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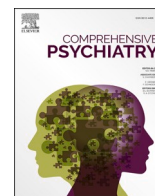
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# Interoceptive sensibility: links with insomnia symptoms, anxiety, and depression in the general population

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## ABSTRACT

**Background:** Diurnal and nocturnal symptoms of insomnia are strongly associated with anxiety and depression. Interoception provides a new reading window for understanding the development and maintenance of psychopathology and sleep disorders. While previous studies have provided preliminary insights into the relationships between depression, anxiety, insomnia, and interoceptive sensibility, to our knowledge, no study has comprehensively examined these relationships.

**Methods:** We used mediation and network analyses to investigate the associations between interoceptive sensibility, diurnal and nocturnal symptoms of insomnia, anxiety, and depression in a sample of 542 individuals from the general population. The Multidimensional Assessment of Interoceptive Awareness, the Sleep Condition Indicator, and the Hospital Anxiety and Depression Scale were used for the assessment.

**Results:** The results showed that the dimensions “trust” and “attention regulation” of interoceptive sensibility are central nodes in the interrelationship network. The “trust” dimension is strongly and negatively related to depression and anxiety. Nocturnal symptoms are more strongly related to anxiety, and diurnal symptoms are more strongly related to depression. Mediation analyses highlight the predominant mediating role of the “trust” dimension in the relationships between insomnia symptoms and clinical variables.

**Conclusions:** These findings suggest that interoceptive sensibility plays a critical role in bridging the relationship between both nocturnal and diurnal insomnia symptoms and anxiety-depressive symptomatology.

## 1. Introduction

Insomnia, affecting both clinical and non-clinical populations, is associated with numerous adverse outcomes, including reduced quality of life [1], decreased work productivity, and elevated risk of psychiatric disorders, particularly depression and anxiety [2]. This disorder is characterized by difficulty initiating sleep, difficulty maintaining sleep, or experiencing poor sleep quality, despite having an adequate opportunity for sleep. In addition, insomnia is also characterized by daytime symptoms. Individuals with poor sleep often experience fatigue, sleepiness, cognitive impairments, and mood disturbances throughout the day [3]. Ji et al. [4] demonstrated that these daytime symptoms are more strongly associated with depressive symptoms than nighttime disturbances. These findings emphasize the substantial impact of daytime manifestations on overall psychopathology and highlight the importance of addressing them with particular care.

Therapeutic approaches such as Cognitive Behavioral Therapy for Insomnia (CBT-I) have demonstrated promising results in managing insomnia and reducing associated comorbidities such as depression [4]. However, a meta-analysis [5] found that CBT-I is more effective in treating nocturnal symptoms than daytime manifestations. These findings suggest a gap in both theoretical frameworks and empirical investigations regarding the daytime aspects of insomnia, which may contribute to a lack of comprehensive interventions that target full spectrum of the disorder.

Insomnia is strongly associated with both anxiety [6] and depression [7], with affected individuals being up to five times more likely to exhibit symptoms of either condition [8]. Sleep disturbances, particularly difficulties initiating sleep, are among the strongest predictors of future depressive episodes, while depressive symptoms themselves increase the likelihood of developing insomnia [9,10]. A similar bidirectional relationship exists between insomnia and: longitudinal studies

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suggesting that anxiety disorders elevate the risk of subsequent insomnia, whereas insomnia serves as a strong predictor for the onset of anxiety disorders [2,11]. Although most studies consistently report a strong association between insomnia and anxiety, it remains unclear to what extent different subtypes of insomnia are associated with a specific clinical profile. Gould et al. [12] addressed this question by differentiating anxiety expressions into affective, cognitive, and somatic components. Their findings indicated that only somatic anxiety was significantly associated with both poorer sleep quality and increased diurnal sleepiness. In this context, physiological patterns of clinical variables can offer an interesting framework, considering that somatic anxiety, compared to affective and cognitive anxiety, has been associated with both poorer sleep quality and increased daytime sleepiness.

A novel framework for understanding sleep disorders is emerging through the lens of interoceptive processes – defined as the perception and response to internal bodily signals. Traditionally, interoception encompasses visceral sensations as well as physiological states such as hunger, thirst, nociception and thermoception. According to the broader definition, interoceptive processes can be differentiated into three components: a) interoceptive accuracy i.e. objective performance on interoceptive tasks, b) interoceptive sensibility i.e. self-reported assessment of subjective interoception and c) interoceptive awareness i.e. the correspondence between interoceptive accuracy and sensibility. [13]. Interoceptive processes have been linked to insomnia. Wei et al. [14] identified neural correlates of interoceptive accuracy in individuals with insomnia disorders. Alfi et al. [15] explored the relationship between interoceptive sensibility and the subjective experience of consciousness during insomnia. Their findings revealed that individuals with insomnia exhibit heightened interoceptive sensibility, especially in detecting bodily sensations and emotional awareness. However, they also demonstrated a reduced attentional regulation, a tendency to worry about bodily cues, and diminished trust in these internal signals. Notably, heightened emotional awareness was associated with a 2.49-fold higher likelihood of subjectively experiencing altered states of consciousness during insomnia. A recent study [16] examined the link between interoceptive sensibility and sleep quality, suggesting that individuals who can identify, trust, and regulate responses to uncomfortable bodily sensations tend to experience better sleep. Conversely, heightened awareness of the connection between bodily sensations and emotional states has been associated with a greater vulnerability to sleep disturbances. Furthermore, interoception-based interventions (IBIs) have recently shown promising results in the treatment of various psychopathological conditions [17].

