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Network structure of non-suicidal self-injury and multidomain psychiatric symptoms among adolescents with elevated depressive symptoms: a cross-sectional study

Qin Zhang
Sichuan Province Nanchong Mental Health Center (The Second People's Hospital of Nanchong), No. 55 Baituba Road, Shunqing District

Fan Wang
Wenzhou Medical University

Ke Yang
Sichuan Province Nanchong Mental Health Center (The Second People's Hospital of Nanchong), No. 55 Baituba Road, Shunqing District

Dan Zhao
Sichuan Province Nanchong Mental Health Center (The Second People's Hospital of Nanchong), No. 55 Baituba Road, Shunqing District

Yongqing Lan
Sichuan Province Nanchong Mental Health Center (The Second People's Hospital of Nanchong), No. 55 Baituba Road, Shunqing District

Ke Zhao
Wenzhou Medical University

Wei Tang
Sichuan Province Nanchong Mental Health Center (The Second People's Hospital of Nanchong), No. 55 Baituba Road, Shunqing District

Yunfei Jia
fei813787500@163.com

Qingdao Zhengyang Psychiatric Hospital

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Abstract

Background

Non-suicidal self-injury (NSSI) commonly co-occurs with depressive symptoms during adolescence, but its position within broader symptom-domain systems among adolescents with elevated depressive symptoms remains unclear. Examining this PHQ-defined subgroup may clarify whether NSSI is primarily linked with depressive symptoms or also connected with other domains relevant to follow-up assessment. This study examined how NSSI was embedded within a multidomain psychiatric symptom network among school-based adolescents with Patient Health Questionnaire (PHQ) module scores of 5 or higher.

Methods

This cross-sectional school-based screening study included 1,146 adolescents who met the Patient Health Questionnaire (PHQ) ≥ 5 inclusion criterion and had complete data on 10 symptom-domain nodes. A Spearman correlation matrix and EBICglasso were used to estimate the primary network. Signed-spinglass community detection with repeated seeds and 1,000 case-bootstrap networks was used to identify and validate data-driven communities. Node predictability, centrality, bridge expected influence, bootstrap stability, and relative importance analyses characterized symptom-domain organization and explained-variance patterns.

Results

The final network contained 43 nonzero edges among 45 possible edges. Signed-spinglass community detection identified a reproducible two-community organization: a core symptom community containing Ma, Pa, PTSD, GAD, PHQ, OCD, and NSSI, and a separation/social/school anxiety community containing SeP, SoP, and ScP. The two-community solution occurred in 999 of 1,000 case-bootstrap networks. Depressive symptoms showed the highest strength, one-step expected influence, two-step expected influence, and predictability. Bridge expected influence was highest for separation anxiety, school anxiety, and social anxiety symptoms, followed by depressive and obsessive-compulsive symptoms. NSSI showed moderate predictability ($R^2 = 0.246$), and depressive symptoms made the largest relative-importance contribution to NSSI explained variance.

Conclusions

Among adolescents with elevated depressive symptoms, NSSI was linked most closely with depressive, trauma-related, obsessive-compulsive, and generalized anxiety symptom domains. The findings suggest that NSSI in this subgroup was associated with depressive symptoms but was not limited to mood-

related distress. Screening and follow-up assessment for adolescents with elevated depressive symptoms may benefit from considering trauma-related, repetitive/intrusive, and worry-related symptoms alongside depressive severity and NSSI. Because the data were cross-sectional and based on screening-domain scores, the findings should be interpreted as descriptive symptom-domain associations rather than causal pathways.

Background

Non-suicidal self-injury (NSSI) is a major adolescent mental health concern because it commonly emerges during a developmental period characterized by rapid emotional, interpersonal, and academic changes [1, 2]. Although NSSI is defined by self-inflicted injury without suicidal intent [3], it is consistently associated with psychological distress, functional impairment [4, 5], and elevated future risk for suicidal thoughts and behaviors [6]. School-based screening is therefore important, particularly because many adolescents with self-injury-related distress may not initially present in specialist clinical settings [7, 8]. In this context, identifying how NSSI is embedded within broader symptom patterns may help inform more comprehensive follow-up assessment after screening.

Depressive symptoms provide a clinically important context for understanding adolescent NSSI [9]. Prior reviews and meta-analyses have linked NSSI with depression and other emotional disorders [10], and functional models suggest that self-injury may be used to regulate intense negative affect or distressing internal states [11, 12], while self-critical thoughts have also been associated with NSSI [13]. However, depressive symptoms commonly co-occur with other psychiatric symptoms [14, 15]. Adolescents with elevated depressive symptoms may also experience panic symptoms, generalized worry, social and separation anxiety, school-related anxiety, trauma-related symptoms, obsessive-compulsive or intrusive/repetitive symptoms [16], and affective activation [17]. An elevated-depressive-symptom screening subgroup may therefore show a compact symptom system in which NSSI is related not only to mood severity but also to multiple co-occurring domains of distress.

This broader symptom-domain perspective is especially relevant because several mechanisms linked to NSSI extend beyond depression alone [18, 19]. Trauma and childhood maltreatment have been associated with NSSI [20], supporting the importance of trauma-related distress and emotion regulation difficulties [21]. Rumination and repetitive negative thinking are also consistently related to NSSI [22, 23] and may provide a conceptual bridge between depressive distress, worry, intrusive thoughts, and self-injury-related urges [24, 25]. In addition, obsessive-compulsive symptoms (OCD) in screening data may reflect intrusive or repetitive mental content rather than a formal obsessive-compulsive disorder diagnosis [26], so any NSSI-OCD association should be interpreted cautiously [27]. These considerations suggest that, among adolescents with elevated depressive symptoms, NSSI should be examined within a multidomain symptom system rather than as an isolated correlate of depression.

Network analysis offers a useful framework for this question because it estimates conditional associations among symptom domains after accounting for the other domains in the network [28]. In

such models, nodes represent symptoms or symptom domains, and edges represent pairwise associations conditioned on the remaining nodes [29]. Centrality indices can describe which nodes are most strongly connected [30], while bridge expected influence can identify nodes that connect predefined symptom communities [31]. Node predictability further quantifies the proportion of variance in a node that can be explained by the rest of the network [32]. Relative importance analysis can complement the network model by decomposing explained variance in cross-sectional regression models, thereby showing which domains contribute most to each target node's explained variance [33]. Because centrality and directed explained-variance contributions do not establish causality, these indices are best interpreted as descriptive indicators of symptom-domain organization [34].

