overweight and obese: 55 female, 20 male Normal weight controls: female and male (no numbers reported)	NR	Laboratory University	Accuracy - Performance	Heartbeat tracking task	We found evidence for reduced objective interoceptive accuracy in overweight and obese individuals. These differences were accompanied by an inverse correlation between the BMI and the objective interoceptive accuracy score in overweight and obese participants, while no such relationship was observed for normal weight range.	4 (Moderate)
44	Iatridi (2021)	Observational	64 total 31 sweet-likers 33 sweet dislikers	Sweet-likers: M = 22.4 (SEM = 0.05) Sweet dislikers: M = 24.3 (SEM = 0.08)	Women	67.2 % Caucasian 21.9 % Asian	NR	Accuracy - Performance Accuracy - Beliefs Attention - Beliefs Awareness	Heartbeat tracking and discrimination tasks, and water load task, with confidence ratings Porges Body Perception Questionnaire	Statistically significant differences in interoceptive abilities between the two sweet taste phenotypes were observed for all accuracy-based tasks. Specifically, participants who expressed heightened liking for strong sweetness, performed better than	6 (Moderate)

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ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										sweet dislikers in detecting their heartbeats accurately despite being similarly confident about their responses. For the gastric mode of interoception, sweet likers reported to feel satiated after they ingested a lower amount of water in relation to their total stomach capacity compared to sweet dislikers.	
49	Lovan (2022)	Observational	66	M = 19.8 (SD = 1.4)	37.9 % male 62.1 % female	Race: 75.8 % White 18.2 % Black or African American 4.5 % Asian 1.5 % American Indian Ethnicity: 74.2 % Hispanic	University	Attention - Beliefs	Body Awareness Questionnaire and Body Responsiveness Questionnaire	Students with higher levels of self-reported interoceptive attention reported lower levels of restricted eating and lower sensitivity to emotional and external stimuli that may trigger overconsumption. Moreover, self-reported interoceptive attention was significantly correlated with intuitive eating skills, where individuals rely on physiological cues and bodily needs for energy consumption.	4 (Moderate)
50	Mailloux (2014)	Observational	1447	M = 19.16 (SD = 1.07, range = 18–21)	Female	NR	University	Attention - Beliefs	Interoceptive Awareness subscale from Eating Disorder Inventory−2 questionnaire	Contrary to our hypothesis, a deficit in self-reported interoceptive attention was not associated with overeating and binge eating in our sample of young, healthy, college women.	4 (Moderate)
53	Nishimura (2020)	Observational	65 total 15 overweight 50 normal weight	Total: M = 23.7 (SD = 4.9) Overweight: M = 23.9 (SD = 5.7) Normal weight: M = 23.6 (SD = 4.7)	Female	NR	Laboratory	Accuracy - Performance	Heartbeat tracking task	The results showed that young women who were overweight formed two groups according to their objective interoceptive accuracy (IA); that is, women with low IA who showed little decrease in hunger and prospective consumption due to dietary intake, and	3 (Low)

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ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										women with high IA who tended to have disinhibited eating behavior. Interestingly, although distinguishing characteristics were not observed in the normal body weight women with low IA, those with high IA did display significantly higher prospective consumption.	
54	Oswald (2017)	Observational	200	M = 22.15 (SD = 3.71, range = 17–30)	Female	89.3 % White/ Caucasian 4.6 % Asian 1 % African 1 % Aboriginal or Torres Strait Islander 4.6 % other	Online survey	Attention - Beliefs	Body Awareness Questionnaire and Body Responsiveness Questionnaire	The current investigation into the association between body appreciation, interoception, and intuitive eating indicates that interoceptive awareness and interoceptive responsiveness (both self-reported interoceptive attention measures) have important and differing roles in facilitating adaptive eating behaviors.	4 (Moderate)
99	Palascha (2021)	Quasi-Experimental	226 in study 1 217 in study 2	Study 1: M = 31.9 (SD = 3.4) Study 2: M = 22.0 (SD = 2.1)	Study 1: 57 male, 169 female Study 2: 217 female	NR	Laboratory	Accuracy - Performance	Two-step water load test	We showed that a brief mindfulness exercise (body scan) did not have an impact on the ability to perceive bodily signals of satiation (Study 1), but it improved the ability to perceive bodily signals of hunger substantially (Study 2).	6 (Moderate)
76	Palazzo (2022)	Randomized-Controlled Trial	19 intervention 18 control	Intervention: M = 36.78 (SD = 12.73) Control: M = 36.00 (SD = 12.53)	Female	NR	NR	Accuracy - Performance	Heartbeat tracking task	The results of this study showed that the Food and Nutrition Education Program with Sensory and Cognitive Exercises promoted an increase in objective interoceptive accuracy and in the expression of exteroceptive perception in women who had	4 (Moderate)

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ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										difficulty controlling their body weight.	
56	Robinson (2021)	Observational	1181	M = 37.2 (SD = 12.6)	576 (49 %) female	89 % White	Online survey	Accuracy - Beliefs Attention - Beliefs	Interoceptive Accuracy Scale and Body Awareness subscale from the Body Perception Questionnaire-Short Form	Poorer self-reported interoceptive accuracy was significantly associated with higher BMI. Poorer self-reported interoceptive accuracy was also associated with participants being less likely to report eating in response to internal satiety signals ('intuitive eating') and being more likely to report emotional overeating, and there was evidence that these behavioral tendencies explained the association between poorer self-reported interoceptive accuracy and higher BMI. Self-reported interoceptive attention was not significantly associated with BMI, but was associated with participants reporting higher levels of emotional overeating, trait hunger and trait satiety responsiveness.	5 (Moderate)
101	Rominger (2021)	Quasi-Experimental	24 study 1 70 study 2	Study 1: M = 23.88 (SD = 3.00) Study 2: M = 22.24 (SD = 2.36, range = 18–30)	Study 1: 14 female Study 2: 31 male, 38 female	NR	NR	Accuracy - Performance	Heartbeat tracking and discrimination task	In the present study, we assessed objective interoceptive accuracy by two established paradigms in two consecutive and independent studies. We found that short-term fasting of 16-h appears well suited to alter the autonomic regulation of the heart, reducing heartrate and increasing vagally-mediated heartrate variability. Furthermore, fasting was found to benefit objective interoceptive accuracy.	5 (Moderate)

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ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
102	Schulz (2015)	Quasi-Experimental	16	M = 22.6 (range = 20–26)	Female	NR	Laboratory	Accuracy - Performance	Heartbeat evoked potentials	18 h of food deprivation increased subjective feelings of hunger and motivation to eat, but did not induce an increase in heart rate or in normalized low frequency heartrate variability. We observed higher heartbeat evoked potential amplitudes after food deprivation compared to normal food consumption.	4 (Moderate)
59	Stevenson (2023)	Observational	180 part 1 107 in part 1 and 2	Part 1: M = 21.5 (SD = 7.0) Part 1 and 2: M = 22.2 (SD = 7.6)	Part 1: 147 female Part 1 and 2: 90 female	NR	University	Attention - Beliefs	Hunger questions from Monello and Mayer (1967)	People differ in how many interoceptive hunger cues are relevant to them (as indicated by their intensity) and in the combinations they possess. There was evidence for relationships between interoceptive hunger and Three Factor Eating Questionnaire dimensions, particularly uncontrolled eating. Both homeostatic and learning/environmental beliefs about the causes of hunger were related to various facets of interoceptive hunger.	2 (Low)
61	Tylka (2006)	Observational	391	M = 20.85 (SD = 6.21, range = 17–61)	Female	87.7 % Caucasian American 3.8 % Asian American 3.4 % Multiracial 3.1 % African American 2.8 % Native American 0.5 % Latina 0.3 % NR	Classroom	Attention - Beliefs	Reliance on Hunger/ Satiety Cues subscale of Intuitive Eating Scale questionnaire and Interoceptive Awareness subscale from Eating Disorder Inventory−2 questionnaire	The hypothesis that the Intuitive Eating Scale (IES) would be negatively related to body dissatisfaction, poor self-reported interoceptive attention, pressure for thinness, and internalization of the thin-ideal stereotype was investigated. As predicted, the total IES was strongly related in a negative direction to these variables. For the IES subscales, Unconditional Permission to Eat was moderately to strongly	2 (Low)