Interoceptive sensibility has been implicated in anxiety-related processes [18]. In particular, Elliot and Pfeifer [18] showed that individuals with high COVID-19-related anxiety exhibited impairments in trusting bodily signals, managing worry about bodily sensations, and regulating attention to interoceptive cues. Expanding on this, Lee et al. [19] examined individuals with depressive and anxiety disorders and found that the interoceptive dimensions of “attentional regulation,” “noticing,” and “trust” significantly predicted anxiety scores in linear regression analyses. In contrast, for depressive symptoms, only “attentional regulation” emerged as a significant predictor. More recently, Ruggiero et al. [20] reported a negative correlation between interoceptive sensibility and depressive symptoms, further supporting the relevance of interoceptive processes in emotional disorders.

Given the strong links between anxiety, depression, and insomnia [9,11], and in the light of recent findings implicating interoceptive sensibility in both sleep regulation and psychopathology [17,16], the present study aimed to re-examine the associations between depression, anxiety, and insomnia subtypes (i.e., nocturnal and diurnal symptoms) through the lens of interoceptive sensibility within a general population. To this end, we employed network analysis, a method increasingly utilized in sleep research for its capacity to identify central variables and their interactions [21,22]. Additionally, mediation analyses were conducted to quantitatively explore the pathways linking interoceptive

sensibility, insomnia symptoms, and psychopathological variables.

Although the study is exploratory in nature, based on previous evidence [9] [11] [16], we expected network analysis to reveal robust associations between nocturnal and diurnal insomnia symptoms, depression, and anxiety, and dimensions of interoceptive sensibility.

Regarding the mediation analyses, we further hypothesized that interoceptive variables would mediate the relationships between insomnia symptoms and psychopathological outcomes.

## 2. Method

### 2.1. Participant recruitment and study protocol

#### 2.1.1. Questionnaire diffusion

The questionnaire was distributed via social media platforms (Facebook, WhatsApp, LinkedIn) between April 4, 2022 and May 10, 2022. Participants were informed of the purpose of the study, the study procedures, data analysis, the voluntary nature of their participation, confidentiality, objectives, methods, institutional affiliations, expected benefits, potential risks of the research, and the possible inconveniences. Ethical considerations were addressed in accordance with the Declaration of Helsinki.

#### 2.1.2. Questionnaire structure

The entire protocol was conducted online. Participants first gave informed consent before completing a demographic questionnaire. Participants then completed the hetero-questionnaires, which were distributed in the following order: Multidimensional Assessment of Interoceptive Awareness, Hospital Anxiety and Depression Scale, and Sleep Condition Indicator. The total duration of the research protocol was approximately 20 min.

### 2.2. Psychometric evaluation

The Hospital Anxiety and Depression Scale (HADS) [23], assesses the severity of depression and anxiety. The French version of the HADS consists of 14 items coded from 0 to 3, of which seven relate to anxiety symptoms and seven to depressive symptoms. The authors of the scales determined threshold scores for anxiety and depression: a score between 0 and 7 indicates the absence of anxiety or depression symptoms; a score between 8 and 10 indicates a moderate doubt about the presence of symptoms, a score greater than or equal to 11 indicates a significant number of anxiety or depression symptoms corresponding to confirmed cases. Scores can therefore range from 0 to 21. The internal consistency for the depression scale, Cronbach's alpha, is 0.78, according to the validation study [23]. For the anxiety scale, it is 0.81. The correlation between the anxiety and depression scores was 0.62. In the current sample, Cronbach's alpha was 0.72 for the depression scale and 0.69 for the anxiety scale.

The Sleep Condition Indicator (SCI) [24] was used to assess insomnia using 8 items with their respective rating scales. Participants were asked to rate the severity of their nocturnal and diurnal symptoms on 4-point Likert scales (0–3), with lower scores indicating higher insomnia intensity. The cut-off score is  $\leq 16$ . Items 1, 2, 3, 4, and 8 assess nocturnal symptoms, while items 5, 6, and 7 assess diurnal symptoms. The French version of the SCI scale demonstrated good internal consistency ( $\alpha = 0.87$ ), as reported in the validation study [24]. The Cronbach's alpha for the current sample is 0.63.