Previous adolescent network studies have examined depression, anxiety, and NSSI-related symptoms, including recent work in Chinese adolescent samples [35, 36]. However, less is known about how NSSI is positioned within a broad symptom-domain network specifically among school-based adolescents who already show elevated depressive symptoms. This distinction matters because restricting the sample to adolescents with Patient Health Questionnaire (PHQ) scores of 5 or higher may change the organization of NSSI-related associations [37]: depressive symptoms may remain the dominant organizing feature, or trauma-related, repetitive/intrusive, worry-related, and anxiety-arousal symptoms may become particularly informative. The present study therefore examined a 10-node symptom-domain network among adolescents with PHQ module scores of 5 or higher. The network included depressive symptoms, NSSI, panic symptoms, generalized anxiety symptoms, separation anxiety symptoms, social anxiety symptoms, school anxiety symptoms, post-traumatic stress disorder (PTSD) symptoms, obsessive-compulsive symptoms, and mania/hypomania-related symptoms. We aimed to estimate the primary network structure, identify NSSI-related connections, detect and validate community structure, evaluate centrality, bridge expected influence, predictability, and bootstrap stability, and use relative importance analysis to characterize explained-variance contribution patterns. Based on the elevated-depressive-symptom nature of the sample, we expected depressive symptoms to be highly connected, while NSSI would also show links with trauma-related, repetitive/intrusive, and anxiety-related symptom domains.

Methods

Study design and participants

This cross-sectional, school-based screening study was conducted in six junior and senior high schools in Ngawa Tibetan and Qiang Autonomous Prefecture, Sichuan Province, China, from October 2022 to April 2023. Students aged 12–18 years completed the screening questionnaires independently in group settings. Eligibility required sufficient Chinese-language comprehension and the ability to complete the questionnaire independently. Severe physical illness, cognitive impairment affecting questionnaire completion, ongoing psychiatric medication or psychological treatment, and invalid responses were exclusion criteria.

A total of 2,586 adolescents participated in the original survey. After excluding 207 participants who did not meet the eligibility criteria and 26 low-quality or invalid questionnaires, the cleaned parent sample comprised 2,353 adolescents. For the present analysis, 1,207 adolescents with PHQ scores below 5 were excluded. The final analytic sample included 1,146 adolescents with PHQ scores of 5 or higher, all of whom had complete data on the 10 retained network nodes. No missing-data imputation was performed (Supplementary Figure S1).

Measures and network nodes

A school-based mental health screening tool was used to assess NSSI and related psychiatric symptoms. Ten symptom-domain nodes were retained: mania/hypomanic symptoms (Ma), panic symptoms (Pa), separation anxiety symptoms (SeP), social anxiety symptoms (SoP), school anxiety symptoms (ScP), post-traumatic stress disorder (PTSD) symptoms, generalized anxiety symptoms (GAD), depressive symptoms (PHQ), obsessive-compulsive symptoms (OCD), and NSSI. The analysis focused on mood-, anxiety-, trauma/OCD-, and NSSI-related domains relevant to the research question. Item counts, scoring rules, time frames, and representative content are summarized in Additional file 1: Supplementary Table S1.

The five anxiety-related nodes were derived from the corresponding Screen for Child Anxiety Related Emotional Disorders domains [38, 39]. PTSD symptoms were assessed with a Child PTSD Symptom Scale-derived module [40], depressive symptoms with the PHQ-9 module [41–43], OCD symptoms with a Short OCD Screener-derived module [26], and mania/hypomania-related symptoms with a Child Mania Rating Scale-derived module [44]. The NSSI node was a five-item NSSI-AT-derived screening module [45, 46]. The resulting NSSI module score ranged from 0 to 6, with higher values indicating greater endorsement of NSSI-related behaviors or characteristics. The primary analyses used the raw score, and ordinal scoring was examined in sensitivity analysis.

Four nodes from the broader screening framework were not retained in the primary 10-node network. Medication/substance-related exclusion and medical disease-related exclusion items were excluded because they represented exclusion-related indicators rather than symptom domains. Tic symptoms and conduct-related symptoms were excluded because they were outside the focused mood-, anxiety-, trauma/OCD-, and NSSI-related scope of the present manuscript. The retained node dictionary and excluded-node rationale are provided in Supplementary Table S1.

All network nodes were analyzed as module-level raw scores. Higher scores indicated greater symptom severity or stronger endorsement of the corresponding domain. Elevated depressive symptoms were operationally defined as a PHQ score of 5 or higher, corresponding to at least mild depressive symptom severity. This screening threshold does not constitute a clinical diagnosis of depressive disorder. PHQ was retained in the primary network because depressive symptom severity was both the cohort-defining construct and a central part of the research question.

For descriptive purposes in Table 1, predefined module screening categories were also summarized for Ma, Pa, SeP, SoP, ScP, PTSD, GAD, PHQ, and OCD. The thresholds used to define positive screening categories were Ma ≥ 3, Pa ≥ 7, SeP ≥ 5, SoP ≥ 8, ScP ≥ 3, PTSD > 15, GAD ≥ 9, PHQ > 9, and OCD > 0. NSSI was summarized as a raw score only and was not dichotomized in Table 1. The PHQ ≥ 5 criterion used to define the analytic cohort was therefore distinct from the PHQ > 9 positive screening category shown in Table 1.

Table 1
Baseline characteristics by sex among adolescents with elevated depressive symptoms

Characteristic	Category	Total	Male	Female	Statistic	P value	Effect size
Educational stage	Junior high school	407 (35.5%)	177 (31.0%)	230 (40.0%)	χ^2 = 10.14	0.001	V = 0.094
	Senior high school	739 (64.5%)	394 (69.0%)	345 (60.0%)			
Age group	< 15 years	367 (32.0%)	157 (27.5%)	210 (36.5%)	χ^2 = 10.72	0.001	V = 0.097
	≥ 15 years	779 (68.0%)	414 (72.5%)	365 (63.5%)			
Age, years	Score, mean ± SD	15.10 ± 1.58	15.29 ± 1.44	14.92 ± 1.68	t = 4.02	< 0.001	d = 0.238
Ma	Score, mean ± SD	1.14 ± 2.00	1.11 ± 2.01	1.16 ± 1.99	t = -0.45	0.653	d = -0.027
	Positive, n (%)	262 (22.9%)	128 (22.4%)	134 (23.3%)	χ^2 = 0.13	0.721	V = 0.011
	Negative, n (%)	884 (77.1%)	443 (77.6%)	441 (76.7%)			
Pa	Score, mean ± SD	3.11 ± 5.76	2.66 ± 5.37	3.55 ± 6.09	t = -2.62	0.009	d = -0.155
	Positive, n (%)	255 (22.3%)	111 (19.4%)	144 (25.0%)	χ^2 = 5.20	0.023	V = 0.067
	Negative, n (%)	891 (77.7%)	460 (80.6%)	431 (75.0%)			
SeP	Score, mean ± SD	3.06 ± 3.43	2.43 ± 3.07	3.69 ± 3.66	t = -6.35	< 0.001	d = -0.375
	Positive, n (%)	368 (32.1%)	142 (24.9%)	226 (39.3%)	χ^2 = 27.39	< 0.001	V = 0.155

1) The analytic sample met the PHQ ≥ 5 criterion. Values are mean ± SD or n (%). Continuous variables were compared using independent-samples t-tests; categorical variables were compared using chi-square tests.

