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Interoception as a key node in the multidimensional psychological structural model of depression: a structural equation model analysis of integrating environmental, cognitive and behavioral-emotional factors

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Abstract

Background The psychological structural model of major depressive disorder (MDD) is complex and multifaceted, consisting of the environment factors (EF), cognitive function (CF), and behavioral-emotional manifestations (BEM). Currently, the diagnosis and treatment of MDD is difficult to improve the disease state as a whole through an intervention point. Constructing the psychological structural model of MDD and finding the critical node of the psychological structural model are meaningful for the diagnosis and treatment of MDD.

Methods 308 MDD patients (MDDs) participated in this research. They completed assessments of 34 psychological factors, including EF, CF, BEM and interoception function (IF). Pearson correlation was used to investigate the relationship between IF and each factor in the depressive multidimensional psychological structural model (EF, CF and BEM) which was constructed by structural equation modeling (SEM). Critical nodes were identified by the goodness of fit of the model. The depressive multidimensional psychological structural model (EF, CF and BEM) was created through SEM. IF was added to the depressive multidimensional psychological structural model to further verify the pathways and effects of interoception in the network.

Results IF was significantly correlated with all psychological factors. In the depressive multidimensional psychological structural model, EF ($\beta_{direct} = 0.163$, $p = 0.033$) and BEM ($\beta_{direct} = 0.230$, $p = 0.003$) can directly influence MDD. When adding IF to the model, interoception predicted all the factors in the model. The poorer EF led to the lower IF ($\beta_{direct} = -0.346$, $p < 0.001$). Interoception dysfunction increased the risk of the CF (β_{direct} = -0.525,

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$p=0.002$) and BEM ($\beta_{direct}=-0.250$, $p=0.031$) of the patients. EF had the largest total effect on MDD ($\beta_{direct}=0.365$, $\beta_{indirect}=0.150$, $\beta_{total}=0.515$), IF ($\beta_{direct}=-0.309$, $\beta_{indirect}=-0.126$, $\beta_{total}=-0.434$) are second only to EF.

Conclusions IF is a part of the psychological structural model of MDD that predicts EF, CF, and BEM. It could be a potential intervention point to improve the depressive state as a whole.

Keywords Major depressive disorder, Interoception function, Environmental factors, Cognitive function, Behavioral-emotional manifestations, Structural equation modeling

Background

Major depressive disorder (MDD), a leading cause of mental health-related disability globally, represents a significant and growing public health challenge [1]. It is characterized by heterogeneity, manifesting in diverse symptoms [2]. This heterogeneity has been found to influence the course of illness and response to treatment, which makes it essential to identify variables that explain this variance [3]. Current research has constructed a preliminary multidimensional psychological structural model of MDD to better elucidate its complex heterogeneous structure. The environment factors (EF), cognitive function (CF), and behavioral-emotional manifestations (BEM) are considered core components of this model, revealing personalized characteristics [4–7]. The interplay among these components underscores the complex and multifaceted nature of MDD, providing a framework for more targeted and effective therapeutic interventions.

Research indicated that approximately 50% of patients with MDD (MDDs) have experienced adverse early-life events [8, 9], and social support in adulthood is insufficient to fully mitigate the effects of childhood maltreatment [10]. Nevertheless, social support remains crucial in the pathogenesis of depression. Low social support combined with high life stress significantly increases the risk of depression [11, 12]. This suggests that the unique early and recent life environments of individuals influence the onset of depression through distinct pathological mechanisms [13]. Additionally, MDDs also exhibit cognitive impairments, primarily involving executive function, emotional regulation and somatosensory information processing. These cognitive deficits push the changes in thought and behavior patterns, which lead to the depressive behavioral - emotional manifestations. For example, the impaired inhibitory control is associated with rumination, leading to more focus on negative events and emotions [14]. Dysregulation of emotion correlates with deficiencies in social functioning [15] and anhedonia [16], presenting as challenges in forming or sustaining interpersonal relationships and a diminished capacity to experience interest or pleasure in activities. Diminished pain perception signifies decreased psychological resilience, evidenced by a weakened capacity to manage negative events and recover swiftly [17]. Decreased psychological resilience, impaired social function, anhedonia, and rumination are considered strong predictors of depression [18–21]. The pathophysiology of depression is complex and multifaceted, making it challenging to achieve comprehensive improvement through a single intervention. Although targeted intervention strategies are effective, they require substantial resources, increasing the economic burden. Additionally, there are significant limitations in interventions targeting environmental factors, as the healthcare system has limited capacity to alter macro-environmental trends. Therefore, further elucidation of the depressive psychological structural model and identification of key nodes linking EF, CF, and BEM are critical for optimizing diagnosis and treatment.

Interoception refers to the perception of individual's internal state [22], possessing the potential to link EF, CF, and BEM. Exposure to acute or chronic stress during critical developmental periods can have long-lasting effects on brain structures and functions critical for interoception [23], which enhance the risk of MDD mediated by alterations in interoception sensitivity and awareness [24–27]. Neuroimaging studies have confirmed the relationship between interoception and emotion [28, 29], impulsivity [30], and pain threshold [31] from the perspective of neural encoding. It is suggested that interoception constructed the physiological background for cognitive activities and is the foundation for brain cognitive functions [32]. Research on pain vigilance also demonstrated that interoception links emotion regulation, behavioral inhibition/activation, pain vigilance, and rumination [33]. Furthermore, studies have found associations between interoception and anhedonia [34], rumination [35], and social function [36], indicating that enhancing interoceptive ability can effectively improve these symptoms [37, 38]. These findings suggest that interoception may be a critical nodal factor in the depressive multidimensional psychological structural model. Researches on interoception in MDD could further elucidate the pathological pathways and potentially achieve comprehensive improvement through single-point interventions.