The French version of the Multidimensional Assessment of Interoceptive Awareness (MAIA) [25] was used to measure interoceptive sensibility. It is a comprehensive 6-point scale with 32 items, ranging from 0 (never) to 5 (always). It is composed of 8 subscales, each of which assesses one dimension of interoceptive sensibility. The Noticing subscale ( $\alpha = 0.65$  and, for the current sample:  $\alpha = 0.51$ ) assesses participants' ability to detect body signals of any valence. The Not Distracting subscale ( $\alpha = 0.42$  and, for the current sample:  $\alpha = 0.59$ ) assesses the

ability to distract oneself from bothersome and/or painful interoceptive signals. The Not-Worrying ( $\alpha = 0.57$  and, for the current sample:  $\alpha = 0.58$ ) assesses the tendency not to worry about painful and/or unpleasant sensations. The Attention Regulation subscale ( $\alpha = 0.87$  and, for the current sample:  $\alpha = 0.42$ ) measures the ability to focus on bodily sensations. The Emotional Awareness subscale ( $\alpha = 0.80$  and, for the current sample:  $\alpha = 0.48$ ) measures awareness of the association of bodily signals and emotional states. The Self-regulation scale ( $\alpha = 0.83$  and, for the current sample:  $\alpha = 0.45$ ) assesses the ability to use body sensations to regulate painful experiences. The Body Listening scale ( $\alpha = 0.84$  and, for the current sample:  $\alpha = 0.48$ ) assesses the tendency to actively listen to bodily sensations to learn from them. Finally, the Trust scale ( $\alpha = 0.84$  and, for the current sample:  $\alpha = 0.50$ ) assesses the tendency to regard bodily sensations as safe and reliable. The scoring of items 5, 6, 7, 8 is reversed. Higher scores indicate a greater interoceptive sensibility for each dimension. The MAIA showed acceptable psychometric properties ( $\alpha = 0.70$ ) according to the validation study [25]. The Cronbach's alpha for the current sample is 0.58.

Data on psychopathologies and medication intake were collected for information purposes, but were excluded from analysis due to the absence of a psychiatric evaluation.

### 2.2.1. Inclusion and exclusion criteria

Inclusion criteria required participants to be at least 18 years old and to have fluent comprehension, reading, and speaking abilities in French. Participants who did not complete all questionnaires or provided incongruent responses (e.g., answering "yes" to a question about age) were excluded from the analyses.

### 2.2.2. Total number of participants included for analysis

The results of 542 participants were retained for statistical analysis after excluding missing data and erroneous responses ( $n = 310$ , 36.38 % of the total number of responses initially obtained).

### 2.2.3. Ethical aspects

The Ethics Committee of the University of Aix-Marseille approved the study 2,020,012,307 according to the Declaration of Helsinki.

## 2.3. Statistical analyses

Statistical analyses were performed using JASP software and Jamovi software. We first calculated the descriptive data using JASP. For network analysis, we used the Jasp network analysis module. The visualised network diagram consisted of variables (nodes) connected by lines (edges). The relationship between nodes was represented by the width of the edges and the thickness of the colour. We estimated partial correlation networks using the graphical Least Absolute Shrinkage and Selection Operator (gLASSO). Extended Bayesian Information Criterion (EBIC) was used to select the optimal network model. The centrality indices used in this study are the strength, interdependence, closeness, and expected influence of nodes. A bootstrap of 5000 cases was used to measure the stability of the data. We used the non-parametric version of JASP with edge correlations.

Mediation analyses were conducted using Jamovi software. Mediation models were tested separately. Given the circular relationships revealed by the network analysis between insomnia and anxiety-depressive symptoms, these analyses examined the pathways from insomnia to psychopathological distress and vice-versa. These analyses were conducted on the relationships between nocturnal symptoms and anxiety, between anxiety and diurnal symptoms, and between diurnal symptoms and depression. All interoceptive variables were tested as mediators, but only significant ones were retained.

## 3. Results

### 3.1. Sample

The total sample consists of 542 French participants. The proportion of women was 80.3 %. Their mean age  $\pm$  standard deviation (S-D) was  $37.7 \pm 12.7$  years. 14.57 % of the sample had received a psychopathological diagnosis in the 6 months prior to the study. Of the total sample, 43.54 % had a pathological score on the insomnia scale. Demographic and clinical information is shown in Table 1.

### 3.2. Sleep, interoceptive, and clinical variables

The scores for the different scales have been summarised in Table 2. The percentage of pathological scores except for interoceptive sensibility, which has no cut-off, have been highlighted. For nocturnal insomnia symptoms (items 1, 2, 3, 4, and 8 of the SCI), 35.60 % of the sample had a pathological score. For diurnal symptoms (items 5, 6, and 7 of the SCI), 53.87 % are above the cut-off. 19.56 % of the participants had a pathological score on the depression scale and 57.93 % on the anxiety scale.

### 3.3. Network analysis

Fig. 1 illustrates the network analysis of the relationships between interoceptive sensibility, depression, anxiety, and both diurnal and nocturnal symptoms of insomnia.

At the network's entry point, a strong positive association was observed between diurnal and nocturnal symptoms, indicating a close relationship between these two dimensions of insomnia. These nodes were negatively associated with the clinical variables (anxiety and depression), given that higher scores on the insomnia scale indicate fewer symptoms due to reverse scoring. The network analysis thus highlights that insomnia subtypes are positively linked to psychopathological symptoms. More specifically, nocturnal symptoms were more positively correlated with depression, whereas diurnal symptoms showed a stronger association with anxiety.