2) Effect sizes are Cohen's d for continuous variables and Cramer's V for categorical variables. Positive screening categories were defined using the prespecified module thresholds reported in the Methods.

3) PHQ = Patient Health Questionnaire depressive symptom module; NSSI = non-suicidal self-injury; Ma = mania/hypomanic symptoms; Pa = panic symptoms; SeP = separation anxiety symptoms; SoP = social anxiety symptoms; ScP = school anxiety symptoms; PTSD = post-traumatic stress symptoms; GAD = generalized anxiety symptoms; OCD = obsessive-compulsive symptoms.

Characteristic	Category	Total	Male	Female	Statistic	P value	Effect size
	Negative, n (%)	778 (67.9%)	429 (75.1%)	349 (60.7%)			
SoP	Score, mean ± SD	5.64 ± 5.19	4.96 ± 5.09	6.31 ± 5.20	t = -4.46	< 0.001	d = -0.263
	Positive, n (%)	453 (39.5%)	197 (34.5%)	256 (44.5%)	χ^2 = 12.04	< 0.001	V = 0.102
	Negative, n (%)	693 (60.5%)	374 (65.5%)	319 (55.5%)			
ScP	Score, mean ± SD	1.10 ± 2.13	0.88 ± 1.93	1.31 ± 2.29	t = -3.44	< 0.001	d = -0.203
	Positive, n (%)	243 (21.2%)	97 (17.0%)	146 (25.4%)	χ^2 = 12.11	< 0.001	V = 0.103
	Negative, n (%)	903 (78.8%)	474 (83.0%)	429 (74.6%)			
PTSD	Score, mean ± SD	3.20 ± 9.51	2.63 ± 8.54	3.76 ± 10.37	t = -2.02	0.044	d = -0.119
	Positive, n (%)	119 (10.4%)	49 (8.6%)	70 (12.2%)	χ^2 = 3.97	0.046	V = 0.059
	Negative, n (%)	1027 (89.6%)	522 (91.4%)	505 (87.8%)			
GAD	Score, mean ± SD	2.60 ± 5.38	1.99 ± 4.70	3.20 ± 5.92	t = -3.83	< 0.001	d = -0.226
	Positive, n (%)	199 (17.4%)	74 (13.0%)	125 (21.7%)	χ^2 = 15.39	< 0.001	V = 0.116
	Negative, n (%)	947 (82.6%)	497 (87.0%)	450 (78.3%)			
PHQ	Score, mean ± SD	8.93 ± 4.03	8.78 ± 3.87	9.07 ± 4.19	t = -1.21	0.226	d = -0.072

1) The analytic sample met the PHQ ≥ 5 criterion. Values are mean ± SD or n (%). Continuous variables were compared using independent-samples t-tests; categorical variables were compared using chi-square tests.

2) Effect sizes are Cohen's d for continuous variables and Cramer's V for categorical variables. Positive screening categories were defined using the prespecified module thresholds reported in the Methods.

3) PHQ = Patient Health Questionnaire depressive symptom module; NSSI = non-suicidal self-injury; Ma = mania/hypomanic symptoms; Pa = panic symptoms; SeP = separation anxiety symptoms; SoP = social anxiety symptoms; ScP = school anxiety symptoms; PTSD = post-traumatic stress symptoms; GAD = generalized anxiety symptoms; OCD = obsessive-compulsive symptoms.

Characteristic	Category	Total	Male	Female	Statistic	P value	Effect size
	Positive, n (%)	342 (29.8%)	165 (28.9%)	177 (30.8%)	$\chi^2 = 0.49$	0.485	V = 0.021
	Negative, n (%)	804 (70.2%)	406 (71.1%)	398 (69.2%)			
OCD	Score, mean ± SD	0.62 ± 0.74	0.62 ± 0.74	0.62 ± 0.73	t = 0.18	0.858	d = 0.011
	Positive, n (%)	534 (46.6%)	266 (46.6%)	268 (46.6%)	$\chi^2 = 0.00$	0.994	V = 0.000
	Negative, n (%)	612 (53.4%)	305 (53.4%)	307 (53.4%)			
NSSI	Score, mean ± SD	0.70 ± 1.35	0.48 ± 1.09	0.91 ± 1.54	t = -5.47	< 0.001	d = -0.323
1) The analytic sample met the PHQ ≥ 5 criterion. Values are mean ± SD or n (%). Continuous variables were compared using independent-samples t-tests; categorical variables were compared using chi-square tests.							
2) Effect sizes are Cohen's d for continuous variables and Cramer's V for categorical variables. Positive screening categories were defined using the prespecified module thresholds reported in the Methods.							
3) PHQ = Patient Health Questionnaire depressive symptom module; NSSI = non-suicidal self-injury; Ma = mania/hypomanic symptoms; Pa = panic symptoms; SeP = separation anxiety symptoms; SoP = social anxiety symptoms; ScP = school anxiety symptoms; PTSD = post-traumatic stress symptoms; GAD = generalized anxiety symptoms; OCD = obsessive-compulsive symptoms.							

Baseline descriptive analysis

Baseline characteristics were summarized for the total analytic sample and by sex. Continuous variables were described using mean and standard deviation and compared between males and females using independent-samples t tests. Categorical variables were described using counts and percentages and compared using chi-square tests or Fisher exact tests when appropriate. Effect sizes were summarized using Cohen's d for continuous variables and Cramer's V for categorical variables.

Primary network estimation

The primary symptom-domain network was estimated as a Gaussian graphical model. Nodes represented symptom-domain variables, and edges represented conditional associations after accounting for the remaining nodes. Because symptom-domain scores could show non-normal distributions, the network was estimated from a Spearman correlation matrix.

Regularized partial-correlation networks were estimated using EBICglasso with gamma = 0.5 and threshold = FALSE. The resulting edge-weight matrix was used to summarize nonzero edges, network density, and mean absolute nonzero edge weight. Network visualization used a spring layout, and edge thickness represented the magnitude of the estimated edge weight.

Node predictability

Node predictability was estimated as the proportion of variance in each node explained by all remaining nodes. For each target node, a nodewise linear model was fitted with the other nine nodes entered as predictors, and the model R^2 was extracted. Predictability was visualized as an outer ring around each node in Fig. 1.