However, there is no systematic research investigating the association between interoception and specific risk factors of MDD, nor are there studies clearly defining the

role of interoception within the depressive multidimensional psychological structural model.

Structural equation modeling (SEM) offers flexibility and precision in testing theoretical models involving complex relationships among variables [39]. It encompasses a blend of factor analysis and multiple regression analysis, allowing researchers to examine a series of dependence relationships simultaneously. SEM is a robust, hypothesis-driven statistical technique that is particularly suited for examining complex causal relationships between variables [40]. SEM requires the establishment of a theoretical framework to guide the construction of causal pathways between variables and allows for the inclusion of latent variables, which cannot be directly observed. These latent variables are indirectly measured through observable indicators, such as responses to survey items. SEM is especially valuable in research that seeks to confirm or test theoretical models and is capable of handling intricate causal relationships and mediating variables [41]. In contrast, Network Analysis focuses on identifying correlations and interaction patterns between variables without necessarily assuming causal relationships [42]. Network Analysis emphasizes the complex interrelationships within systems, such as covariance and correlation, but lacks the capacity to test for direct causality [43]. Given the clear theoretical foundation of the current study and the need to verify latent variables and complex causal relationships, SEM is deemed the more appropriate methodological approach. Its ability to account for both observed and unobserved variables makes SEM particularly valuable in psychological and social sciences research, where theoretical constructs often cannot be directly measured. In summary, SEM's ability to incorporate latent variables and account for measurement errors makes it an invaluable tool in the social sciences and beyond, facilitating a deeper understanding of underlying constructs and their interrelations.

Our study aimed to fill this research gap. Firstly, we systematically evaluated the EF, CF, and BEM of MDDs to identify risk factors associated with interoception dysfunction. Secondly, we constructed a depressive multidimensional psychological structural model to verify the causal relationship among EF, CF, and BEM. Finally, we added interoception to the model to verify the role in the overall depressive multidimensional psychological structural model. Our hypotheses were that (1) interoception dysfunction is associated with the majority of MDD risk factors; (2) in the depressive multidimensional psychological structural model, EF can affect depressive levels by influencing CF and BEM; and CF can affect depressive levels through BEM; and (3) interoception connects the factors in the network and has a significant impact on depressive levels.

Materials and methods

Study design

A cross-sectional, correlational study design was employed. This study was conducted from May 1st, 2023, to January 31st, 2024.

Participants

We conducted structured interviews with a total of 400 MDDs recruited from the Department of Psychology at the Affiliated Wuxi Mental Health Center of Nanjing Medical University, China. Sixty-one patients failed to complete the structured interviews, and the structural interview scores of 31 participants were invalid by the evaluation of two assessors. Finally, 308 MDDs (191 females and 117 males) completed the study. Participants were all Han Chinese, right-handed, and aged between 18 and 55 years. Considering the impact of appetite and circadian rhythm on interoception, participants were instructed to start the experiment between 8:30 and 9:00 AM the next day after signing the informed consent. The entire interview process lasted 1 to 1.5 h and was conducted by trained psychiatrists. (Shown in Fig. 1)

The inclusion criteria for all participants included: (1) meeting the Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM-**5**) MDD criteria; (2) aged from 18 to 55 years old; (3) had no physical illness as determined by clinical evaluations and medical records; (4) had no substance misuse or dependence; (5) had no somatic diseases; (6) had no history of Modified Electroconvulsive Therapy in the past 12 months; (7) was not pregnant or breastfeeding.

Ethical considerations

This study was approved by the Ethics Committee on Human Studies (WXMHCIRB2022LLky010), the Affiliated Wuxi Mental Health Center of Nanjing Medical University, China. It was carried out in accordance with the Declaration of Helsinki.

Measures

Structured interviews

We collected 26 characteristics related to EF, CF, and BEM associated with MDD. Specifically, we measured interoception, encompassing 8 detailed dimensions. The detailed characteristics were as follows. The details of the scales used for assessment are shown in Additional file 1.

Socio-demographic characteristics

We collected demographic characteristics (gender, age, education, and body mass index (BMI)), lifestyle habits (alcohol use, smoking, coffee/tea use, social media use), and economic status (marital status, fertility status, annual household income) of all participants. Physical