From the insomnia-related nodes, the network path extended to the clinical variables (anxiety and depression), when linked to a central interoceptive variable: the "trust" dimension. This "trust" node played a key role in bridging insomnia and interoceptive processes. Although it was also directly linked to the insomnia nodes, these links were weaker than the indirect links mediated via anxiety and depression.

Another central element of the network was the "attention regulation" dimension, which showed a strong positive association with

**Table 1**  
: Demographic characteristics for the full sample ( $N = 542$ ).

Total Sample ( $N = 542$ )	Mean $\pm$ SD
Age (years)	37.7 $\pm$ 12.7
Gender (M/F)	107/435 (19.7 %/80.3 %)
Marital status	
Single	195 (35.97 %)
Cohabitation	180 (33.21 %)
Married	164 (30.25 %)
Other	3 (0.57 %)
Level of education	
(% $\geq$ Bachelor's degree)	515 (95.01 %)
Professional activity	
(Yes/No)	364/178 (67.16 %/32.84 %)
Psychopathological diagnosis received in last 6 months	
Anxiety disorders	24 (4.42 %)
Depression	33 (6.08 %)
Burn-out	13 (2.39 %)
Bipolar disorder	2 (<0.1 %)
Eating disorders	7 (1.29 %)
Psychotropic drug use	71 (13.09 %)

**TABLE 2**  
: Descriptive statistics for primary study variables for the full sample (N = 542).

Measure	MEAN	SD	% Pathological Score
SCI Total	18.44	7.47	43.54 %
SCI- Nocturnal Symptoms	10.03	3.98	35.60 %
SCI- Diurnal Symptoms	8.42	4.27	53.87 %
Depression HAD	6.40	3.76	19.56 %
Anxiety HAD	10.30	2.80	57.93 %
MAIA-Trust	2.90	1.14	
MAIA-Body listening	2.40	1.14	
MAIA-Self regulation	2.58	1.11	
MAIA-Emotional Awareness	3.26	0.99	
MAIA-Attention regulation	2.82	0.94	
MAIA-Not Worrying	2.44	0.94	
MAIA-Not distracting	2.24	0.94	
MAIA-Noticing	3.22	0.89	

SCI = Sleep Condition Indicator; HAD = Hospital Anxiety and Depression scale; MAIA = The Multidimensional Assessment of Interoceptive Awareness.

anxiety. It also acted as a relay node, connecting to other interoceptive dimensions – including emotional awareness, body listening, self-regulation, and noticing - with which it had strong and proximal positive relationships.

In contrast, the “not worrying” dimension appeared on the periphery of the network. It showed a strong negative association with anxiety and was more closely and negatively related to the “not distracting” dimension than to other interoceptive variables.

Overall, the network structure suggested two main entry points: one through insomnia symptoms, and the other through specific interoceptive dimensions. The central nodes – namely anxiety, depression, trust, and attention regulation - emerged as critical relay points in the dynamic interplay between insomnia and interoceptive sensibility.

The centrality indices are shown in Fig. 2. The centrality indices chosen were betweenness, closeness, and strength. As there were some negative edges, we also included the expected influence index. The results showed that the nodes with the highest centrality are the dimensions “trust” (z = 0.723), “anxiety” (z = 0.816), and “emotional awareness” (z = 0.667). For the betweenness index, the most important nodes were “trust” (z = 1.65), depression (z = 1.478), and anxiety (z = 0.789). Concerning the closeness index, the strongest nodes were those of the “trust” dimension (z = 1.099), depression (z = 1.049), and the

anxiety (z = 0.837). For the expected influence, the most important nodes were “self-regulation” (z = 1.060) and “body listening” (z = 1.454).

Regarding the accuracy of the present network, the results of the bootstrap 95 % Confidence Interval (CI) for the edges showed that the 95 % CIs were narrow, indicating that the edges are trustworthy, as shown in Fig. 3. Note that clear recommendations for interpreting the CIs are currently lacking in the literature [26].

### 3.4. Mediation analysis

Mediation analyses were conducted, resulting in a mediation path summarised in Fig. 4. The mediation analysis indicated that all the total indirect effects and all specific indirect effects were significant for all mediations.

The first analysis showed that the “trust” dimension significantly mediated the relationship between nocturnal symptoms and anxiety with a mediation effect of 25.4 % (estimate: -0.077, Z = 5.94, I-C 95 % [-0.103–0.051], p. < 0.01).

The second mediation analysis showed that two interoceptive dimensions emerged as significant mediators between anxiety and diurnal symptoms:

- The “trust” dimension with an indirect effect of 17.1 % (estimate: -0.116, Z = -3.83, I-C 95 % [-0.176–0.06], p. < 0.01).

- The “not worrying” dimension with an indirect effect of 5.78 % (estimate: -0.04, Z = -2.06, I-C 95 % [-0.082–0.002], p. = 0.03).