Data-driven community detection and bridge centrality

Community structure was evaluated from the regularized signed partial-correlation network rather than assigned manually. The primary partition was obtained using signed spinglass community detection on the signed edge-weight matrix [47]. Because spinglass is stochastic, the full network was fitted using 100 prespecified random seeds, and the modal node partition was retained. This procedure identified a core symptom community containing Ma, Pa, PTSD, GAD, PHQ, OCD, and NSSI and a separation/social/school anxiety community containing SeP, SoP, and ScP.

As a stability check, the network was re-estimated in 1,000 case-bootstrap resamples. Signed spinglass was rerun with 10 seeds within each resample, and the modal partition was retained. Walktrap was recorded as an exploratory magnitude-based partition using absolute edge weights but was not used as the primary definition because the formal analysis retained signed edge information.

Bridge expected influence was calculated using the locked signed-spinglass communities. One-step bridge expected influence was defined as the sum of signed edge weights connecting a node to nodes in the other community. Bridge values quantify cross-community statistical connectivity and do not represent causal transmission, temporal direction, diagnostic boundaries, or treatment-target priority.

Node centrality was evaluated using strength, one-step expected influence, two-step expected influence, and one-step bridge expected influence. Strength summed absolute edge weights, whereas expected influence retained their signs. Two-step expected influence summarized direct and indirect two-step connectivity.

Bootstrap accuracy and centrality stability

Nonparametric bootstrap analysis used 1,000 samples to examine edge-weight accuracy and edge/centrality difference tests. Case-dropping bootstrap analysis used 1,000 samples to evaluate the stability of strength and expected influence. Correlation stability coefficients above 0.50 were interpreted

as acceptable for descriptive interpretation. The separate 1,000-resample community-validation procedure described above assessed reproducibility of the community partition and was distinct from the bootnet accuracy and case-dropping analyses.

Relative importance analysis

Relative importance analysis was conducted as a complementary explained-variance analysis. For each target node, a linear regression model was fitted with the remaining nine nodes entered as predictors. The model R^2 was used to summarize the total explained variance of each target node.

The contribution of each predictor to the target-node R^2 was estimated using the Lindeman-Merenda-Gold (LMG) approach implemented through relative-importance decomposition [33]. LMG estimates were available for all target-node models. Because the NSSI module score was bounded and zero-concentrated, its outcome model was additionally examined using a rank-normalized NSSI score, ordinal logistic regression across scores 0–6, and binary logistic regression using the prespecified screening cutoff of NSSI > 3. These analyses evaluated whether the leading NSSI-related predictors depended on the continuous-outcome specification (Supplementary Table S2).

For visualization, the relative importance network retained the top 40 directed explained-variance contribution edges. These directed edges represent predictor contributions to outcome R^2 in cross-sectional linear models and were interpreted as noncausal explained-variance contributions, not as causal or temporal pathways.

Software

All analyses were conducted in R. Data management and table generation used readr, dplyr, tidyr, openxlsx, and related packages. Network estimation and visualization used qgraph and bootnet [29, 48]. Centrality and bridge centrality analyses used qgraph, igraph, networktools, and custom summary code. Relative importance analyses used relaimpo [33], and ordinal and logistic outcome sensitivities used MASS and base R functions.

Results

Sample characteristics

Among 2,353 screened adolescents, 1,146 participants met the PHQ ≥ 5 inclusion criterion and had complete data on the 10 selected network nodes. The analytic sample included 571 males and 575 females. The mean age was 15.10 years (SD = 1.58), and males were older than females on average (15.29 +/- 1.44 vs. 14.92 +/- 1.68 years; t = 4.02, P < 0.001, d = 0.238). Senior high school students accounted for 64.5% of the sample, and educational stage differed by sex (chi-square = 10.14, P = 0.001, Cramer's V = 0.094).

Using the predefined module screening cutoffs summarized in the Methods, OCD showed the highest positive screening rate (46.6%), followed by SoP (39.5%), SeP (32.1%), PHQ (29.8%), Ma (22.9%), Pa (22.3%), ScP (21.2%), GAD (17.4%), and PTSD (10.4%). The PHQ positive screening rate refers to the PHQ > 9 category used for descriptive Table 1 reporting and is distinct from the PHQ ≥ 5 criterion used to define the analytic cohort. Compared with males, females showed higher scores or positive screening rates for several anxiety-related and trauma-related domains, including Pa, SeP, SoP, ScP, PTSD, and GAD. Females also had higher NSSI scores than males (0.91 +/- 1.54 vs. 0.48 +/- 1.09; t = -5.47, P < 0.001, d = -0.323). Baseline characteristics are summarized in Table 1.

Primary 10-node symptom network

The primary network was estimated using Spearman correlations and EBICglasso with gamma = 0.5 and threshold = FALSE. The final 10-node network contained 43 nonzero edges among 45 possible edges, corresponding to a network density of 0.9556. The mean absolute nonzero edge weight was 0.0907. Because the estimated network was dense, especially small edge weights should be interpreted cautiously.

The strongest edges in the network were SeP-SoP (weight = 0.209), GAD-PHQ (weight = 0.201), Pa-OCD (weight = 0.170), Ma-Pa (weight = 0.163), and PTSD-OCD (weight = 0.147). The strongest NSSI-related edges were PHQ-NSSI (weight = 0.138), PTSD-NSSI (weight = 0.122), OCD-NSSI (weight = 0.105), and GAD-NSSI (weight = 0.085). These findings indicate that, within adolescents with elevated depressive symptoms, NSSI had its strongest local conditional associations with depressive, trauma-related, obsessive-compulsive, and generalized anxiety symptom domains (Fig. 1; Supplementary Table S3; Supplementary Tables S4 and S5).

Data-driven community structure

Signed spinglass community detection was used to identify communities from the signed regularized partial-correlation network. Across 100 random seeds applied to the full network, the modal partition occurred in 93 runs and contained two communities. The core symptom community included Ma, Pa, PTSD, GAD, PHQ, OCD, and NSSI. The separation/social/school anxiety community included SeP, SoP, and ScP.

The community count was highly reproducible in case-bootstrap validation. Across 1,000 bootstrap re-estimations of the network, signed spinglass produced two communities in 999 resamples (99.9%) and three communities in one resample (0.1%). This result supports the two-community solution as the primary data- driven organization of the network. The community assignment was used for node colours in Fig. 1 and for bridge expected influence in Fig. 2 and Supplementary Table S6.

Sensitivity results were dependent on the EBIC tuning parameter. Under gamma = 0.5, the mild, moderate, and PHQ ≥ 15 networks retained 33, 0, and 21 of 36 possible edges, respectively; the moderate network was selected as empty. Under gamma = 0, the corresponding networks retained 33, 27, and 21 edges. Gamma = 0 yielded no Holm-adjusted pairwise difference in global strength or network structure.