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ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										related in a negative direction to these variables, Eating for Physical Rather Than Emotional Reasons was moderately related in a negative direction to these variables, and Reliance on Internal Hunger/ Satiety Cues was slightly to moderately related in a negative direction to these variables.	
63	van Strien (2000)	Observational	200	M = 21.2 (SD = 3.2)	Female	NR	University	Attention - Beliefs	Interoceptive Awareness subscale from Revised Eating Disorder Inventory	In the present sample of non–eating-disordered women, ice-cream consumption was best predicted by emotional eating, which in turn was best predicted by the EDI scales, asceticism, interoceptive awareness (self-reported interoceptive attention), and social insecurity.	3 (Low)
84	Young (2019)	Randomized-Controlled Trial	100	Glucose, low IAc: M = 20.3 (SD = 0.9) Glucose, high IAc: M = 20.3 (SD = 1.1) Sucralose, low IAc: M = 20.7 (SD = 2.7) Sucralose, high IAc: M = 19.8 (SD = 1.0) Water, low IAc: M = 20.1 (SD = 1.1) Water, high, IAc: M = 21.4 (SD = 2.2) Nothing, low IAc: M = 20.4 (SD = 1.4) Nothing, high IAc: M = 22.8 (SD = 4.7)	Female	NR	NR	Accuracy - Performance	Heartbeat tracking task	Key findings were that after consuming glucose individuals with high objective interoceptive accuracy (IAc) had lower blood glucose levels, a decline in anxiety (but not depression or fatigue), and greater autonomic nervous system reactivity. Those with high IAc also had a decline in hunger after consuming either glucose or sucralose.	8 (High)
C. Alcohol consumption											
65	Abrams (2018)	Randomized-Controlled Trial	61	Total: M = 22.0 (SD = 3.73) Men: M = 21.4	26 male 35 female	41 (67.2 %) White 10 (16.4 %)	Clinic or hospital	Accuracy - Performance	Heartbeat tracking task, with confidence ratings	Alcohol impaired objective interoceptive accuracy relative to a	9 (High)

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ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
				(SD = 0.64) Women: M = 22.3 (SD = 4.88)		Asian 5 (8.2 %) Black 3 (4.9 %) Hispanic 2 (3.3 %) other		Accuracy - Beliefs		placebo both while quietly standing and following exercise. Also, alcohol led to a higher heart rate relative to placebo drinks. Self-reported interoceptive accuracy improves with higher levels of arousal induced by exercise.	
33	Ates Col (2016)	Observational	55 alcohol addicted 52 control group	Alcohol addicted group: M = 43.38 (SD = 10.83) Control group: M = 41.34 (SD = 11.50)	Alcohol addicted group: 50 (90.9 %) male, 5 (9.1 %) female Control group: 47 (90.4 %) male, 5 (9.6 %) female	NR	Clinic or hospital	Accuracy - Performance	Heartbeat tracking task	It was detected that compared with control subjects, objective interoceptive accuracy was decreased among alcohol-addicted patients.	3 (Low)
85	Betka (2018)	Quasi-Experimental	32	Mdn = 25.1 (range = 18–36)	Male	NR	Clinic or hospital	Accuracy - Performance	Heartbeat tracking and discrimination tasks	No main effects of alcohol on objective interoceptive accuracy was found.	5 (Moderate)
45	Jakubczyk (2019)	Observational	114 alcohol use disorder 110 healthy controls	Alcohol use disorder: M = 43.35 (SD = 11.5) Healthy controls: M = 40.57 (SD = 8.2)	Alcohol use disorder: 89.5 % male Healthy controls: 74.5 % male	NR	Clinic or hospital	Accuracy - Performance Attention - Beliefs	Heartbeat tracking task Private Body Consciousness subscale from Body Consciousness Questionnaire	Individuals with alcohol use disorder are likely characterized by both high self-reported interoceptive attention and low objective interoceptive accuracy.	5 (Moderate)
73	Leganes-Fonteneau (2022)	Randomized-Controlled Trial	31	M = 23.52 (SD = 4.05)	16 male	NR	NR	Accuracy - Performance Accuracy - Beliefs Awareness	Heartbeat discrimination task, with confidence ratings	We found significant differences in objective interoceptive accuracy after alcohol administration, but no effect of alcohol on interoceptive awareness.	8 (High)
74	Leganes-Fonteneau (2019)	Randomized-Controlled Trial	50 total 17 placebo 18 low alcohol 15 high alcohol	Placebo: M = 21.06 (SD = 1.60) Low alcohol: M = 21.06 (SD = 2.38) High alcohol: 23.47 (SD = 6.15)	30 female	NR	Laboratory	Accuracy - Performance Accuracy - Beliefs Attention - Beliefs Awareness	Heartbeat tracking and discrimination tasks, with confidence ratings Awareness subscale from Porges Body Perception Questionnaire	Our main finding is that there was a relationship between interoceptive awareness and the subjective states alcohol induces. However, no direct effects of alcohol administration on objective and self-reported interoceptive accuracy, and self-reported interoceptive attention were found.	9 (High)
52	Meric (2022)	Observational	52 patients with alcohol use disorder 52 healthy controls	AUD: 45.27 (SD = 10.02) Controls: 45.90 (SD = 11.71)	Male	NR	Clinic or hospital	Accuracy - Performance	Heartbeat tracking task	Main findings showed that objective interoceptive accuracy scores were significantly lower in patients with	5 (Moderate)