The third mediation analysis showed that several interoceptive dimensions mediated the relationship between diurnal symptoms and depression:

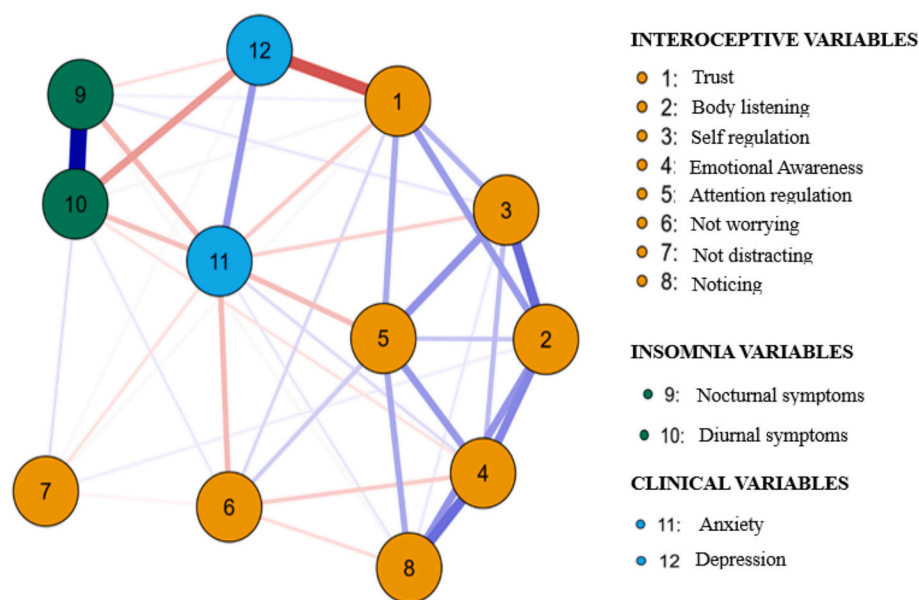
- The “trust” dimension with an indirect effect of 31.7 % (estimate: -0.132, Z = -6.91, I-C 95 % [-0.169–0.091], p. < 0.01).

- The dimension “body listening” with a mediation effect of 6.42 % (Estimate: -0.027, Z = -2.95, I-C 95 % [-0.044–0.009], p. < 0.01).

- The “not worrying” dimension with an indirect effect of 4.4 % (estimate: -0.018, Z = -2.28, I-C 95 % [-0.034–0.002], p. < 0.01).

- The “self-regulation” dimension with an indirect effect of 10.4 % (estimate: -0.043, Z = -3.91, I-C 95 % [-0.064–0.021], p. < 0.01).

- The dimension of “attention regulation” with an indirect effect of 7.62 % (estimate: -0.031, Z = -3.22, I-C 95 % [-0.051–0.012], p. <



**Fig. 1.** Results of a network analysis for the poor sleepers group. Each node represents a variable. Each edge represents the partial correlation (blue = positive correlation; red = negative correlation). Thicker edges represent a stronger association. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

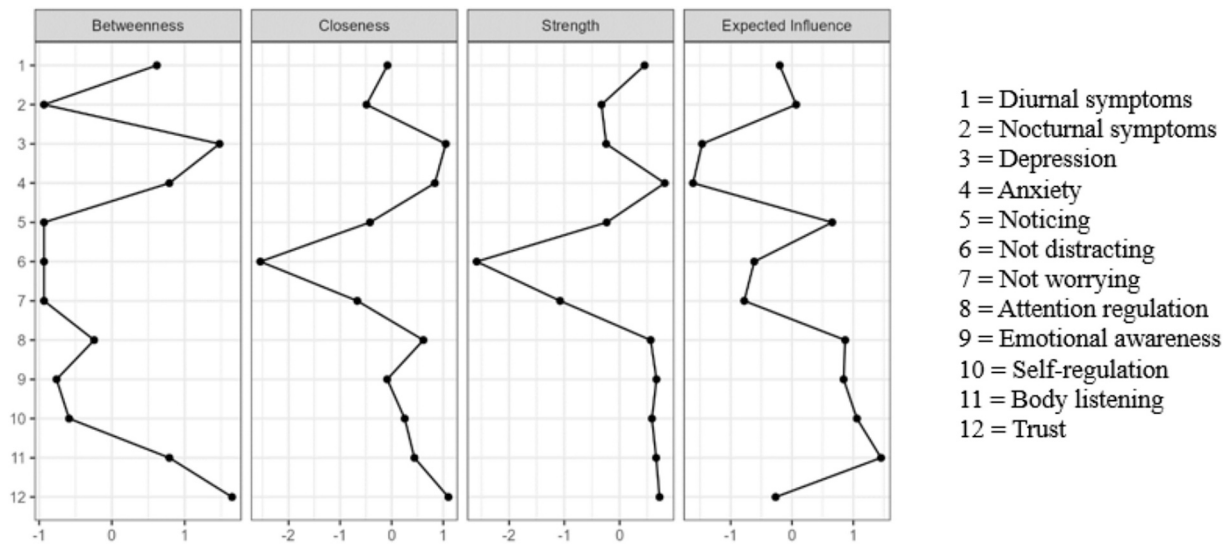


Fig. 2. Centrality plot depicting standardized centrality indices (betweenness, closeness, strength, expected influence).