Under gamma = 0.5, the moderate-versus-PHQ ≥ 15 and mild-versus-PHQ ≥ 15 structure comparisons reached Holm-adjusted significance (both P = 0.033); the former comparison involved the empty moderate network, and neither finding was reproduced under gamma = 0. Equal-size repeated samples supported an ordered mild < moderate < PHQ ≥ 15 global-strength pattern in only 9.0% and 14.2% of repetitions under gamma = 0.5 and gamma = 0, respectively (Supplementary Table S7; Supplementary Figure S2).

In the full analytic sample, excluding PHQ produced a dense nine-node network with 34 of 36 nonzero edges under gamma = 0.5 and 35 of 36 under gamma = 0. The NSSI neighborhood remained most strongly connected with OCD, PTSD, and GAD, indicating that the multidomain NSSI pattern was not solely produced by retaining PHQ as a node (Supplementary Table S8).

Node predictability

Node predictability ranged from $R^2 = 0.202$ to $R^2 = 0.367$. The highest predictability values were observed for PHQ ($R^2 = 0.367$), Pa ($R^2 = 0.348$), and GAD ($R^2 = 0.336$), followed by OCD ($R^2 = 0.273$) and NSSI ($R^2 = 0.246$). These results indicate that depressive symptoms, panic symptoms, and generalized anxiety symptoms had the largest proportions of variance explained by the remaining nodes in the network. NSSI also showed moderate predictability, with approximately one quarter of its variance explained by the other symptom-domain nodes. In Fig. 1, the outer ring around each node represents node predictability (Supplementary Table S6).

Centrality and bridge centrality

Centrality analyses indicated that PHQ was the most central node in the primary network. PHQ ranked first for strength (0.960), one-step expected influence (0.960), and two-step expected influence (1.682). Pa, OCD, and GAD also ranked consistently high across the main centrality indices. For strength, the top five nodes were PHQ, Pa, OCD, GAD, and SoP. For one-step expected influence, the top five nodes were PHQ, Pa, OCD, GAD, and SeP. For two-step expected influence, the top five nodes were PHQ, Pa, OCD, GAD, and SeP. Using the signed-spinglass two-community solution, bridge expected influence was highest for SeP (0.434), followed by ScP (0.426), SoP (0.334), PHQ (0.246), and OCD (0.238). Pa (0.223) and GAD (0.206) showed intermediate values, whereas NSSI (0.128), Ma (0.078), and PTSD (0.075) had lower bridge expected influence under this partition. These values describe signed cross-community statistical connectivity and should not be interpreted as causal transmission or treatment- target rankings (Fig. 2; Supplementary Table S6).

Bootstrap accuracy and centrality stability

Bootstrap analyses were conducted with 1,000 bootstrap samples. Case-dropping bootstrap analyses suggested acceptable centrality stability. The CS coefficient was 0.672 for expected influence and 0.517 for strength. Because both values exceeded 0.50, the centrality estimates were considered sufficiently stable for descriptive interpretation. Edge-weight bootstrap confidence intervals, edge-weight difference tests, centrality difference tests, and case-dropping stability plots are provided in the supplementary

materials (Supplementary Figures S3–S5; Supplementary Table S3). The separate community-validation bootstrap supported the signed-spinglass two-community solution in 999 of 1,000 resamples.

Relative importance network

Relative importance analysis was used as a complementary explained-variance approach. The highest outcome R^2 values were observed for PHQ ($R^2 = 0.367$), Pa ($R^2 = 0.348$), GAD ($R^2 = 0.336$), OCD ($R^2 = 0.273$), and NSSI ($R^2 = 0.246$), which was consistent with the node predictability results.

The largest directed explained-variance contribution was PHQ → GAD (raw R^2 contribution = 0.094; relative contribution within outcome = 28.0%), followed by GAD → PHQ (raw R^2 contribution = 0.092; relative contribution = 25.1%), Pa → GAD (raw R^2 contribution = 0.064; relative contribution = 19.1%), GAD → Pa (raw R^2 contribution = 0.064; relative contribution = 18.3%), and PHQ → Pa (raw R^2 contribution = 0.057; relative contribution = 16.3%). For NSSI, PHQ made the largest explained-variance contribution (raw R^2 contribution = 0.053; relative contribution = 21.6%). These directed relative-importance edges describe cross-sectional explained-variance contributions and should not be interpreted as causal or temporal pathways (Fig. 3; Supplementary Tables S9 and S6).

The raw-score and rank-normalized NSSI relative-importance models produced the same predictor ordering, with PHQ contributing most, followed by PTSD, OCD, Pa, and GAD. PHQ also remained the leading predictor in ordinal and binary outcome sensitivities, although the ordering of secondary predictors varied across specifications. These findings support the robustness of the leading PHQ contribution but warrant caution when interpreting the exact ranking of other NSSI predictors (Supplementary Table S2).

Discussion

This study examined how NSSI was positioned within a 10-node symptom-domain network among adolescents with elevated depressive symptoms. NSSI was embedded in a local neighborhood involving depressive, PTSD, obsessive-compulsive, and generalized anxiety symptoms. Depressive symptoms were the most central and most predictable domain and made the largest explained-variance contribution to NSSI. In addition, data-driven community detection identified a reproducible two-community organization rather than the three manually specified domains used in the earlier analysis. Separation, social, and school anxiety symptoms formed one community, whereas mania/hypomania-related, panic, PTSD, generalized anxiety, depressive, obsessive-compulsive, and NSSI symptoms formed a broader core symptom community. Together, these findings suggest that NSSI in this depression-enriched sample was closely related to depressive severity but situated within a wider, densely connected symptom system.

A dense symptom-domain network in a depression-enriched subgroup

The primary network was highly dense, with 43 nonzero edges among 45 possible edges. This density should be interpreted in relation to the sample definition [37]. Because all participants had PHQ module scores of 5 or higher, the network was estimated in a subgroup already enriched for depressive symptoms rather than in an unselected adolescent population. Anxiety, trauma-related symptoms, repetitive or intrusive symptoms, activation-related symptoms, school anxiety, and NSSI co-occurred and remained conditionally connected in the selected sample, although the contribution of the PHQ inclusion criterion to this pattern cannot be determined. The observed coupling between depressive and anxiety symptoms is consistent with prior adolescent network research [49].

The strongest edges help characterize this compact symptom system. The SeP-SoP edge indicates close statistical coupling between separation and social anxiety symptoms, while the GAD-PHQ edge indicates a strong worry-depression connection. The Pa-OCD and PTSD-OCD edges may reflect shared arousal, intrusive experiences, or difficulty disengaging from distressing internal content [50, 51]. The Ma-Pa edge requires particular caution because the mania/hypomania node was a screening-domain score rather than a diagnostic assessment [52]. It may reflect activation or dysregulation symptoms that overlap statistically with panic-related arousal, but this association cannot distinguish such overlap from a bipolar-spectrum process. Given the dense network, the presence of a small nonzero edge should not by itself be assigned distinct clinical meaning [29]. Interpretation should therefore emphasize the strongest edges, the NSSI neighborhood, and findings supported by stability analyses.