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ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										alcohol use disorder compared to healthy controls.	
77	Price (2019b)	Randomized-Controlled Trial	187 total 74 intervention 46 treatment as usual + active control 67 treatment as usual	Total: Mdn = 35 (range = 20–61) Intervention: Mdn = 35 (range = 22–61) Treatment as usual + active control: Mdn = 36 (range = 20–59) Treatment as usual: Mdn = 35 (range = 22–57)	Female	Race: 75 % White 10 % mixed race 5 % African American 4 % Native American 1 % Asian Ethnicity: 8 % Hispanic	Clinic or hospital	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	Results show interoceptive awareness training to be efficacious for longitudinal health outcomes in substance use disorders. Specifically, reductions in substance use and craving, and increases in self-reported attention were observed, as well as longer term effects as 12 months.	9 (High)
78	Price (2019c)	Randomized-Controlled Trial	217 total 74 intervention 46 active control 67 treatment as usual	Total: Mdn = 35 (range = 20–61) Intervention: Mdn = 35 (range = 22–61) Active control: Mdn = 36 (range = 20–59) Treatment as usual: Mdn = 35 (range = 22–57)	Female	75 % White 10 % mixed race 5 % African American 5 % other 4 % Native American 1 % Asian	Clinic or hospital	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	The study pre-post findings demonstrate that self-reported interoceptive attention was significantly improved after interoceptive awareness training in patients with substance use disorder.	9 (High)
57	Schmidt (2013)	Observational	89	Total: M = 47.49 (SD = 9.19) Women: M = 47.4 (SD = 8.7) Men: M = 47.6 (SD = 9.6)	39 (43.8 %) female	NR	Clinic or hospital	Accuracy - Performance	Heartbeat tracking task	No direct link was found between inter-individual differences in objective interoceptive accuracy and self-reported drinking behavior.	6 (Moderate)
58	Sönmez (2017)	Observational	84 intervention 35 control	Alcohol addicted patients: M = 44.52 (SD = 1.41) Heroin addicted patients: M = 27.72 (SD = 1.16) Cannabis addicted patients: M = 26.50 (SD = 1.25) Control: M = 38.14 (SD = 1.68)	Male	NR	Clinic or hospital	Accuracy - Performance	Heartbeat tracking task	Patients addicted to alcohol, heroin or synthetic cannabinoids had similar objective interoceptive accuracy scores, and their scores were significantly lower than those of healthy control subjects.	3 (Low)
60	Sbay (2021)	Observational	80 total 40 alcohol use disorder 40 opioid use disorder	Participants with alcohol use disorder: M = 46.58 (SD = 10.06)	Male	NR	Clinic or hospital	Accuracy - Performance	Heartbeat tracking task	The objective interoceptive accuracy score of patients with alcohol addiction was significantly lower than	4 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
				Participants with opioid use disorder: M = 27.45 (SD = 8.25) Healthy controls: M = 37.45 (SD = 13.11)						those in the control group, even after controlling for age, BMI, smoking, and impulsiveness score. Objective interoceptive accuracy in patients with alcohol addiction is significantly lower than in healthy control, but alcohol craving is not significantly correlated with objective interoceptive accuracy.	
D. Exercise											
65	Abrams (2018)	Randomized-Controlled Trial	61	Total: M = 22 (SD = 3.73) Male: M = 21.4 (SD = 0.64) Female: M = 22.3 (SD = 4.88)	26 male 35 female	41 (67.2 %) White 10 (16.4 %) Asian 5 (8.2 %) Black 3 (4.9 %) Hispanic 2 (3.3 %) other	Clinic or hospital	Accuracy - Performance Accuracy - Beliefs	Heartbeat tracking task, with confidence ratings	Alcohol impaired objective interoceptive accuracy relative to a placebo both while quietly standing and following exercise. Also, alcohol led to a higher heart rate relative to placebo drinks. Self-reported interoceptive accuracy improves with higher levels of arousal induced by exercise.	9 (High)
66	Almarcha (2022)	Randomized-Controlled Trial	20 total 10 co-designed exercise intervention group 10 standardized exercise program group	Range = 40–50	10 male 10 female	NR	NR	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	The co-designed intervention promoted further mental health and self-reported interoceptive attention, crucial aspects of cognitive and emotional wellbeing. Concerning the self-reported interoceptive attention effects, the light results obtained in the MAIA questionnaire by the standardized exercise program (WHO) group (improving only in three of the eight scales), compared to the co-designed exercise intervention group (seven of eight), can be explained by the lack of emphasis on the WHO intervention on self-reported interoceptive	6 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										attention and stressful experiences of participants.	
67	Amaya (2021)	Randomized-Controlled Trial	44 total 33 exercise group 11 control group	Exercise group: M = 21.1 (SD = 1.1) Control group: M = 21.4 (SD = 0.5)	Exercise group: 9 (27.3 %) female Control group: 5 (45.5 %) female	NR	NR	Accuracy - Performance	Heartbeat tracking task	This preliminary study showed the improvement of objective interoceptive accuracy by persistent aerobic exercise at a level that might potentially increase cognitive function. Although we failed to effectively demonstrate the link between the changes induced by exercise in both interoception and cognitive function, our findings supported the hypothesis that exercise-induced improvement of interoception facilitated improved maintenance of an exercise routine as a result of improved cognitive function.	4 (Moderate)
95	Herbert (2007)	Quasi-Experimental	34	26.4 (SD = 6.8)	15 male 19 female	NR	Laboratory	Accuracy - Performance	Heartbeat tracking task	The present study extends the earlier findings of Pennebaker and Lightner (1980) in demonstrating that the feedback of internal bodily signals affects the self-control of physical load. It was hypothesized that good heartbeat perceivers, showing greater interoceptive sensitivity for cardiac visceral signals, would exert less physical effort and demonstrate a more finely tuned self-control of physical, cardiovascular load during physical exercise than poor heartbeat perceivers.	5 (Moderate)
96	Kosa (2021)	Quasi-Experimental	98	M = 20.8 (SD = 1.82)	51 female	NR	Laboratory	Accuracy - Performance	Heartbeat tracking task	In a laboratory experiment with the participation of 98	4 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										young individuals characterized by regular physical activity, there was no difference between body focused and externally focused attention in terms of performance on a bicycle ergometer (pedal turns), physical exertion (heartrate), and perceived fatigue. Objective interoceptive accuracy was also not associated with physical exertion, physical performance, and perceived fatigue.	
97	Koteles (2020)	Quasi-Experimental	47	M = 21.4 (SD = 1.62)	57.8 % female	NR	Laboratory	Accuracy - Performance Accuracy - Beliefs	Heartbeat tracking task, with confidence ratings	Perception of heartbeats at rest and reproduction of heart rate under physical load are associated only for very low exercise intensity. No sex differences in perception and reproduction performance were found; however, individuals are prone to underestimate their actual physical load. Actual and perceived performance was moderately related to each other at rest, and were not associated under physical load.	3 (Low)
98	Machado (2019)	Quasi-Experimental	15 poor heartbeat perceivers 17 good heartbeat perceivers	Poor heartbeat perceivers: M = 25.1 (CI = 22.7–27.4) Good heartbeat perceivers: M = 22.9 (CI = 21.3–24.6)	Male	NR	Laboratory	Accuracy - Performance	Heartbeat tracking task	Results did not support the research hypothesis given that individuals with high and low objective interoceptive accuracy did not differ in any perceptual or physiological measure in submaximal (i.e., HRVTH) and maximal exercise intensities. Interestingly, individuals with high objective interoceptive accuracy presented	4 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										lower resting heart rate, longer interbeat intervals, and lower diastolic and mean blood pressure.	
81	Teng (2018)	Randomized-Controlled Trial	90 total 45 intervention group 45 control group	Total: M = 52 (SD = 12.98) Intervention: M = 51.64 (SD = 10.48) Control: M = 51.91 (SD = 15.20)	Intervention: 38 (84.4 %) male, 7 (15.6 %) female Control: 34 (75.6 %) male, 11 (24.4 %) female	NR	Clinic or hospital	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	The findings of this randomized, controlled study indicate that a 12-week walking with breating intervention effectively improved tolerance to physical activity and oxygen saturation in patients with heart failure. The findings also reveal that as patients began to trust their self-reported interoceptive attention, their anxiety and QoL were improved.	7 (High)
64	Wallman-Jones (2023)	Observational	70	M = 21.67 (SD = 2.5)	33 (47.1 %) female	NR	Laboratory	Accuracy - Performance Accuracy - Beliefs Attention - Beliefs Awareness	Heartbeat tracking task, with confidence ratings State Mindfulness Scale questionnaire	Our results showed that momentary physical activity was associated with an increase in self-reported interoceptive attention, while in contrast, sedentary behavior was associated with a decrease. Exploratory interactions revealed that baseline objective interoceptive accuracy influenced relationships with physical activity, where model-based predictions revealed low and medium baseline objective interoceptive accuracy (IAcc) scores to be associated with increases in self-reported interoceptive attention, contrasted to observed decreases with high IAcc. Activity type also mattered, whereby in comparison to screen-time behavior, partaking in exercise was associated with a higher increase in self-reported	6 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										interoceptive attention than daily life physical activities. Similarly, non-screen time behavior was associated with higher self-reported interoceptive attention than screen-time behavior, with an even greater difference found for non-screen-based social interactions.	
104	Wallman-Jones (2022)	Quasi-Experimental	48	M = 25.98 (SD = 4.78)	50 % female	NR	Laboratory	Accuracy - Performance Accuracy - Beliefs Attention - Beliefs	Heartbeat tracking task, with confidence ratings Body Awareness Questionnaire	We found that objective interoceptive accuracy was significantly higher after physical activity compared to the rest conditions, however, there was no main effect for the focus of attention manipulation, and no interaction between physical activity and focus of attention. In addition, differential analyses found a significant interaction between physical activity and sporting background (i.e., students majoring in sport vs non-sport focused courses), where individuals with a lower sporting background appeared to benefit the most from the physical activity manipulation. We did not, however, find significant influences of physical fitness (VO2peak), gender, perceived chronic stress, or baseline objective interoceptive accuracy and self-reported interoceptive attention.	6 (Moderate)
E. Smoking											
34	Avery (2017)	Observational	17	M = 33 (SD = 9; range = 22–51)	9 female 8 male	NR	NR	Accuracy - Performance	Functional MRI with interoceptive attention task	During nicotine abstinence, smokers exhibited decreased hemodynamic activity	2 (Low)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										during interoceptive attention to visceral signals within a network of regions involved in viscerosensation, arousal, and reward, including the bilateral orbitofrontal cortex, amygdala, and the mid-insula.	
38	de la Fuente (2019)	Observational	72 total 25 healthy controls 25 smoked cocaine dependent participants 22 clorhidrate cocaine dependent participants	Control: M = 19.60 (SD = 2.62) SCD: M = 20.04 (SD = 2.28) CCD: M = 20.64 (SD = 2.96)	Control: 22 male, 3 female SCD: 23 male, 2 female CCD: 21 male, 1 female	NR	NR	Accuracy - Performance	Heartbeat tracking task	We report multimodal neurocognitive evidence of enhanced objective interoceptive accuracy in addiction, showing that smoked cocaine dependent subjects present boosts in relevant psychophysiological measures (heartbeat detection and heartbeat evoked potential), accompanied by structural and functional connectivity tuning of interoceptive networks. At the theoretical level, our results support the view that addictive behavior involves hyper interoceptive processing.	3 (Low)
43	Hina (2019)	Observational	49 smokers 51 non-smokers	Total: M = 25.67 (SD = 8.71; range = 19–68) Smokers: M = 25.9 (SD = 1.15) Non-smokers: M = 25.3 (SD = 1.31)	Smokers: 21 male, 28 female Non-smokers: 19 male, 32 female	NR	NR	Accuracy - Performance Attention - Beliefs	Heartbeat tracking and discrimination tasks Multidimensional Assessment of Interoceptive Awareness questionnaire	We found that the objective interoceptive accuracy of participants in the 'non-smokers' group performed significantly better on the heartbeat tracking task than participants in the 'smoker' group. However, no significant differences between groups were observed for the heartbeat discrimination task, or the MAIA measures of self-reported interoceptive attention. Meanwhile, within the 'smoker' group, neither objective interoceptive	3 (Low)