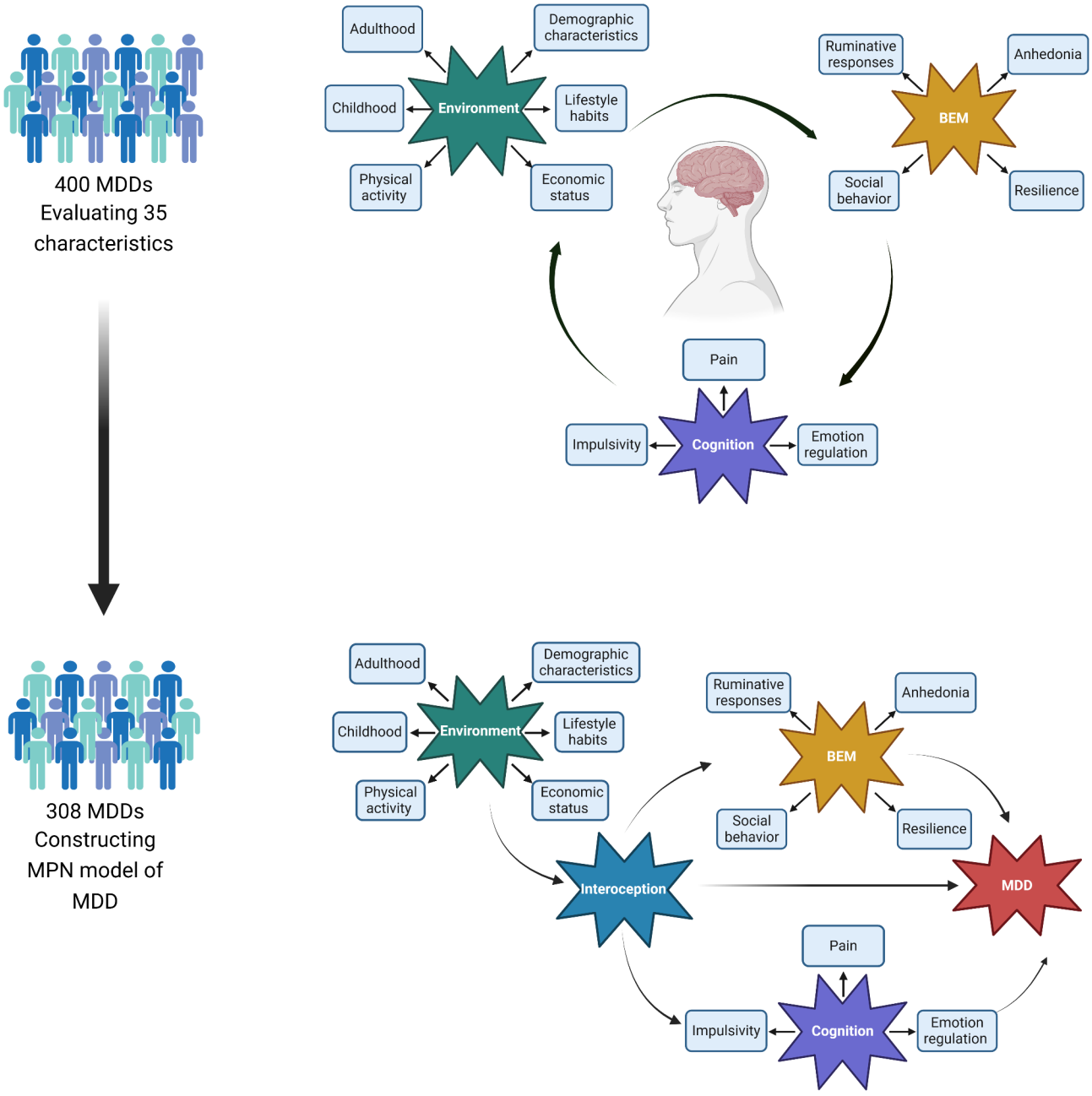

Fig. 1 The flow chart. 400 MDDs participated in the study, and eventually 308 MDDs completed the experiment. EF, CF, and BEM were measured and used to construct a depressive multidimensional psychological structural model. Interoception was placed in the depressive multidimensional psychological structural model to verify its pathways and effects

activity was evaluated by Physical Activity Rating Scale-3 [44].

All of these factors had potential effects on interoception. Providing a comprehensive description of the study population helped to enhance the validity and reliability of the study findings.

Interoception function

The multidimensional assessment of interoception awareness, version 2 (MAIA-2) was used to evaluate interoception [45, 46]. MAIA-2 has 8 dimensions, including (1) noticing, (2) not-distracting, (3) not-worrying, (4) attention regulation, (5) emotional awareness, (6) self-regulation, (7) body listening, and (8) trusting [45]. The higher the score, the higher interoception function.

Environmental factors

We utilized the childhood trauma questionnaire (CTQ) [47] to assess early life environmental factors, focusing on emotional abuse, physical abuse, sexual abuse, emotional

neglect, and physical neglect. Recent environmental factors were evaluated using the social support rating scale (SSRS) [48] and the perceived stress scale (PSS-10) [49], covering dimensions such as subjective support, objective support, support utilization, and psychological stress.

Cognitive function

Impulsivity and emotion regulation were evaluated by the Barratt impulse scale (BIS-11) [50–52], the emotion regulation questionnaire (ERQ) [53, 54]. The total score of the Pain Vigilance and Awareness Questionnaire (PVAQ) [55] reflected pain perception. The main dimensions assessed include trait impulsivity, motor impulsivity, non-planning impulsivity, cognitive reappraisal, expressive suppression, and pain.

Behavioral - emotional manifestations

The Connor-Davidson resilience scale (CD-RISC) [56], the ruminative responses scale (RRS) [57], the temporal experience of pleasure scale (TEPS) [58–61], the Texas social behavior inventory (TSBI) [62] was used to measure participants' behavioral - emotional manifestations.

Eleven traits were obtained as follows. TEPS included abstract anticipatory, contextual anticipatory, abstract consummatory and contextual consummatory. CD-RISC included tenacity, strength, and optimism. RRS included symptom ruminating, contemplation, and reflection. The total score of TSBI reflected sociability.

Assessment of MDD

The patient health questionnaire 9 (PHQ-9) is a standard screening tool for MDD. It is based on the 9 core symptoms of MDD according to the DSM-IV, reflecting the individual's feelings over the past two weeks [63]. The higher the PHQ-9 scores reflected the more severity of MDD.