Sensitivity analyses showed that severity-stratified network comparisons depended on the EBIC tuning parameter, and the ordered increase in global strength was not consistently recovered in equal-size repeated samples. In contrast, excluding PHQ from the full analytic sample retained a dense nine-node network in which NSSI remained most strongly connected with OCD, PTSD, and GAD. These findings support the broader multidomain NSSI neighborhood while reinforcing caution about tuning-dependent subgroup comparisons.

Data-driven communities suggest two levels of symptom organization

Signed spinglass identified two communities, and the same two-community solution was recovered in 999 of 1,000 case-bootstrap networks. The smaller community contained SeP, SoP, and ScP. Their grouping is plausible at the level of symptom organization because all three concern anxiety linked to separation or social and school contexts, and SeP-SoP was the strongest edge in the network [53]. However, the community should not be treated as a diagnosis, a single latent disorder, or evidence that these domains share one causal mechanism [34]. The partition may instead reflect correlated content, common contexts, measurement characteristics, or a combination of these factors [54].

The broader community contained Ma, Pa, PTSD, GAD, PHQ, OCD, and NSSI. This organization suggests that, within a sample selected for elevated depressive symptoms, NSSI was statistically integrated with several forms of internal distress rather than forming a separate mood/NSSI domain. The community is consistent with a broad core of depressive, anxious-arousal, trauma-related, and repetitive or intrusive

symptom domains, but the label "core symptom community" is descriptive rather than diagnostic. Its breadth may partly reflect genuine symptom co-occurrence, the PHQ-based inclusion criterion, and the high density of the estimated network. Accordingly, the two-community solution is best understood as a reproducible summary of this network in this sample, not as a universal taxonomy of adolescent psychopathology.

Depressive symptoms remained central, but not necessarily causal

PHQ ranked first for strength, one-step expected influence, two-step expected influence, and predictability. This finding should be interpreted in light of the elevated-PHQ sampling criterion, which does not by itself establish that PHQ would have higher centrality. Nevertheless, PHQ was not only the cohort-defining variable but also the domain most strongly connected with the remaining network. Depressive severity may therefore serve as a broad marker of distress within this selected adolescent subgroup.

A high centrality value does not demonstrate that depressive symptoms cause other symptoms [30]. PHQ centrality is better understood as descriptive evidence that depressive symptoms were highly informative within the observed symptom-domain system. Predictability and relative importance results support this bounded interpretation: PHQ, Pa, and GAD had the highest explained variance, and the largest relative-importance contributions were concentrated among PHQ, GAD, and Pa. These indices characterize statistical organization and explained variance; they do not establish a unidirectional pathway or rank treatment targets [55].

NSSI was related to depressive severity but not confined to mood symptoms

The strongest NSSI-related edge was PHQ-NSSI, and PHQ made the largest explained-variance contribution to NSSI. This pattern supports the clinical relevance of depressive severity for NSSI among adolescents with elevated depressive symptoms. Functional models propose that NSSI may serve intrapersonal functions, including reducing intense negative affect or other difficult-to-tolerate internal experiences [56, 57]. The present cross-sectional data cannot show that depressive symptoms lead to NSSI; they show that depressive severity was the most statistically informative symptom domain for NSSI in this network.

The PTSD-NSSI edge indicates that trauma-related distress contributed information beyond depressive and anxiety-related domains. Prior meta-analytic evidence links childhood maltreatment with NSSI [58], and trauma-related experiences may be associated with self-injury through intrusive memories, hyperarousal, avoidance [59, 60], shame [61], or difficulties regulating affect [19]. The OCD-NSSI edge also requires careful interpretation because the OCD node was a screening module rather than a clinical diagnosis. It includes intrusive thoughts and repetitive behaviors; overlap with rumination and repetitive

negative thinking, which have been associated with NSSI [62], is a possible interpretation that was not directly assessed. The GAD-NSSI edge further suggests that persistent worry and anticipatory tension may be relevant in this subgroup. Overall, the NSSI neighborhood argues against a narrow mood-only assessment while remaining insufficient to establish mechanisms.

The leading contribution of PHQ to NSSI explained variance was also retained across raw-score, rank-normalized, ordinal, and binary NSSI specifications. Secondary predictor ordering varied, so PTSD, OCD, Pa, and GAD are better interpreted as contributing domains than as a fixed hierarchy.

Moderate NSSI predictability identifies an important boundary

The other nine symptom-domain nodes explained approximately one quarter of the variance in NSSI ($R^2 = 0.246$). Thus, NSSI was not isolated from the symptom system, but most of its variance remained unexplained. The network did not include many interpersonal, family, behavioral, and contextual factors known to be relevant to NSSI [63]. Family conflict, peer victimization [64, 65], loneliness [66], social support [67], emotion-regulation strategies [19], impulsivity [68], shame [61], exposure to self-injury [69], acute stressors [70], and access to help [71] may provide additional explanatory information. Symptom-domain screening can therefore identify part of the NSSI-related pattern but should not be treated as a complete model of why adolescents engage in NSSI.

Bridge expected influence reflects the two-community partition

Under the signed-spinglass partition, bridge expected influence was highest for SeP, followed by ScP and SoP. PHQ and OCD were the highest-ranking bridge nodes within the broader core symptom community. This pattern differs materially from the earlier analysis based on manually assigned domains. The prominence of SeP, ScP, and SoP is partly structural: each belongs to the smaller anxiety community, so its connections to the seven-node core community contribute to bridge expected influence [31]. Their high values indicate signed statistical connectivity across the detected community boundary, not that these symptoms transmit distress between disorders.

Bridge expected influence is conditional on the estimated network and its community partition [31]. The values should therefore not be interpreted as causal influence, temporal spread, diagnostic comorbidity pathways, or evidence that intervening on the highest-ranked node will improve other symptoms [55]. The results may help describe which screening domains lie closest to the detected community boundary, but assessment or intervention priorities require longitudinal, experimental, and clinically validated evidence.

Relative importance clarified the explained-variance structure

Relative importance analysis provided a complementary view of the symptom system. Whereas the primary network estimated conditional associations, the relative importance analysis decomposed each target node's explained variance into predictor-specific contributions [33]. The largest contributions were concentrated among PHQ, GAD, and Pa. For NSSI, PHQ was the largest contributor, followed by PTSD, OCD, Pa, and GAD. The directed arrows in the relative importance network are not temporal or causal directions. They indicate which domains contributed most to the cross-sectional explained variance of each target. Their role here is therefore descriptive: depressive symptoms were the most informative contributor to NSSI variance, while trauma-related and repetitive or intrusive domains provided additional information.