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ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										accuracy or self-reported interoceptive attention, were associated with nicotine-addiction severity.	
77	Price (2019b)	Randomized-Controlled Trial	187 total 74 intervention 46 treatment as usual + active control 67 treatment as usual	Total: Mdn = 35 (range = 20–61) Intervention: Mdn = 35 (range = 22–61) Treatment as usual + active control: Mdn = 36 (range = 20–59) Treatment as usual: Mdn = 35 (range = 22–57)	Female	Race: 75 % White 10 % mixed race 5 % African American 4 % Native American 1 % Asian Ethnicity: 8 % Hispanic	Clinic or hospital	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	Results highlight the significant longitudinal reduction in days abstinent from substance use for women enrolled in intervention (MABT) + treatment as usual (TAU) compared to TAU at 6 and 12 month follow-up. Treatment as usual plus active control (WHE) + TAU also showed a significant increase in abstinent days compared to TAU at 6 months, suggesting that time and attention played an important role for abstinence during substance use disorder (SUD) treatment. However, the longer-term effect at 12 months for MABT, once SUD treatment supports were no longer in place, emphasizes the positive effect of self-reported interoceptive attention training to reduce risk of relapse to substance use.	9 (High)
78	Price (2019c)	Randomized-Controlled Trial	217 total 74 intervention 46 active control 67 treatment as usual	Total: Mdn = 35 (range = 20–61) Intervention: Mdn = 35 (range = 22–61) Active control: Mdn = 36 (range = 20–59) Treatment as usual: Mdn = 35 (range = 22–57)	Female	75 % White 10 % mixed race 5 % African American 5 % other 4 % Native American 1 % Asian	Clinic or hospital	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	The study pre-post findings demonstrate that self-reported interoceptive attention was significantly improved for participants in intervention (MABT) when delivered as an adjunct to women's substance use disorder treatment. The significant changes for MABT compared with active control and treatment as usual on the majority of MAIA scales	9 (High)

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ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
										indicates that the processes for learning interoceptive skills through MABT were highly effective for this population.	
F. Sleep											
32	Arora (2021)	Observational	609	Mdn = 21 (range = 19–22)	61 (10 %) male 548 (90 %) female	541 (88.83 %) Emirati 46 (7.55 %) Gulf/MENA (non-UAE) 13 (2.13 %) Asian 7 (1.15 %) Caucasian 2 (0.33 %) other	Online survey	Attention - Beliefs	Multidimensional Assessment of Interoceptive Awareness questionnaire	We observed consistent, significant correlations between various sleep parameters and four features of self-reported interoceptive attention, namely: 'Noticing', 'Non-Distracting', 'Emotional Awareness' and 'Trusting'. Our regression analyses confirmed small but statistically significant associations between the latter three interoceptive measures.	5 (Moderate)
36	Billeci (2021)	Observational	39	23 (SD = 2.24)	26 female	NR	Home	Accuracy - Performance Attention - Beliefs	Heartbeat evoked potential Multidimensional Assessment of Interoceptive Awareness questionnaire	This is the first report of association between heartbeat evoked potential (HEP) amplitude during sleep and self-reported interoceptive attention, which had been already observed during wakefulness in resting and task conditions. Their association during sleep (when attention is not focused on heartbeats, and vigilance is reduced) suggests that self-reported interoceptive attention co-operates with objective interoceptive accuracy to the HEP amplitude.	4 (Moderate)
39	Ewing (2017)	Observational	180 total 42 healthy controls 138 participants with mental health diagnoses	Healthy controls: M = 28.19 (SD = 9.8) Major depression: M = 34.27 (SD = 14.25) Anxiety: M = 24.88 (SD =	Healthy controls: 8 (19 %) male, 34 (81 %) female Major depression: 13 (29.5 %) male, 30 (68.2 %) female, 1 (2.3 %)	NR	NR	Accuracy - Performance Accuracy - Beliefs Attention - Beliefs Awareness	Heartbeat tracking and discrimination tasks, with confidence ratings Porges Body Perception Questionnaire	Poor sleep quality, including perceptions about both sleep difficulties and sleep effectiveness, appears to adversely affect objective interoceptive accuracy, while (falsely)	4 (Moderate)

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Table 2 (*continued*)

ID	Author (Year)	Study design	Participants	Age	Sex	Ethnicity	Setting	Interoception (domain - measure)	Name of interoceptive measure	Main findings	Quality score (grade)
				8.54) Mixed: M = 34.50 (SD = 14.84)	other Anxiety: 4 (16.7 %) male, 20 (83.3 %) female Mixed: 3 (16.7 %) male, 15 (83.3 %) female					increasing self-reported interoceptive accuracy, for participants with depression, anxiety and mixed anxiety and depressive disorder. Healthy control participants with greater sleep difficulties showed enhanced objective interoceptive accuracy during the heartbeat discrimination task. Reduced self-reported interoceptive attention was related to greater sleeping difficulties.	
62	Vabba (2023)	Observational	245	M = 30.68 (SD = 9.68, range = 19–62)	119 male	NR	Online survey	Accuracy - Performance Attention - Beliefs	Heartbeat tracking task Multidimensional Assessment of Interoceptive Awareness questionnaire and Porges Body Perception Questionnaire	Self-reported interoceptive attention domains, such as a greater capacity to self-regulate using bodily cues, not-distracting oneself from body cues, not worrying excessively about them, and trusting the body as a safe place, appeared to be consistently linked to greater subjective well-being (lower depression, anxiety, and sleep disturbance) both during and after the national lockdown. Objective interoceptive accuracy was not related to depression, anxiety, and sleep disturbance.	5 (Moderate)

2022; Ewing et al., 2017; Fazia et al., 2021; Floyd et al., 2022; Haase et al., 2015; Hanley et al., 2017; Hina and Aspell, 2019; Iatridi et al., 2021; Jakubczyk et al., 2019; Leganes-Fonteneau et al., 2019; Loucks et al., 2021; Lovan et al., 2022; Mailloux et al., 2014; Oswald et al., 2017; Price et al., 2019a–c; Roberts et al., 2021; Robinson et al., 2021; Shen et al., 2023; Stevenson et al., 2023; Teng et al., 2018; Thomas et al., 2019; Tylka, 2006; Vabba et al., 2023; van Strien, 2000; Wallman-Jones et al., 2022, 2023). Six studies quantified interoceptive awareness (i.e., the interaction between interoceptive accuracy and attention) (Ewing et al., 2017; Iatridi et al., 2021; Wallman-Jones et al., 2023; de Lima-Araujo et al., 2022; Leganes-Fonteneau et al., 2022, 2019). In terms of lifestyle factors, 26 studies on cognitive leisure and relaxation activities, 19 studies on eating behavior, 12 studies focused on alcohol consumption, 10 studies on exercise, five studies on smoking, and four studies on sleep were identified. Some studies included more than one interoceptive domain, interoceptive measure, or lifestyle factor and were therefore analyzed in multiple categories.

Studies assessing objective interoceptive accuracy mainly used cardiac measures (n = 41), such as heartbeat tracking and discrimination tasks (see Fig. 3 and Table 2). Respiratory measures were used in 5 studies and gastrointestinal measures in 3 studies. One study measured multiple modalities in determining objective interoceptive accuracy. Most self-reported interoceptive accuracy measures came from confidence ratings (n = 15), with the other three studies focusing on blood glucose levels, heartrate, or using a questionnaire to assess interoceptive accuracy. The majority of self-reported interoceptive attention measures used the Multidimensional Assessment of Interoceptive Awareness (MAIA) questionnaire (n = 24). Other studies used questionnaires focusing on the gastrointestinal modality (i.e., interoception subscales of eating behavior questionnaires; n = 4) or more general interoceptive questionnaires (n = 10). Quality scores ranged from two to nine, with a mean quality score of 5.5. We identified 17 studies with high, 42 studies with moderate, and 14 studies with low methodological quality.