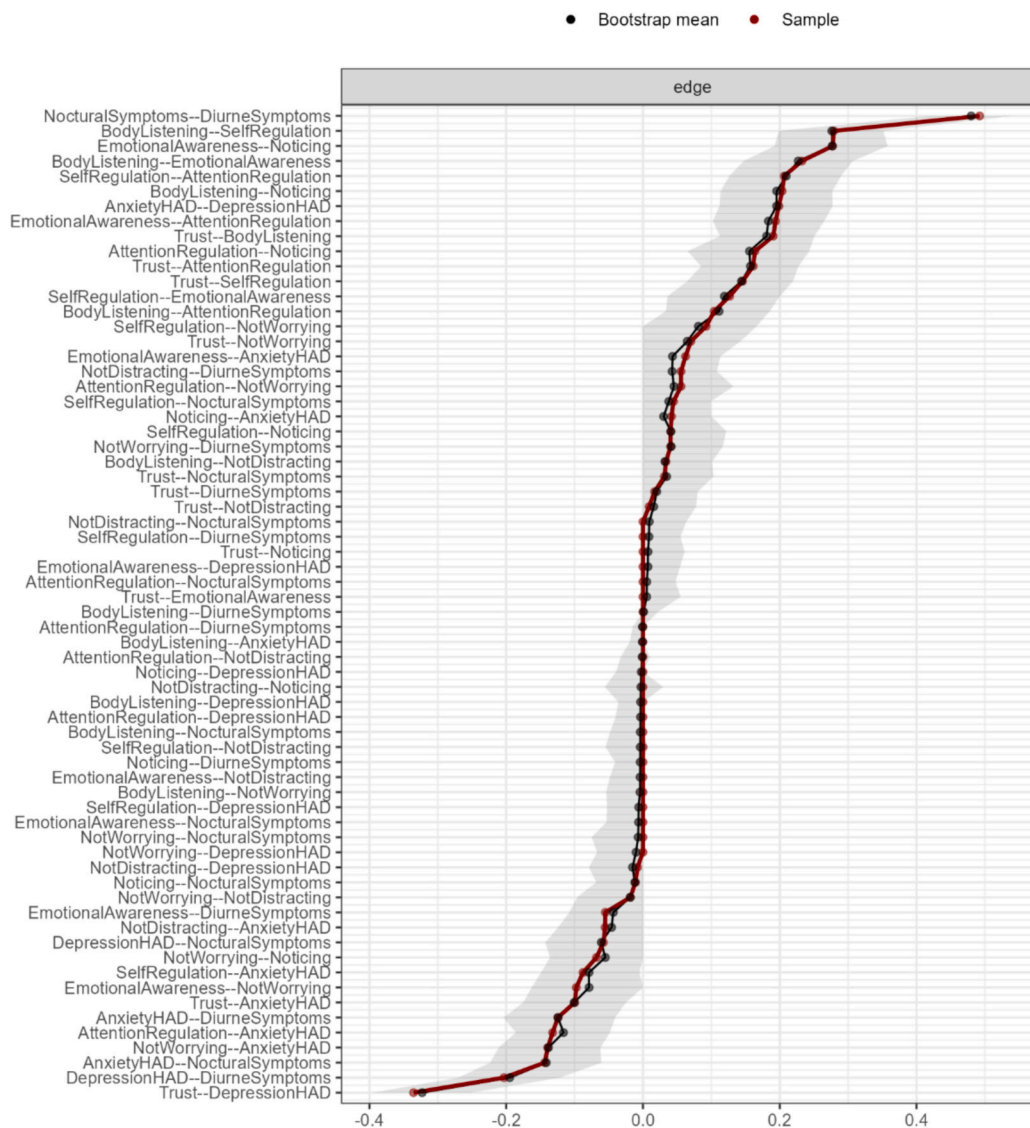


Fig. 3. Bootstrap 5000 confidence intervals were estimated to indicate the magnitude of the edges-weighted between variables in the network structure. The gray ranges are the bootstrap confidence interval. The dots are plotted with polychoric correlation coefficient values.