Statistical analysis

The mean and standard deviation are used when describing numeric variables, and frequency and percentage are used when describing classified variables. Pearson correlation was used to investigate the relationship between interoception and each factor in the depressive multidimensional psychological structural model. The depressive multidimensional psychological structural model was constructed by SEM. Maximum likelihood was used in this study. In the latent factor of IF, we fixed the factor loading of trusting to 1. In the latent factor of EF (childhood trauma, life stress and social support), we fixed the factor loading of perceived stress to 1. In the latent factor of BEM (resilience, rumination, anhedonia, sociability), we fixed the factor loading of reflective ruminations to 1. In the latent factor of CF (impulsivity, emotion regulation, pain), we fixed the factor loading of expressive suppression to 1. In the latent factor of MDD, we fixed the factor loading of PHQ-9 to 1. Firstly, we systematically evaluated the EF, CF, and BEM. Then, in order to elucidate the role of interoception in the depressive multidimensional psychological structural model, we added interoception to the model to verify their role in the overall depressive multidimensional psychological structural model. The goodness of fit of the model was evaluated synthetically by various fitting indexes: $\chi 2$, degrees of freedom (df), $\chi 2/df$ (< 3), Tucker-Lewis index (TLI) (> 0.9), comparative fit index (CFI) (> 0.9), goodness of fit index (GFI) (> 0.9), and root mean square error of approximation (RMSEA < 0.08), and standardized root mean square residual (SRMR ≤ 0.1). The direct (B_{direct}, β_{direct}), indirect ($B_{indirect}$, $\beta_{indirect}$) and total (B_{total}, β_{total}) effects of each pathway in the model were evaluated using the non-standardized (B) and standardized regression (β) coefficient. The effect of the path is described with the standard error and p value of β. The effect of each latent variable in the model on MDD levels was assessed by the total effect. The significance level of all analysis data was set as $\alpha = 0.05$ (double tail). All the optimal SEM was tested by 3000 sample size of Bootstrap [39].

Statistical Package for the Social Sciences (SPSS) software 17.0 and Analysis of Moment Structures (AMOS) software version 19.0 (IBM Corp., Armonk, NY, United States) are used to analyze the data.

Results

Socio-demographic characteristics of participants

The study population primarily consisted of unmarried (71.43%), childless (74.35%) young adults (the average age = 26) with a normal Body Mass Index (BMI) (the average BMI = 21.5). The distribution of males and females is nearly equal (37.99% and 62.01%). All participants had received education at least at the high school level (the average education = 12.88) and generally belonged to lower economic strata (< 300,000 RMB/year: 80%). Most subjects did not smoking (80.84%) or drinking (86.04%) and infrequently consumed tea or coffee (62.66%). Furthermore, they tended to spend more time on social media (> 5 h/day: 53.90%) and exhibited low levels of physical activity (the average physical activity = 10). More detailed socio-demographic characteristics of the participants are show in Table 1.

Relationship between interception and depressive risk factors

Correlation results showed that interoception was associated with all depressive risk factors ($p < 0.05$) in Fig. 2.

Traits that were associated with both interoception and PHQ-9 included the EF such as emotional abuse, emotional neglect, physical abuse and physical neglect

Table 1 Socio-demographic characteristics of participants (Mean ± SD)

Characteristic	*N* = 308	95% CI
Age	26 ± 9	25, 27
Education	12.88 ± 2.88	13, 13
BMI	21.5 ± 4.8	21, 22
Physical Activity	10 ± 15	8.7, 12
Gender		
male	117 (37.99%)	33%, 44%
female	191 (62.01%)	56%, 67%
Marital status		
unmarried	220 (71.43%)	66%, 76%
married	80 (25.97%)	21%, 31%
divorced/widowed	8 (2.60%)	1.2%, 5.3%
Childbearing status		
no children	229 (74.35%)	69%, 79%
one child	69 (22.40%)	18%, 28%
two children	10 (3.25%)	1.7%, 6.1%
Smoking		
no	249 (80.84%)	76%, 85%
yes	59 (19.16%)	15%, 24%
Tea or coffee consumption		
infrequency	193 (62.66%)	57%, 68%
frequency	115 (37.34%)	32%, 43%
Drinking		
no	265 (86.04%)	82%, 90%
yes	43 (13.96%)	10%, 18%
Social media use (per day)		
< 3 h	51 (16.56%)	13%, 21%
3–5 h	91 (29.55%)	25%, 35%
5–8 h	70 (22.73%)	18%, 28%
> 8 h	96 (31.17%)	26%, 37%
Annual household income (Chinese Yuan)		
< 100,000	70 (22.73%)	18%, 28%
100,000-300,000	200 (64.94%)	59%, 70%
300,000-600,000	28 (9.09%)	6.2%, 13%
> 600,000	10 (3.25%)	1.7%, 6.1%

Notes: SD, Standard Deviation; n (%); CI, Confidence Interval; the frequency of tea or coffee consumption is defined as weekly consumption behavior

reflecting childhood trauma, perceived stress reflecting life stress, subjective and objective support reflecting social support. CF included expressive suppression reflecting emotion regulation, pain, and trait impulsivity reflecting impulsivity. BEM included resilience (tenacity, strength, and optimism), rumination (depressive ruminations, reflective ruminations, and brooding ruminations), sociability, and abstract anticipatory reflecting anhedonia. More detailed information is shown in Additional file 2.

The depressive multidimensional psychological structural model

The estimated model is depicted in Fig. 3, with model fit indices indicating a good fit $\chi^2 = 938.0$, df = 127, χ^2 /df = 7.386; RMSEA = 0.144; CFI = 0.691; GFI = 0.698;TLI = 0.584; SRMR = 0.1375. The model fit is far beyond what we can accept, so the estimated model without interoception is currently not valid.