3.1. *Cognitive leisure and relaxation activities (Bornemann et al., 2015; Chen et al., 2021; D'Antoni et al., 2022; Daubenmier et al., 2013; de Lima-Araujo et al., 2022; Eusebio et al., 2022; Fairclough and Goodwin, 2007; Farb et al., 2013; Fazia et al., 2021; Fischer et al., 2017; Floyd et al., 2022; Haase et al., 2015, 2016; Hanley et al., 2017; Khalsa et al., 2008, 2019; Kiken et al., 2018; Loucks et al., 2021; Melloni et al., 2013; Parkin et al., 2014; Price et al., 2019a; Roberts et al., 2021; Schillings et al., 2021; Shen et al., 2023; Thomas et al., 2019; Wu et al., 2021)*

The cognitive leisure and relaxation activities identified in this review were mindfulness, Tai-Chi, yoga, and meditation activities. Strong evidence suggests mindfulness skills and training positively relates to self-reported interoceptive attention. Additionally, moderate evidence was found for the positive relation between mindfulness and objective interoceptive accuracy. There was limited evidence on the positive effect of Tai-Chi practices on self-reported interoceptive attention. Several studies indicated there were no effects of meditation techniques or no differences between meditators and non-meditators in both objective and self-reported accuracy, showing moderate and limited levels of evidence, respectively. Conflicting results were found for the relationship between meditation practices and self-reported interoceptive attention. Both movement- and interoception-focused yoga programs were found to positively relate to self-reported interoceptive attention. Quality scores of the studies within this lifestyle factor ranged from three to eight, with an average of 6.0.

3.2. *Eating behavior (Avery et al., 2017b; Herbert et al., 2013, 2012; Herbert and Pollatos, 2014; Iatridi et al., 2021; Lovan et al., 2022; Mailloux et al., 2014; Nishimura et al., 2020; Oswald et al., 2017; Robinson et al., 2021; Stevenson et al., 2023; Tylka, 2006; van Strien, 2000; Palazzo et al., 2022; Young et al., 2019; Flasbeck et al., 2021; Palascha et al., 2021; Rominger et al., 2021; Schulz et al., 2015)*

Strong positive relations between eating behavior (i.e., intuitive eating and eating behaviors that allow for better tracking of energy needs), objective interoceptive accuracy, and self-reported interoceptive attention were observed. The relation between eating behavior and self-reported interoceptive accuracy was positive, but with limited evidence. A moderate level of evidence was found for the association that fasting increases objective interoceptive accuracy. Additionally, two studies reported that mindfulness-based eating interventions have a positive effect on objective interoceptive accuracy. These studies combined had a limited level of evidence. Eating behavior quality scores averaged 4.1, ranging from two to eight.

3.3. *Alcohol consumption (Abrams et al., 2018; Ates Col et al., 2016; Betka et al., 2018; Jakubczyk et al., 2019; Leganes-Fonteneau et al., 2019, 2022; Meric and Sonmez, 2022; Price et al., 2019b,c; Schmidt et al., 2013; Sönmez et al., 2017; Sübay and Sönmez, 2021)*

Moderate evidence was found on the negative relation between alcohol consumption and objective interoceptive accuracy: most of the studies showed that objective interoceptive accuracy is impaired in individuals suffering from alcohol use disorders, or that the use of alcohol decreases objective interoceptive accuracy scores in healthy individuals. Similar evidence was found for the negative effect of alcohol on self-reported interoceptive accuracy.

Additionally, two studies showed that interoceptive training helps in improving self-reported interoceptive attention, abstinence of substance use, and reducing risk of relapse in substance use disorders (e.g., alcohol, smoking, and other substances), providing a moderate level of evidence. The quality score of alcohol consumption studies had a mean of 6.3 and a range of three to nine.

3.4. *Exercise (Wallman-Jones et al., 2023, 2022; Abrams et al., 2018; Almarcha et al., 2022; Amaya et al., 2021; Teng et al., 2018; Herbert et al., 2007; Kosa et al., 2021; Koteles et al., 2020; Machado et al., 2019)*

Based on four studies, a moderate level of evidence was found for the positive relation between exercise and self-reported interoceptive attention. Similarly, based on three studies, a moderate level of evidence indicated a positive relation between exercise and self-reported interoceptive accuracy. A moderate level of evidence was found on the positive relation between exercise and objective interoceptive accuracy: five studies showed a positive relation between exercise and objective interoceptive accuracy, however three studies reported there was no relation between the two. Also, one study mentioned that there was no relation between self-reported interoceptive accuracy and exercise. The majority of studies in this section investigated the effect of acute exercise protocols on interoceptive accuracy and attention. The mean quality score for studies on interoception and exercise was 5.4, with a range from three to nine.

3.5. *Smoking (Avery et al., 2017a; de la Fuente et al., 2019; Hina and Aspell, 2019; Price et al., 2019b, 2019c)*

Results on the relation between smoking behavior, objective interoceptive accuracy, and self-reported interoceptive attention were inconclusive due to low-quality studies and varying findings. In substance use disorders (e.g., smoking, alcohol, and other substances), interoceptive training can improve self-reported interoceptive attention and abstinence of substance use, while reducing risk of relapse. The

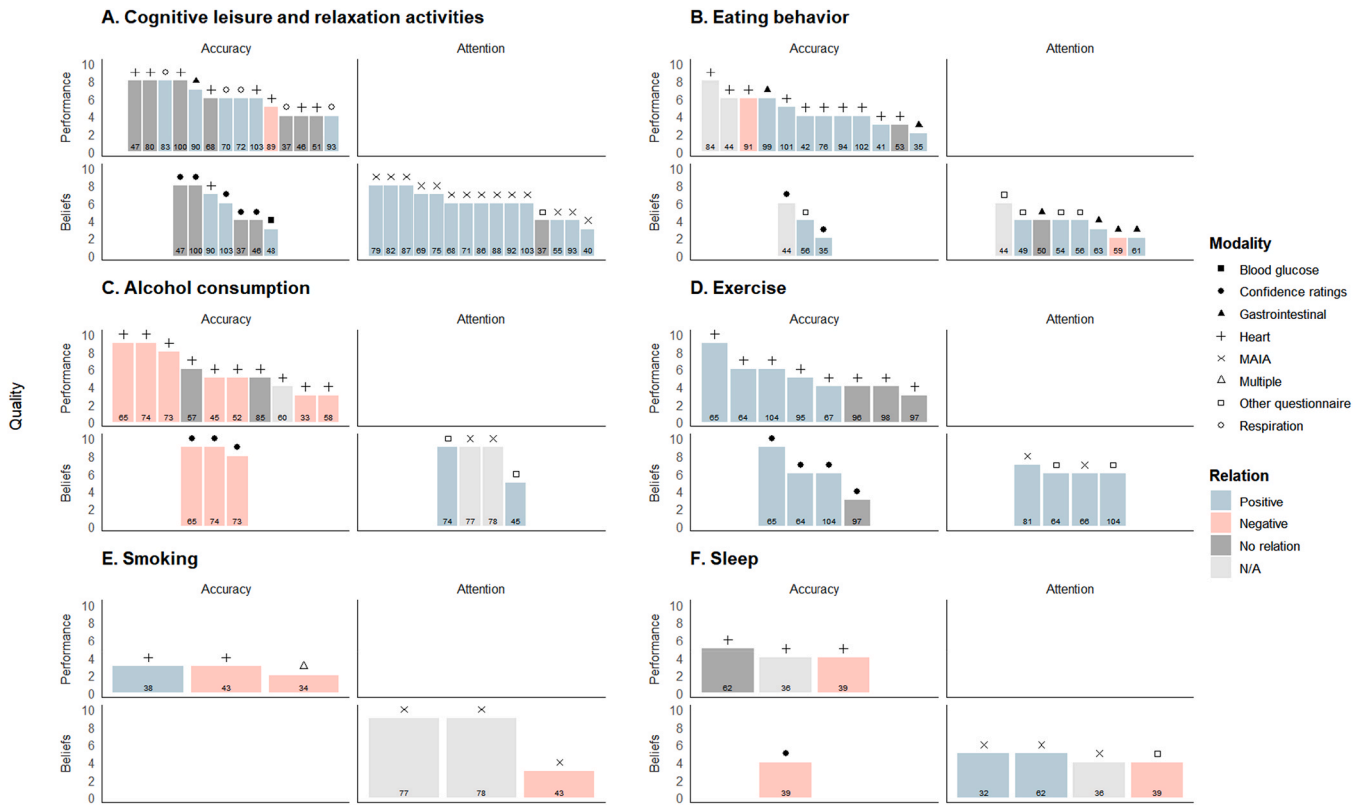

Fig. 3. Harvest plots per lifestyle factor (A-F), based on the 2 × 2 factorial model for interoception. Each bar represents a single study, with reference numbers within the bar. The height of each bar represents the assigned quality score (0–10), the color of each bar the direction of the relation between the lifestyle factor and interoceptive domain, and the symbol above the bar the modality that was measured (MAIA = Multidimensional Assessment of Interoceptive Awareness; Multiple = multiple modalities measured). Note: some studies measured both interoceptive accuracy and attention, and/or multiple lifestyle factors (e.g., eating behavior and exercise). These articles are therefore represented in multiple lifestyle factors, and/or plots.

quality score from studies in this section averaged 5.2, with a range of two to nine.