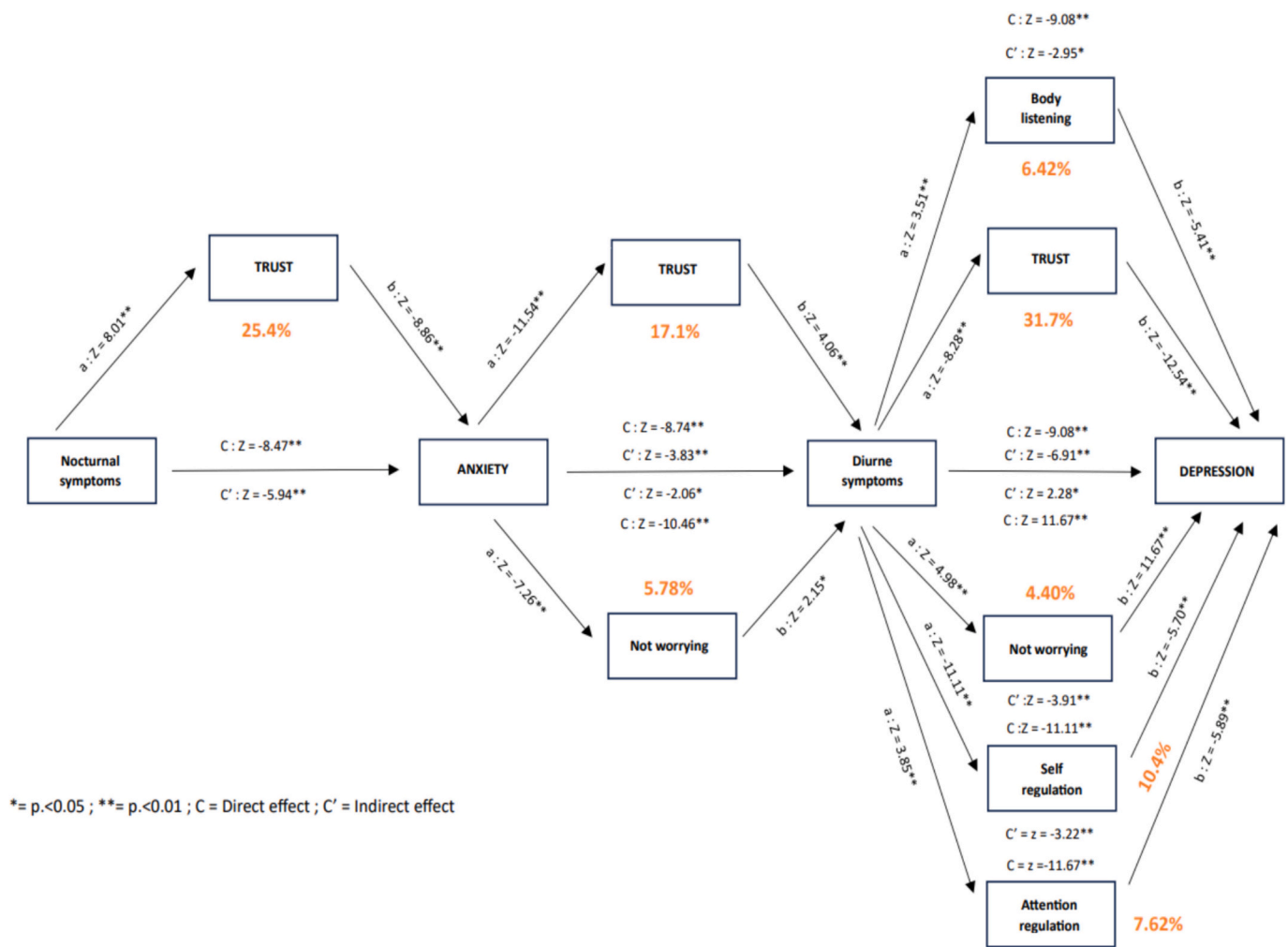


Fig. 4. : Mediation analyses between nocturnal and diurnal symptoms of insomnia, anxiety, depression and interoceptive sensibility dimensions.

0.01).

#### 4. Discussion

This research elucidated the relational structure linking nocturnal and diurnal insomnia symptoms, anxiety, depression, and dimensions of interoceptive sensibility. Specifically, we investigated how nocturnal and diurnal insomnia symptoms relate to anxiety and depression through the intermediary role of interoceptive sensibility.

To explore these relationships, we first conducted a network analysis between these variables. The results partially confirmed our hypotheses, revealing strong associations between the different symptoms of insomnia, depression, anxiety, and specific dimensions of interoceptive sensibility.

The present discussion aims to integrate and interpret these findings in light of the relationships between interoceptive sensibility, insomnia subtypes, and anxiety-depressive symptomatology.

Our results are consistent with prior research demonstrating bidirectional associations between insomnia, depression, and anxiety [11,27]. Notably, we found that diurnal symptoms were more strongly associated with depression, while nocturnal symptoms were more closely linked to anxiety. This distinction supports the findings of Ji et al. [4], who reported a specific relationship between diurnal symptoms and depressive symptoms and aligns with Ma et al. [28], who identified the symptom “hard to get started” as central in their insomnia-depression network model. Collectively, these findings underscore the importance of differentiating between diurnal and nocturnal insomnia symptoms

when evaluating their psychopathological correlates.

Regarding interoceptive sensibility, our hypothesis was partially confirmed. The network analysis highlighted the central role of specific interoceptive dimensions, particularly “trust” referring to the confidence one places in their bodily signals. This dimension demonstrated a strong negative association with both depression and anxiety nodes, more markedly with depression. These results support prior findings from Dunne et al. [29], who reported that lower trust in bodily sensations was associated with more severe depressive symptoms. While the broader literature has yielded inconsistent results concerning depression and heartbeat perception [30], the “trust” dimension has emerged as a more consistent marker across studies [19,22,29]. In our model, depression and anxiety nodes also served as intermediaries between insomnia symptoms and interoceptive dimensions, particularly those related to trust and attentional regulation. These findings are consistent with prior work by Arora et al. [16], who identified “trust” as a predictor of sleep quality, and Alfi et al. [15], who reported diminished trust in individuals with insomnia. Additionally, Heim et al. [17], in a recent meta-analysis, emphasized the therapeutic relevance of this dimension. Overall, these findings suggest that altered interoceptive sensibility—especially reduced trust in bodily signals—may disrupt the regulation of both sleep and emotional states, thereby contributing to the persistence of insomnia, anxiety, and depression. In parallel, deficits in attentional regulation may exacerbate or reflect homeostatic dysregulation, consistent with prior research on attentional dysregulation in these conditions [31–33].