The role of interoception in the depressive multidimensional psychological structural model

The goodness-of-fit indicators of the depressive multidimensional psychological structural model (**See** Fig. 4) incorporating interoception were obtained: $\chi^2 = 510.3$, df = 223, χ^2 /df = 2.288; RMSEA = 0.065; CFI = 0.915; GFI = 0.885;TLI = 0.876; SRMR = 0.099. Interoception connected all the factors in the model. (Shown in Table 2). EF was negatively associated with interoception. The more terrible EF resulted in the lower IF (B = – 0.836, β = – 0.346, $p < 0.001$). IF was negatively associated with BEM and CF. The lower interoception function was associated with the more serious BEM (B = – 0.399, β = – 0.250, $p = 0.031$) and CF (B = – 0.280, β = – 0.525, $p = 0.002$). NO, NW, SR and TR occupied a dominant position in interoception. (Shown in Additional file 3).

Throughout the model, EF and IF accounted for the first and second total effects on MDD, respectively. EF had both direct ($\beta_{direct} = 0.365$, $p < 0.05$) and indirect ($\beta_{indirect} = 0.150$, $p < 0.001$) effects on MDD through IF, and it had the largest cumulative total effect on MDD ($\beta_{total} = 0.516$, $p < 0.001$). 29.1% of the total effect of EF on MDD were produced through IF. IF can have both direct ($\beta_{direct} = -0.309$, $p < 0.001$) and indirect effects ($\beta_{indirect} = -0.126$, $p < 0.05$) on MDD. (Shown in Table 3)

Discussion

This study is the largest sample to verify the role of interoception in the depressive multidimensional psychological structural model which was constructed by the SEM. Firstly, our study found that interoception is significantly associated with the majority of depression-related risk factors. Specifically, interoceptive function was closely linked to core components of the multidimensional psychological structural model of MDD, including EF, CF, and BEM, i.e., the impaired interoceptive sensitivity was correlated with elevated levels of rumination and reduced emotional regulation, which are central cognitive deficits in MDD. Additionally, the diminished interoceptive awareness was associated with anhedonia and deficiencies in social functioning, highlighting its potential impact on behavioral and emotional outcomes. Moreover, the role of interoception in linking adverse early-life events and adult psychosocial stress underscores its significance as a mediator between environmental factors and depressive symptoms. These findings suggest that interoception mediates the interaction among these components.

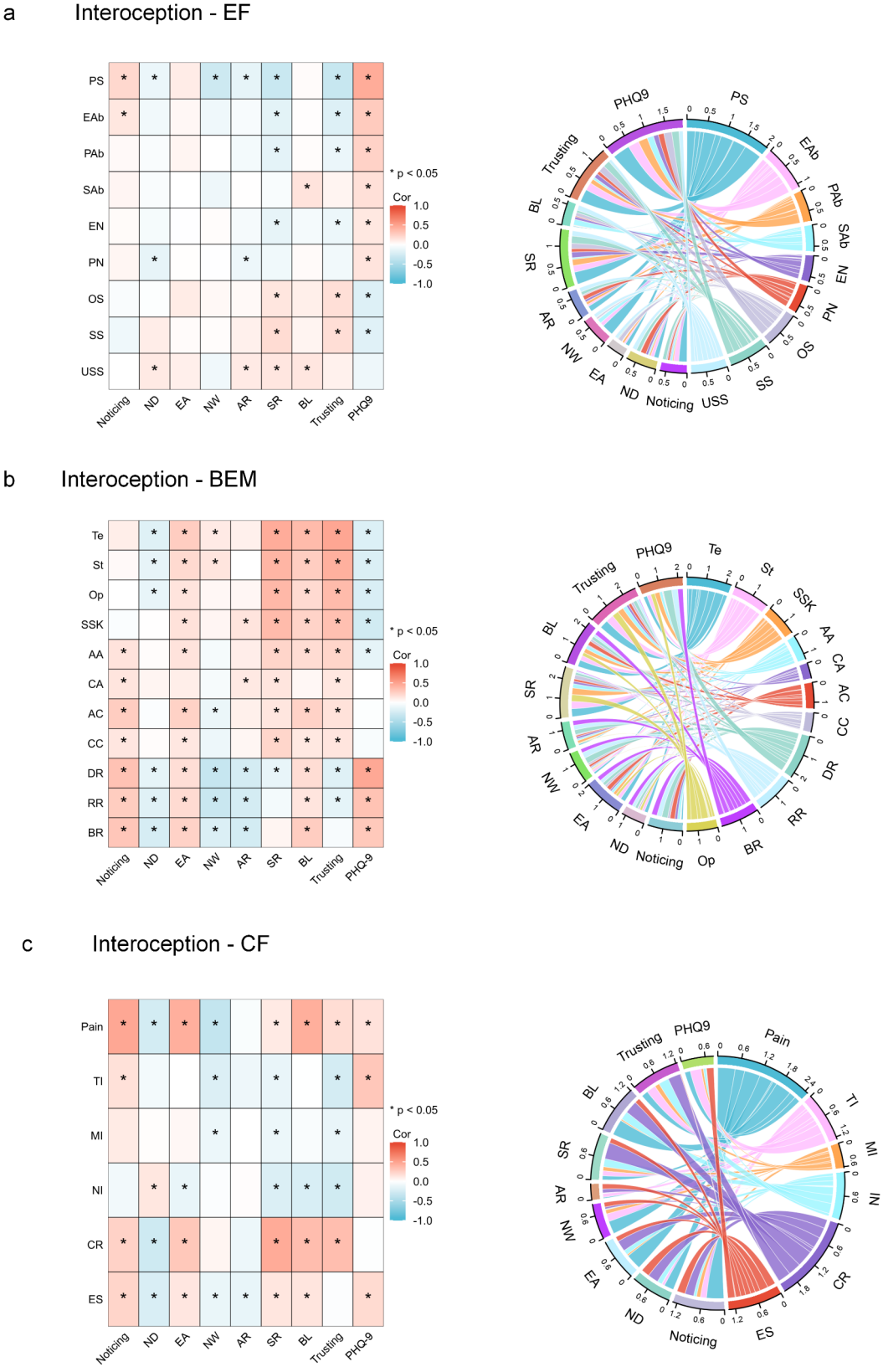

Fig. 2 (See legend on next page.)