3.6. Sleep (Arora et al., 2021; Billeci et al., 2021; Ewing et al., 2017; Vabba et al., 2023)

Limited evidence shows that there is a positive relation between sleep quality and self-reported interoceptive attention. Conversely, the relation between sleep and objective interoceptive accuracy was found to be negative. More sleep difficulties were reported to be related to enhanced interoceptive accuracy scores. The mean quality score for the four studies in the interoception and sleep section was 4.5 and ranged from four to five.

4. Discussion

4.1. General overview

The aim of the current systematic review was to provide insight into the current state of evidence about the role of several interoceptive domains in lifestyle factors (i.e., alcohol consumption, cognitive leisure and relaxation activities, eating behavior, exercise, sleep, or smoking). Most of the 73 included studies investigated cognitive leisure and relaxation activities or eating behavior, while fewer studies focused on the role of interoceptive accuracy and attention in alcohol consumption, exercise, smoking, or sleep. More articles focused on interoceptive accuracy (i.e., an individual's ability to perceive interoceptive signals accurately) than interoceptive attention (i.e., the degree to which interoceptive signals are objects of attention). The instances of objective performance measures and self-reported beliefs were equally distributed. However, while several studies measured both objective performance and self-reported beliefs, only six studies quantified interoceptive awareness.

In general, findings in this review show positive relations between interoceptive accuracy and attention, and the lifestyle factors cognitive leisure and relaxation activities, eating behavior, and exercise. Conversely, the consumption of alcohol is negatively related to those interoceptive domain. Studies in the smoking and sleep lifestyle factors were sparse and of varying methodological quality, making it difficult to determine a clear direction of the relationship of these factors with interoception. The varying findings may suggest a non-linear relation between interoception and lifestyle factors. In studies focusing on alexithymia and anxiety, adaptive (i.e., balanced awareness of bodily signals and being attuned to internal sensations is beneficial for guiding health-promoting behaviors) and maladaptive (i.e., excessive focus on or misinterpretation of bodily signals leads to negative health outcomes) forms of interoception have been mentioned (Aaron et al., 2020; Trevisan et al., 2023). The findings of these studies show the complex nature of interoception, arguing that a moderate level of interoception may be optimal. Studies in the cognitive leisure and relaxation activities category were mostly experimental in design, suggesting a causal relationship with interoceptive accuracy and attention. In other lifestyle factors study designs were either equally distributed between observational and experimental designs or skewed towards observational designs. Notably, no studies were identified that investigated objective interoceptive attention, suggesting that no methods to measure this domain are available, or the available methods are not deemed reliable, valid, or feasible. Most studies were of moderate or high methodological quality. Below we will discuss the findings for each lifestyle factor in more detail.

4.2. Cognitive leisure and relaxation activities

Most studies in this review focusing on cognitive leisure and relaxation activities included an element of mindfulness. Mindfulness is a psychological concept with emphasis on present moment awareness, focus on purpose, and non-judgmental thinking (Kabat-Zinn, 2003). Mindfulness-based interventions encourage individuals to consciously focus on bodily sensations without judgement, and with openness, curiosity, and self-compassion (Weng et al., 2021). In the current review, as well as in previous reviews (Weng et al., 2021; Britton, 2019), the main finding in terms of mindfulness is that these practices improve interoceptive accuracy and attention. Emotional-motivational states are strengthened through mindfulness training, and mindfulness practice helps in the development of interoceptive brain regions (Bornemann et al., 2015; D'Antoni et al., 2022; de Lima-Araujo et al., 2022; Fazia et al., 2021; Fischer et al., 2017; Hanley et al., 2017; Kiken et al., 2018; Loucks et al., 2021; Thomas et al., 2019). Additionally, these mindfulness interventions have been shown to promote functional connectivity, resulting in greater anterior insula activation (Farb et al., 2013; Haase et al., 2016, 2015; Roberts et al., 2021). Tai-chi and yoga, types of mindfulness practices that combine physical movement with mental focus, show that combining a focus on the mind with physical movement can enhance the regulative ability of interoception and awareness of internal stimuli (Eusebio et al., 2022; Schillings et al., 2021; Chen et al., 2021; Shen et al., 2023). Conversely, meditation, which differs from mindfulness training in that it is more focused on mental and emotional calmness, does not seem to be related to interoception. Several studies identified in this review indicate no difference between meditators and nonmeditators in terms of interoceptive accuracy (Daubenmier et al., 2013; Khalsa et al., 2008, 2019; Melloni et al., 2013; Parkin et al., 2014). One of the explanations for these findings can be found in the heartbeat tracking or discrimination tasks used to assess interoceptive accuracy (see Fig. 3 and Table 2), possibly presenting results from a unidimensional point of view in terms of modalities. Training in meditation traditions is commonly focused on breathing, which might not translate to other bodily sensations such as heartrate (Khalsa et al., 2008, 2019). These findings are not in line with other narrative and systematic reviews on mediation and interoception, where increases in size and activation of the insular cortex have been observed in meditators but not in nonmeditators (Britton, 2019; Boccia et al., 2015). In general, mindfulness and practices related to mindfulness seem beneficial in the development of interoceptive abilities.

4.3. Eating behavior

The results of the current review indicate a positive relationship between interoceptive domains and intuitive eating. Intuitive eating uses hunger and satiety cues to guide eating behavior, as opposed to emotions (Herbert et al., 2013). These findings replicate results from other reviews that show the association of interoception with awareness of hunger and satiety cues, which is used to regulate food intake (Cadena-Schlam and Lopez-Guimera, 2014; van Strien, 2018). After eating, there is an increase in sensitivity to visceral-afferent signals, which signals fullness via hormonal and neural pathways (Flasbeck et al., 2021). Even when emotional eaters are able to perceive bodily signals as well as intuitive eaters, it seems emotional eaters respond less positively to these signals or they are not used as much in decision-making processes related to eating behavior (Oswald et al., 2017; Robinson et al., 2021). For example, in healthy weight individuals hunger is perceived as a physiological desire for energy, while in obese individuals hunger is perceived as the absence of reward (Avery et al., 2017b). Additionally, the relation between interoception and eating behavior may be bidirectional. Interoception plays a key role in guiding eating behavior through hunger and satiety signals, while eating behaviors can also modify interoceptive processes. For example, dysfunctions in interoception can lead to eating disorders, while those same eating disorders can alter accuracy and attention towards interoceptive signals (Herbert and Pollatos, 2019). The connection between interoception and eating behavior is in the insular cortex, which plays a vital role in detecting energy needs (Simmons and DeVille, 2017). Several studies have indicated activation of brain structures that are relevant for interoception during periods of fasting, showing the relationship between hunger and interoception is found in these areas of the brain (Herbert et al., 2012; Rominger et al., 2021; Schulz et al., 2015). Interestingly, one study showed that individuals with lower interoceptive abilities were more likely to overeat, but also that overweight individuals with high interoception scores were more prone to overeat and make unhealthy food choices (Nishimura et al., 2020). This multidimensionality and individual nature of hunger cues (Stevenson et al., 2023), combined with the effect specific diets can have on sensitivity to interoceptive hunger and satiety cues (Davidson and Stevenson, 2022), shows the need for individualized eating interventions which include interoceptive aspects. It must be emphasized that most studies in this section used a heartbeat focused measure to assess objective interoceptive accuracy. One could raise the question as to whether this is an appropriate choice for research focusing on eating behavior, or whether researchers should consider more directly related modalities such as gastrointestinal measures of interoception.