Our mediation analyses further elucidated the mechanisms to this

understanding by demonstrating that several interoceptive dimensions mediate the link between insomnia and psychopathology. Specifically, “trust” mediated the relationship between nocturnal symptoms and anxiety, suggesting that low bodily trust may contribute to heightened nighttime hyperarousal and related symptoms. Furthermore, both “trust” and “not worrying” mediated the link between anxiety and diurnal symptoms, implying that anxious individuals may interpret fatigue and other bodily diurnal cues as threatening, thereby perpetuating daytime dysfunction. The dimensions “trust,” “body listening,” “not worrying,” “self-regulation,” and “attention regulation” also mediated the association between diurnal symptoms and depression, aligning with prior research that identifies interoceptive dysfunctions as potential mechanisms underlying depression [29,34].

Across both network and mediation analyses, “trust” consistently emerged as a central dimension, highlighting its potential role as a central mechanism linking insomnia and affective symptoms. While the directionality of these associations cannot be inferred from these data, the recurrent prominence of bodily trust highlights its relevance for future theoretical models and therapeutic innovations. Other interoceptive dimensions, though implicated, exhibited more circumscribed effects.

By distinguishing between diurnal and nocturnal insomnia symptoms and examining their interplay with interoceptive sensibility and emotional symptomatology, our study advances a more nuanced understanding of insomnia. Given the frequent clinical overlap between insomnia, anxiety, and depression, identifying shared and distinct pathways is essential. Recent meta-analyses confirm that CBT-I not only effectively treat insomnia but also yields significant reductions in depressive and anxiety symptoms [35,36]. Therefore, our findings may inform refinements to CBT-I protocols, particularly by integrating components that target interoceptive dysfunctions.

In line with a symptom-based approach advocated by Takano et al. [21] and supported by network models that identify central symptoms, our results highlight the importance of targeting diurnal symptoms—such as fatigue—which are less responsive to standard CBT-I [8] but closely linked to interoceptive dysregulation [37]. Accordingly, incorporating interoception-based interventions (e.g., interoceptive exposure, mindfulness, vagus nerve stimulation [17]) may enhance CBT-I’s efficacy, particularly for addressing daytime complaints.

#### 4.1. Limitations

This study has several limitations that warrant consideration. Although, the bootstrap procedure suggested acceptable stability in network estimation, the sample size remains modest and limits the generalizability of the findings. The recruitment of participants from the general population, coupled with an online self-report methodology, introduces potential selection and participation biases. Furthermore, the gender distribution was skewed, with a predominance of female participants. A substantial proportion of the sample also reported subclinical or clinical symptom levels based on self-reports, which were not corroborated through structured clinical interviews. Taken together, these limitations suggest that the findings should be interpreted with caution and may not be fully representative of clinical populations or the general public.

Despite these limitations, the present findings highlight the potential relevance of interoceptive sensibility, particularly the « trust » dimension, in the interplay between insomnia and emotional disorders. These insights may inform future development of targeted psychological interventions aimed at restoring interoceptive balance to enhance treatment outcomes in comorbid insomnia, anxiety, and depression.

Future research should aim to replicate and extend these findings using **longitudinal designs**, which would allow for a more nuanced understanding of how nocturnal and diurnal insomnia symptoms evolve over time and interact with anxiety and depressive symptomatology. Such studies could clarify the temporal and causal relationships among

these variables and shed light on the etiopathogenesis of insomnia within an interoceptive framework. In addition, research should explore the **clinical applicability** of these findings. Testing the model in clinical populations would help determine whether specific interoceptive dysfunctions correspond to distinct psychopathological profiles. Finally, experimental studies assessing the effectiveness of **interoception-focused interventions** — such as mindfulness training, interoceptive exposure, or biofeedback— may pave the way for integrative, non-pharmacological approaches to treating insomnia and associated emotional disorders.

## 5. Conclusion

This study shed light on the interrelations between nocturnal and diurnal insomnia symptoms, interoceptive sensibility, and anxiety–depressive symptomatology. The use of network analysis provided a nuanced understanding of the associations between affective symptoms and distinct insomnia components. Furthermore, our findings support the role of reduced interoceptive sensibility —particularly the “trust” dimension —as a potential mechanism linking insomnia with emotional disturbances. These insights may inform future research and contribute to the development of more targeted psychological interventions.

### CRedit authorship contribution statement

**Faccini Julie:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Joshi Vrutti:** Validation, Methodology, Data curation. **Del-Monte Jonathan:** Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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### Declaration of competing interest

Authors declare no conflict of interest.

### Data availability

Data available on request from the corresponding author.

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