(See figure on previous page.)

Fig. 2 The bivariate correlation all factors and interoception in MDD. *$p < 0.05$. Picture a represents the correlation between interoception and EF. PS: perceived stress; EAb: emotional abuse; PAb: physical abuse; SAb: sex abuse; EN: emotional neglect; PN: physical neglect; OS: objective support; SS: subjective support; USS: utilization of social support; ND: not-distracting; EA: emotional awareness; NW: not-worrying; AR: attention regulation; SR: self-regulation; BL: body listening; **2b** represents the correlation between interoception and BEM. Te: tenacity; St: strength; Op: optimism; SSK: social skills; AA: abstract anticipatory; CA: contextual anticipatory; AC: abstract consummatory; CC: contextual consummatory; DR: depressive ruminations; RR: reflective ruminations; BR: brooding ruminations; **2c** represents the correlation between interoception and CF. TI: trait impulsivity; MI: motor impulsivity; NI: nonplanning impulsivity; CR: cognitive reappraisal; ES: expressive suppression

Secondly, our study showed that in this model, the environment factors exert an independent influence on the severity of MDD and are negatively correlated with it, which is similar to the recent findings, i.e., of the five subtypes of childhood trauma, emotional abuse had the strongest association with depression [64]. In the model, the emotion neglect constitutes a significant component of these the environment factors, cognitive function impacts MDD through behavioral-emotional manifestations, and the diminished cognitive function is associated with the more severe behavioral-emotional manifestations. Our finding showed that emotional neglect is the most significant component of environmental factors affecting MDD, which is consistent with previous studies [65, 66]. Our finding highlights the centrality of emotional abuse and neglect to mental health, supporting the childhood trauma-depression model. Additionally, behavioral-emotional manifestations are positively correlated with the severity of MDD, and they have the most substantial impact on the disorder. Based on the above results, the depressive multidimensional psychological structural model elucidated the complex interplay between the environment factors, cognitive function, and MDD. On the one hand, it posits a direct, positive association between the environment factors, specifically emotion neglect, and the severity of MDD, which suggests that poorer environmental conditions could potentially aggravate the symptoms of MDD. This result is consistent with the findings of the previous studies, i.e., the worse the environmental factors, the higher the incidence of depression, and the more severe the depression; in particular, individuals who experienced emotional neglect in childhood had a higher incidence of depression in adulthood than those who did not experience childhood trauma [67–70]. On the other hand, the model suggests that diminished cognitive function exacerbates behavioral-emotional manifestations, which in turn increase the severity of MDD. This pathway aligns with existing literature that underscores the role of cognitive impairments in MDD [7, 71, 72].

Thirdly, our study showed that Interoception predicted all depressive risk factors within the model, i.e., the environment factors, cognitive function and behavioral-emotional manifestations. In particular, interoceptive dysfunction indirectly exacerbates the severity of MDD through cognitive function and behavioral-emotional performance. In this study, the environment factors were negatively associated with interoception, such that poorer environmental conditions were linked to diminished interoception function. Lower interoception function was associated with more severe behavioral-emotional manifestations and impaired cognitive function. The aspects of Noticing, Not-worrying, Self-regulation, and Trusting were prominent in interoception. In this model, the environment factors and interoception function were the primary and secondary total effectors on MDD, respectively. The environment factors exerted both direct and indirect effects on MDD through interoception function, contributing the largest cumulative total effect on MDD. Approximately 29.1% of the total effect of the environment factors on MDD was mediated through interoception function. Interoception function could exert both direct and indirect influences on MDD via cognitive function and behavioral-emotional manifestations. This model emphasizes the role of interoception and the environment factors in influencing MDD. Namely, it employed a comprehensive approach to integrating multiple psychological dimensions and elucidating the pathways through which the environment factors impact MDD via interoception. Our finding suggests that interoceptive function may be the key node connecting a multi-dimensional psychological network.

Summarily, the goodness-of-fit indices for the depressive multidimensional psychological structural model, which incorporates interoception, were obtained. Interoception is a part of the psychological structural model of MDD that predicts environment factors, cognitive function and behavioral-emotional manifestations. It could be a potential intervention point to improve the depressive state as a whole due to the core role of interoception in the depressive multidimensional psychological structural model.