Assessment implications

The findings support a multidomain assessment perspective. Among adolescents with elevated depressive symptoms, follow-up assessment of NSSI may also consider trauma-related symptoms, repetitive or intrusive distress, generalized worry, panic-related arousal, and relevant family and peer context [72]. The smaller SeP/SoP/ScP community further indicates that separation, social, and school anxiety formed a coherent part of the observed symptom organization, supporting attention to their distinct symptom content rather than an undifferentiated anxiety label when interpreting the network.

These implications should not be overextended. The analysis does not indicate which symptom should be treated first or whether changing one node would alter another. It supports broader screening and hypothesis generation, not a treatment sequence. Clinical decisions still require individual assessment, including evaluation of NSSI severity, function, immediacy of risk, and contextual factors not represented in the network [46, 72].

Strengths and limitations

This study focused on a depression-enriched adolescent subgroup and combined EBICglasso network estimation, data-driven signed community detection, predictability, centrality, bridge expected influence, bootstrap stability, and relative importance analysis. Repeated full-network estimation and 1,000 case-bootstrap networks provided direct evidence that the selected two-community partition was reproducible under the prespecified procedure.

Several limitations remain. First, the cross-sectional design prevents conclusions about temporal order, causal influence, or symptom transmission. Network edges, bridge expected influence, and relative-importance arrows are statistical summaries rather than causal pathways [28, 34]. Second, the PHQ ≥ 5 restriction limits generalizability to adolescents without elevated depressive symptoms and may have influenced PHQ centrality and community organization, although the direction and magnitude of any selection effect were not established. Third, the school-based sample may not generalize to clinical populations or other settings. Fourth, nodes were screening-module scores rather than diagnoses. Differences in score ranges, item content, construct breadth, and reliability may have influenced both the edge structure and community assignment [73, 74].

Fifth, the estimated network was dense and included many small edge weights. Community detection and bridge expected influence are functions of the entire weighted network, so weak edges may affect the detected boundary and bridge rankings even when the two-community count is highly reproducible [31, 47]. The bootstrap frequency supports stability under resampling but does not prove that the partition is unique, clinically definitive, or invariant under other estimators, tuning parameters, node definitions, or community algorithms [75]. Sixth, the three-node versus seven-node imbalance should be considered when comparing bridge expected influence across communities because nodes in the smaller community have more potential cross-community connections. Finally, the 10-node model excluded family, peer, interpersonal, behavioral, and broader contextual factors that may be important for NSSI [76]. Replication in independent samples, alternative network specifications, and longitudinal data is needed before interpreting these communities as persistent developmental structures.

Conclusions

Among adolescents with PHQ scores of 5 or higher, a signed-spinglass analysis identified a reproducible two-community organization: separation, social, and school anxiety formed one community, while NSSI was embedded in a broader core community containing depressive, panic, generalized anxiety, trauma-related, obsessive-compulsive, and mania/hypomania-related symptoms. Depressive symptoms remained the most central and predictable domain and the largest explained-variance contributor to NSSI. Bridge expected influence was highest for SeP, ScP, and SoP under the data-driven partition, but these rankings describe cross-community statistical connectivity rather than causal or treatment relevance. The findings support multidomain assessment and further hypothesis testing while remaining bounded by the cross-sectional design, screening-based nodes, dense network, and selected sample.

Abbreviations

CS
correlation stability
EBIC
extended Bayesian information criterion
EBICglasso
extended Bayesian information criterion graphical lasso
EI
expected influence
GAD
generalized anxiety symptoms
LMG
Lindeman-Merenda-Gold relative importance
Ma
mania/hypomanic symptoms
NSSI

non-suicidal self-injury
OCD
obsessive-compulsive symptoms
Pa
panic symptoms
PHQ
Patient Health Questionnaire
PTSD
post-traumatic stress disorder symptoms
R^2
explained variance
ScP
school anxiety
SeP
separation anxiety
SoP
social anxiety.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of Wenzhou Kangning Hospital under approval number 2020-k021-02. Written informed consent was obtained from all adolescent participants and their parents or legal guardians before participation.

Consent for publication

Not applicable. This manuscript does not report identifiable individual-level information.

Availability of data and materials

Deidentified data and analysis code are available from the corresponding author upon reasonable request, subject to applicable ethical and institutional restrictions. The summary data supporting the reported tables and figures are included in the article and supplementary materials.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

ZQ led the drafting of the original manuscript, integrated the scientific narrative, and contributed substantially to manuscript revision. WF led the formal analysis and interpretation of the results, and contributed substantially to investigation, data collection, data curation, and manuscript revision. ZQ and WF contributed equally to this work and share first authorship. YK contributed to study implementation, participant coordination, and data collection. ZD contributed to data collection, data management, and project administration. LY contributed to supervision and critically reviewed the manuscript. KZ conceptualized the study, established the research direction, supervised the work, and critically reviewed the manuscript. TW provided methodological and technical advice and critically reviewed the manuscript. JY contributed to supervision and critically reviewed the manuscript. All authors read and approved the final manuscript.