4.4. Alcohol consumption

In line with previous reviews (Lovelock et al., 2021; Wisniewski et al., 2021), the current review found that the consumption of alcohol impairs interoceptive accuracy. Alcohol has a negative effect on the functioning of the insular cortex (Abrams et al., 2018; Ates Col et al., 2016; Meric and Sonmez, 2022; Schmidt et al., 2013; Sübay and Sönmez, 2021; Wisniewski et al., 2021), a region of the brain that is important in the processing of interoceptive signals. This may also indicate a bidirectional relationship, where the use of alcohol harms brain structures involved in interoception, and disrupted interoception results in increased use of alcohol (Wisniewski et al., 2021). The insular cortex plays a key role in the latter, since it is involved in decision-making processes. These processes rely on emotional signals from the body, signals that individuals with substance use disorders are less likely to monitor effectively. Damage to the insular cortex, for example caused by alcohol consumption, can result in impaired interoceptive accuracy (Verdejo-Garcia et al., 2012). Subsequently, non-emotional sources (such as habits) are used to manage decision-making processes, leading to the making of more disadvantageous choices (Ates Col et al., 2016; Meric and Sonmez, 2022; Schmidt et al., 2013; Sübay and Sönmez, 2021). Interestingly, while interoceptive accuracy is impaired by the use of alcohol, some studies found that interoceptive attention increases (Jakubczyk et al., 2019; Leganes-Fonteneau et al., 2019). The increase in interoceptive attention may be a compensatory strategy for poor interoceptive accuracy. Previous and current findings indicate the acute and long-term negative influence of alcohol use on brain structures involved in interoception, while better interoceptive skills may prevent alcohol abuse. However, comparable to the previous section on eating behavior, measures of objective interoceptive accuracy on alcohol consumption solely relied on heartbeat tests. Alcohol consumption not only affects the heart (Georgescu et al., 2024; Piano, 2017), but also the gastrointestinal (Bode and Bode, 2003; Bujanda, 2000) and respiratory systems (Simet and Sisson, 2015), suggesting research on these modalities in the context of interoception and alcohol consumption is also necessary.

4.5. Exercise

Our results indicate that acute exercise has a positive influence on self-reported interoceptive attention. One possibility for the increase in interoceptive attention during exercise, is that increased arousal narrows attentional resources on physiological signals (Wallman-Jones

et al., 2023, 2022). Predictive coding models say that predictions are compared against afferent information to produce error signals, which are then used for interpretation of incoming stimuli and ensuring the correct behavioral responses (Wallman-Jones et al., 2021). The utilization of attentional resources can be trained through exercise interventions focusing on interoception, resulting in increases in exercise tolerance, self-control, and confidence and trust in physical abilities (Almarcha et al., 2022; Teng et al., 2018). On the other hand, results regarding interoceptive accuracy identified in the current review were conflicting. Studies indicating better interoceptive accuracy during acute exercise show an increase in anterior cruciate cortex and insular cortex activity (Abrams et al., 2018; Amaya et al., 2021), which is in line with a review article that additionally mentions an increase in neurochemical activity during exercise to explain the role of interoception in exercise (Wallman-Jones et al., 2021). This latter article also suggests a feedback loop where increased interoceptive signals improve alignment between perceived fatigue and the actual physiological state, allowing for better regulation of exertion. This feedback loop suggests a possible bidirectional relationship between interoceptive signals and exercise: participation in exercise improves accuracy of interoceptive signals, while better perception of interoceptive signals allows for improved regulation of exercise exertion (Wallman-Jones et al., 2021). Additionally, exercise background or experience influences baseline interoceptive accuracy (Wallman-Jones et al., 2022), allowing for more finely tuned self-regulation of physical needs during exercise (Herbert et al., 2007). Conversely, two studies indicate that interoceptive accuracy does not influence physical performance (Kosa et al., 2021; Machado et al., 2019), while another study adds that interoceptive accuracy at rest is only transferable to very low physical loads (Koteles et al., 2020). This latter study explains that this might be the case because of higher internal noise (e.g., increased overall arousal, faster breathing, or rhythmic movements) during exercise. Also, physical, physiological, and interoceptive responses to exercise might be influenced by the intensity of the exercise, whether the exercise is dynamic or static, and the design of the exercise (Machado et al., 2019). Interestingly, only one article investigated the longitudinal effects of exercise on interoception, where most studies focused on the effect of acute exercise on interoceptive abilities. This longitudinal study found that self-reported interoceptive attention only increased after two to three months of moderate intensity, indicating that repeated exposure to exercise may be necessary for exercise to influence interoceptive abilities (Amaya et al., 2021). Finally, the studies in this section focused on cardiovascular exercise protocols and heartrate related measures of interoception, thus we cannot say anything about the relation between several interoceptive domains and other forms of exercise (e.g., resistance training), or whether these findings may be different when other modalities (e.g., respiratory or gastrointestinal) are considered.

4.6. Smoking

Few studies on the relation between smoking, interoceptive accuracy, and interoceptive attention were found, indicating a lack of research on this relation. The only study investigating differences between smokers and non-smokers showed that non-smokers performed better on an interoceptive accuracy task, while there were no differences in interoceptive attention (Hina and Aspell, 2019). It was argued that specific brain areas involved with interoceptive accuracy are affected by cigarette smoking, while areas associated with subjective interpretation of bodily signals remain intact. Another study adds to this by showing that insula activity is decreased in cigarette smokers during nicotine withdrawal, along with changes in physiological and behavioral interoceptive measures (Avery et al., 2017a). Interestingly, while the use of cigarettes mainly affects the respiratory system, none of the studies in this section use respiratory interoceptive measures. Comparable to the line of reasoning in the alcohol consumption section, complex decision-making processes are reliant upon bodily signals, which are processed in the ventromedial prefrontal cortex, insula, and amygdala. Structural and functional damage to these regions may cause substance addicts to be less sensitive to internal signals about negative consequences of drug use, increasing engagement in risky behaviors (Verdejo-Garcia et al., 2012). This may indicate a bidirectional relation between interoception and smoking, comparable to the one argued in the alcohol consumption section. However, mindfulness based interventions may be an effective tool to improve interoceptive abilities and lessen the severity of substance use disorders (including alcohol use and cigarette smoking) (Price et al., 2019b, 2019c). Unlike the studies on cigarette smoking in this review, research in individuals using smoked or crack cocaine seems to indicate an increase in interoceptive processing as a result of drug use, but this may be dependent on the type of drug or the way the drug is administered (de la Fuente et al., 2019). While the use of cigarettes seems to negatively impact interoceptive accuracy and attention, research on the relation between smoking and interoception should be expanded to draw conclusions.

4.7. Sleep

While the current findings on the interaction between interoceptive domains and sleep did not allow for strong conclusions, the identified studies may shed light on the way the body reacts to poor sleep quality and stressful situations. One study found that during the COVID-19 lockdown, greater interoceptive attention was linked to greater subjective well-being (including sleep quality) (Vabba et al., 2023). This study also notes that individual differences in interoception are associated with physiological health, through heart rate variability (HRV). HRV is not only linked to interoception but is also a biomarker of stress and can be an indicator of resilience under stressful situations (Vabba et al., 2023). This indicates the crucial relation between interoception, stress, and general well-being (including sleep quality). Impairments in interoceptive attention may alter psychological and neurological factors, which leads to changes in mood and sleep quality (Arora et al., 2021). Conversely, interoceptive accuracy was found to be increased in individuals with greater sleep difficulties (Ewing et al., 2017). One explanation for the finding that poor sleep quality relates to decreased interoceptive attention and increased interoceptive accuracy may be because interoception during sleep is related to the heartbeat evoked cortical potential representing cognitive information processing (Billeci et al., 2021). Research on sleep deprivation has shown sleep-deprived individuals are able to accurately assess cognitive task performance (Baranski, 2007), and sleep-deprived doctors are able to monitor work performance successfully (Lewis et al., 2002). It may be possible that when sleep quality is impaired, interoceptive pathways ensure a functional level of cognitive ability (i.e., a survival mechanism). It could be that good sleep quality improves one's ability to perceive internal signals, and increased interoceptive abilities allow for better sleep quality, suggesting a bidirectional relationship.