The psychological structural model of MDD is complex and multifaceted. Currently, the diagnosis and treatment of depression is difficult to improve the disease state as a whole through an intervention point. Constructing the psychological structural model of MDD and finding the critical node of the psychological structural model are meaningful for the diagnosis and treatment of MDD. However, while the model provides an interesting

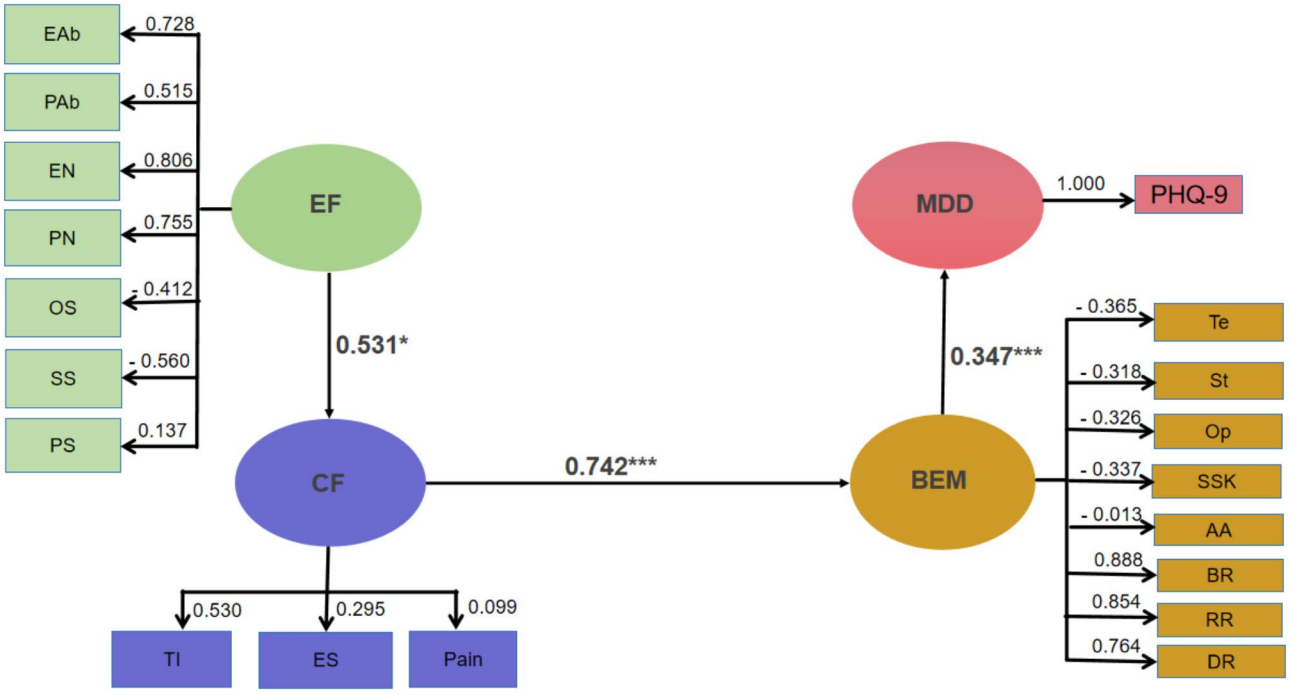

Fig. 3 The estimated model without interoception. Ovals represent the error-adjusted latent variables. One-headed arrows represent standardized direct effects. EF: environmental factors; PS: perceived stress; EAb: emotional abuse; PAb: physical abuse; EN: emotional neglect; PN: physical neglect; OS: objective support; SS: subjective support; BEM: behavioral-emotional manifestations; Te: tenacity; St: strength; Op: optimism; SSK: social skills; AA: abstract anticipatory; DR: depressive ruminations; RR: reflective ruminations; BR: brooding ruminations; CF: cognitive function; TI: trait impulsivity; ES: expressive suppression. MDD: major depressive disorder. Numbers represent the standardized path coefficients; insignificant paths are undescribed. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. All observed variables are depicted in this figure

Table 2 Standardized regression coefficients and standard errors for all pathways of the SEM ($n = 308$)

Path	B	β	S.E.	*p*
EF → IF	-0.836	-0.346	0.238	***
IF → CF	-0.280	-0.525	0.089	0.002
IF → BEM	-0.399	-0.250	0.185	0.031
CF → BEM	2.093	0.698	0.558	***
BEM → MDD	0.251	-0.204	0.124	0.043
IF → MDD	-0.606	-0.309	0.182	***
EF → MDD	1.730	0.365	0.845	0.041

Notes: ***$p < 0.001$; SEM: structural equation modeling; S.E.: standard error; B: non-standardized regression coefficients; β: standardized regression coefficients EF: environmental factors; IF: interoception function; CF: cognitive function; BEM: behavioral-emotional manifestations; MDD: Major depressive disorder

Table 3 Standardized direct effect, indirect effect and total effect of the latent variables on MDD ($n = 308$)

Variables/Effect	Standard direct effect	Standard indirect effect	Standard total effect
EF	0.365	0.150	0.515
IF	−0.309	−0.126	−0.434
CF	-	0.143	0.143
BEM	0.204	-	0.204

perspective on the factors influencing MDD, it requires further empirical validation and a more rigorous theoretical framework to be considered robust in academic discourse. Future research should explore whether enhancing interoceptive function through specific therapeutic interventions, such as mindfulness-based approaches or biofeedback, could mitigate key depressive symptoms.

There is a limitation in our study. We only conducted a cross-sectional study and had a causal relationship analysis to investigate the external risk factors of interoception dysfunction in MDD, therefore, our results are preliminary. Future longitudinal studies on the improvement of interoception function need to be analyzed to further validate our findings.

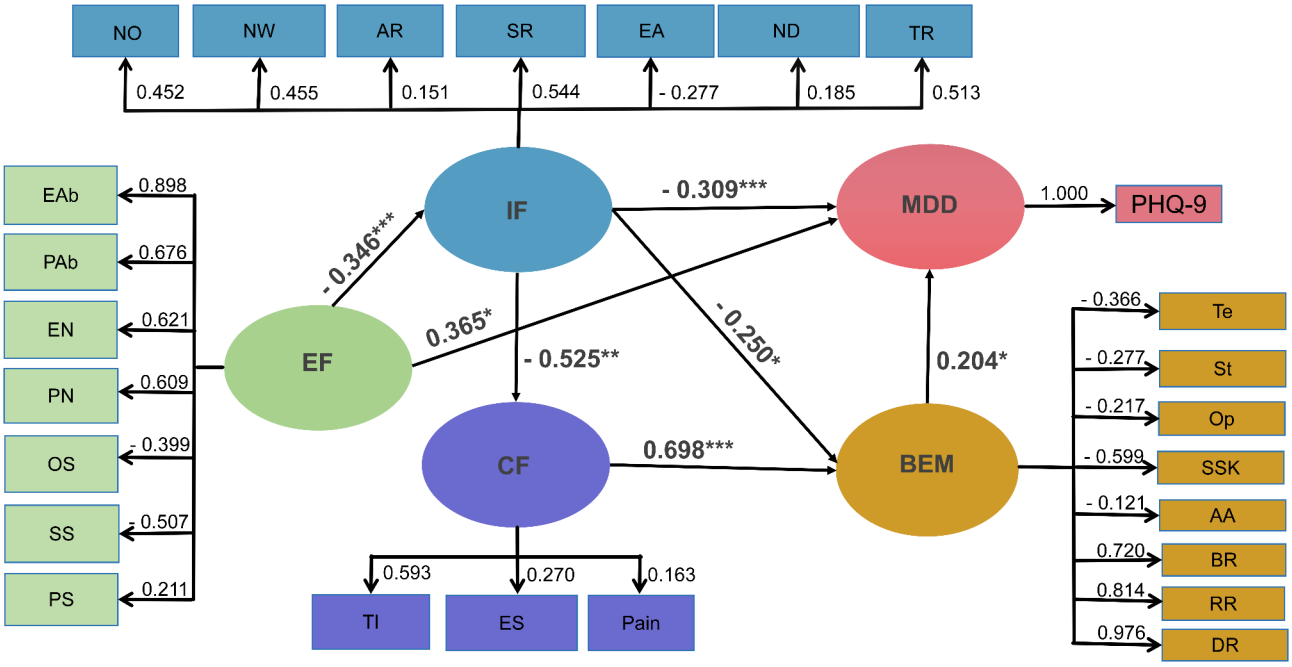

Fig. 4 The fully trimmed final model. Ovals represent the error-adjusted latent variables. One-headed arrows represent standardized direct effects. EF: environmental factors; PS: perceived stress; EAb: emotional abuse; PAb: physical abuse; EN: emotional neglect; PN: physical neglect; OS: objective support; SS: subjective support; BEM: behavioral-emotional manifestations; Te: tenacity; St: strength; Op: optimism; SSK: social skills; AA: abstract anticipatory; DR: depressive ruminations; RR: reflective ruminations; BR: brooding ruminations; CF: cognitive function; TI: trait impulsivity; ES: expressive suppression. MDD: major depressive disorder. IF: interoception function; NO: noticing; ND: not-distracting; EA: emotional awareness; NW: not-worrying; AR: attention regulation; SR: self-regulation; TR: trusting. Numbers represent the standardized path coefficients, unsignificant paths are undescribed. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. All observed variables are depicted in this figure

Conclusions

In conclusion, interoception is a part of the psychological structural model of MDD that predicts environment factors, cognitive function and behavioral-emotional manifestations. It could be a potential intervention point to improve the depressive state as a whole.

Abbreviations

MDD	Major depressive disorder
EF	Environment factors
CF	Cognitive function
BEM	Behavioral-emotional manifestations
MDDs	Major depressive disorder patients
IF	Interoception function
SEM	Structural equation modeling
DSM-V	The Diagnostic and Statistical Manual of Mental Disorders, fifth edition
DSM-IV	The Diagnostic and Statistical Manual of Mental Disorders, fourth edition
BMI	Body mass index
df	Degrees of freedom
TLI	Tucker-lewis index
CFI	Comparative fit index
GFI	Goodness of fit index
RMSEA	Root mean square error of approximation
B	The non-standardized coefficient
β	The standardized regression coefficient

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12888-025-06648-z.

Supplementary Material 1: Detailed description of the scale.

Supplementary Material 2: Correlation results among interoception, most depression risk factors and MDD.

Supplementary Material 3: The factor weights of latent variables.

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Author contributions

Jikang Liu, Jiaxu Li, Tiantian Wang, Yuqing Wu, Hongliang Zhou and Zhenhe Zhou conceptualized, designed, and supervised the study. Jikang Liu and Yuqing Wu collected the data. Xiaohong Liu, Jiaxu Li and Hongliang Zhou performed the data analysis. Jikang Liu wrote the manuscript. Jikang Liu, Tiantian Wang, Yuqing Wu and Xuezheng Gao were responsible for recruiting patients and recording clinical data. All authors revised the manuscript for important intellectual contents and read and approved the final manuscript for submission.

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Data availability

Data will be available to researchers with a signed data access agreement. Data will be made available to researchers whose proposed use of the data has been approved. Data will be made available for any purpose. Data will be available to researchers by hongliangzh@jiangnan.edu.cn.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee on Human Studies (WXMHCIRB2022LLky010), the Affiliated Wuxi Mental Health Center of Nanjing Medical University, China. It was carried out in accordance with the Declaration of Helsinki. The written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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