4.8. Strengths and limitations

To the best of our knowledge, this is the first review to provide a comprehensive overview of the relation between several interoceptive domains and various lifestyle factors. The overarching view of this review is a strength, as it makes it possible to cross-compare the role of interoceptive accuracy and attention between different lifestyle factors. This allows for the identification of lifestyle factors where the role of interoception has been investigated most extensively, as opposed to those lifestyle factors where there is a lack of research. Additionally, by synthesizing findings per lifestyle factor, generalizable conclusions can be made to support evidence-based decision-making processes in a clear and structured manner.

We used the 2 × 2 factorial structure for interoception to synthesize results found in the included studies. The model constantly asks two questions which are easy to answer ("what was measured?" and "how

was this measured?"), and thus ensures quality of subdivision of studies and creates a complete picture of interoception. This model extends the interoceptive model by Garfinkel, which involves three primary components: 1) interoceptive accuracy is the objective measurement of the accuracy of perceiving internal bodily signals, 2) interoceptive sensibility refers to the subjective measurement of sensitivity to internal states, and 3) interoceptive awareness is the metacognitive dimension entailing insight into interoceptive abilities (Garfinkel et al., 2015). Comparison of both models shows that the type of measurement is embedded into the definitions in the model by Garfinkel, whereas the 2 × 2 model separates the interoceptive domains and the way in which the domain was measured. By making the distinction between the domain of interest and the way in which this domain was measured, the 2 × 2 model allows for greater precision in determining patterns in interoception (Murphy et al., 2019). Some concerns about inconsistencies in definitions and measurements across studies, the influence of factors such as emotional awareness and general body awareness on self-report measures of interoception, and interoceptive questionnaires measuring different constructs, have been posited in literature recently (Desmedt et al., 2022, 2023a; Vig et al., 2022). The 2 × 2 factorial structure for interoception is a promising development and provides a structured approach to alleviate these issues through clear distinction between accuracy and attention, offering a framework that can help standardize definitions and improve precision (Murphy et al., 2019; Desmedt et al., 2022).

The current study was also limited by studies that only included one of the quadrants from the 2 × 2 model (e.g., accuracy and objective performance), presenting only part of the complex nature of interoception. Also, since this model was developed only recently, many articles included here did not use the exact same terms used in the 2 × 2 structure. Many studies on interoception use the same terms for different domains, or different terms for the same domains (Forkmann et al., 2016). This means we had to make choices as to the placement of the studies (or parts of studies) within the 2 × 2 factorial structure, which could subsequently lead to studies being placed within an interoceptive domain the authors of the study did not intend to investigate. In addition, even though definitions of interoceptive measures and domains were discussed between authors in order to limit discrepancies, there is the risk of authors assigned to screening records come to different conclusions on the definitions of measures and domains. However, we are confident in the correct placement of individual studies, as the model is easy to interpret. In fact, we would argue for increased use of this model, as it creates clarity in the definitions of interoceptive domains and allows for cross-correlations between domains and measures (e.g., the correlation between objective performance tests and self-reported beliefs, which is defined as interoceptive awareness).

In addition to the strengths and limitations of the 2 × 2 factorial structure for interoception, we would like to show the reader that there are multiple ways to categorize research on interoception. One of these methods is to look at bodily modalities, such as the heart, respiratory system, and gastrointestinal system. For example, Ferentzi and colleagues (Ferentzi et al., 2018) found that the ability to detect heartbeats does not translate to the ability to detect gastric or respiratory signals. This prompts guidelines suggesting distinguishing between bodily systems when conducting interoceptive research (Desmedt et al., 2023a; Suksasilp and Garfinkel, 2022). Since the 2 × 2 factorial structure lacks the clear differentiation between modalities, we would like to suggest researchers to use a combination of both methods of categorizing as described here: classify interoception based on domain (accuracy or attention) and measurement (objective or self-report), and analyze within these quadrants separately for different modalities; or group results on modality first, and then determine differences between domains and measures.

Based on literature, we determined six overarching lifestyle factors, which were written out in detail in the search strings. While this allowed for an overview and cross-comparisons of the relation between interoception and lifestyle factors, it might have resulted in studies not being found. For example, in the cognitive leisure and relaxation activities part of the search string, terms like leisure activities, cognitive stimulation, and mental stimulation were used. This resulted in identifying several articles on mindfulness, tai-chi, yoga, and meditation, even though these terms were not specifically mentioned in the search strings. This choice was made to cover studies investigating the role of cognitive leisure activities such as reading, gardening, or puzzles in interoception, as well as the mindfulness-related activities. Nevertheless, the current findings give a good overview of the influence of mindfulness on interoceptive abilities, while also showing the lack of research on other cognitive stimulating activities. Future review articles specifically focusing on the role of mindfulness, tai-chi, yoga, and meditation in interoception, could define these constructs more comprehensively in their search strings.

4.9. Implications for practical and future research

This review showed that mindfulness, and practices related to mindfulness, seem to be effective in improving interoceptive skills and may therefore be recommended to be included in lifestyle interventions (Farb et al., 2013). Both brief and longer interoceptive training sessions have been shown to be effective in improving interoception and reducing anxiety in healthy populations, individuals suffering from autism spectrum disorders, and older adults (Quadt et al., 2021; Sugawara et al., 2020; Warschburger et al., 2022). For example, mindfulness-based interventions targeting individuals suffering from substance use disorders have been shown to be beneficial in improving self-reported interoceptive attention and decreasing substance related problems (Price et al., 2019b, 2019c). Furthermore, interventions aimed at improving intuitive eating behavior should also consider adding interoceptive training, as our review indicates that intuitive eating and interoception are closely related.

Research investigating the relation between interoception and exercise are currently mainly focusing on the effect of acute exercise on interoception. Additional research should also consider the effect of longitudinal exposure to exercise on interoception, or vice versa. Consistently participating in exercise is beneficial for long-term health, thus understanding the role of interoception can help in the development of longitudinal exercise programs. Additionally, specific types of exercise might influence the development of interoceptive abilities differently, and interoception might be more beneficial in some exercise activities compared to others. Understanding the bidirectional relationship between interoception and exercise can help in the development of lifestyle interventions.

The 2 × 2 factorial structure for interoception reveals two literature gaps. First, there's a lack of measures for objective interoceptive attention, suggesting the need for new instruments like experience-sampling methods. Second, interoceptive awareness, defined as the relationship between performance and beliefs, is rarely quantified. Only 6 out of 21 studies that used both performance and belief measures did so. To increase our understanding of the different interoception domains, future research should examine at least two quadrants of the 2 × 2 structure and quantify the relation between these quadrants, in order to improve quality of interoception and health behavior research. In addition to these gaps in literature, some interesting trends were found in this review. First, most studies on self-reported beliefs used the MAIA questionnaire. Second, the majority of studies on objective interoceptive accuracy use heartbeat tasks, even though these tasks are considered to suffer from critical limitations. A recent review article indicates that measuring objective interoceptive accuracy remains a significant challenge, and researchers are stimulated to investigate other interoceptive dimensions as well (Desmedt et al., 2023b). Based on these previous and current findings, we would like to encourage researchers to critically think of the dimension and modality that fits their research question and target population, choose the appropriate measures and questionnaires

for these goals, and investigate and compare more than one interoceptive domain.

5. Conclusion

The current review indicates the importance of several interoceptive domains in various health behaviors. Strong support was found indicating the importance of mindfulness qualities and interventions in the promotion of interoception, and the relation between interoception and eating behavior. The evidence for a positive relation between interoception and exercise, and the negative relation between interoception and alcohol consumption, was moderate. A limited number of studies of good methodological quality with varying findings were identified on the relation between interoception, smoking behavior, and sleep to draw clear conclusions, which was a gap in literature identified in this review. Moreover, a complete picture of the complex nature of interoception in a healthy lifestyle is not always presented, as indicated by the lack of quantification of interoceptive awareness in the current literature. Thus, future longitudinal studies with more objective measures of interoception are needed in order to better understand the interrelations between interoception and lifestyle factors.

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Author contributions

Study conception and design was performed by JM, JK. Data collection and analyses were performed by JM, MBo, LV, MBr. The first draft of the manuscript was written by JM. All authors critically revised and commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jesper Mulder reports financial support was provided by Velux Stiftung. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neubiorev.2025.106018.

Data availability

Data will be made available on request.

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