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Figures

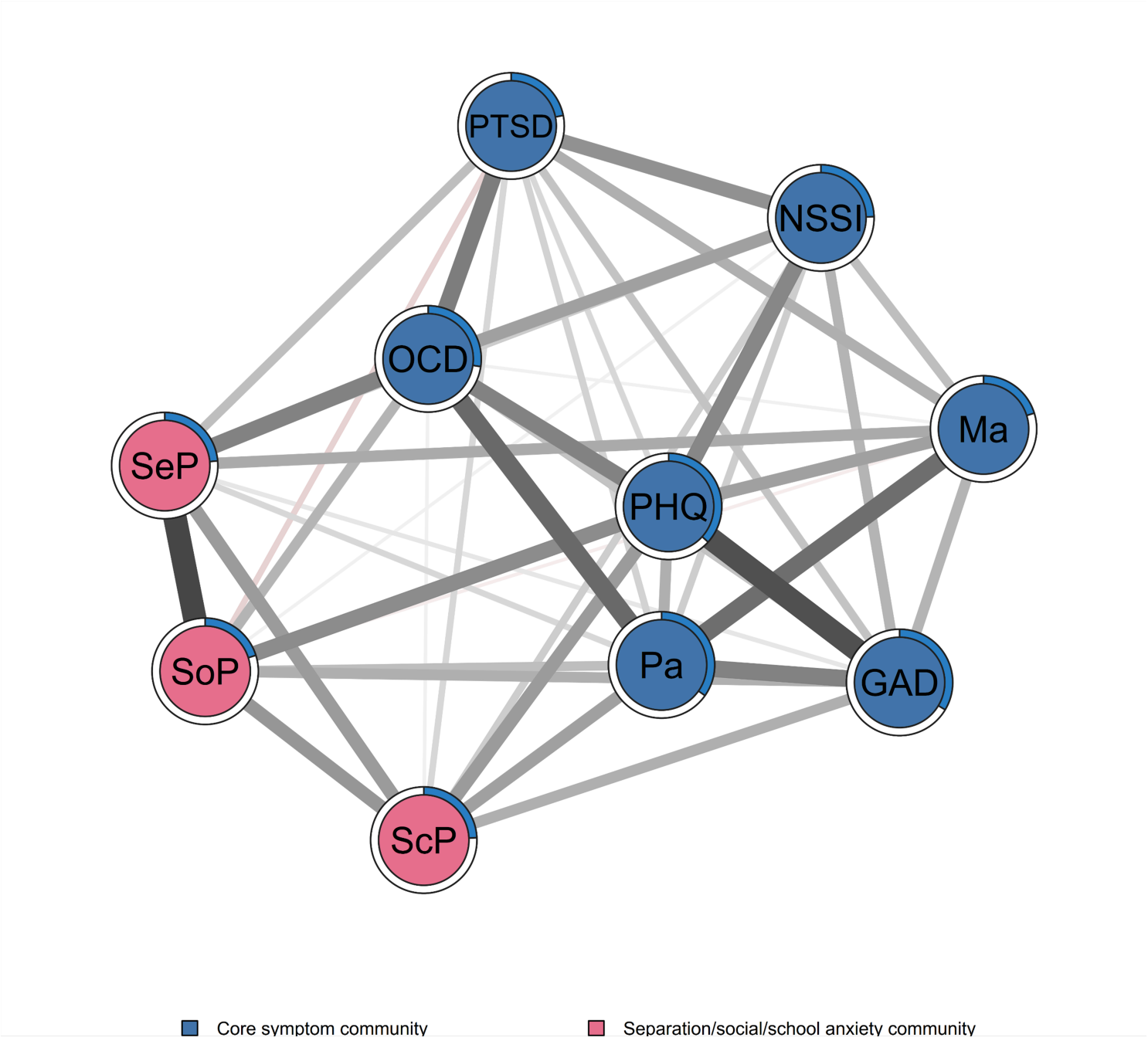


Figure 1

Estimated partial-correlation network and node predictability.

Nodes represent the ten symptom domains, and edges represent regularized partial correlations. Grey edges indicate positive associations and red edges indicate negative associations; edge width and saturation are proportional to association strength. Node colours indicate the two signed-spinglass communities. The outer ring represents node predictability (R^2). NSSI, non-suicidal self-injury; PHQ, depressive symptoms; GAD, generalized anxiety; Pa, panic; SeP, separation anxiety; SoP, social anxiety; ScP, school avoidance; OCD, obsessive-compulsive symptoms; PTSD, post-traumatic stress symptoms; Ma, manic symptoms.

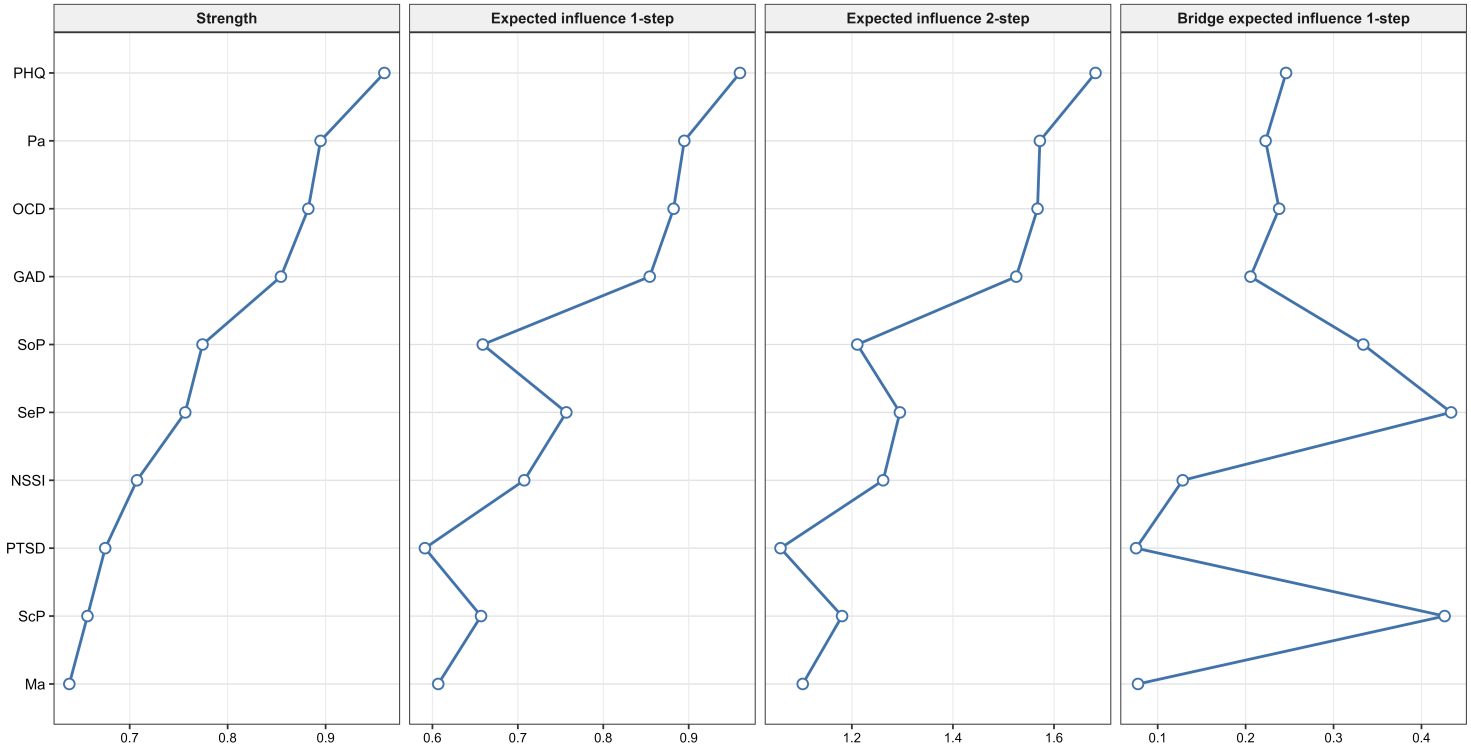


Figure 2

Centrality and bridge expected-influence indices.

Values are shown on their original scales, with nodes ordered by strength. Higher values indicate greater statistical connectivity under the corresponding index. Abbreviations are defined in Figure 1.

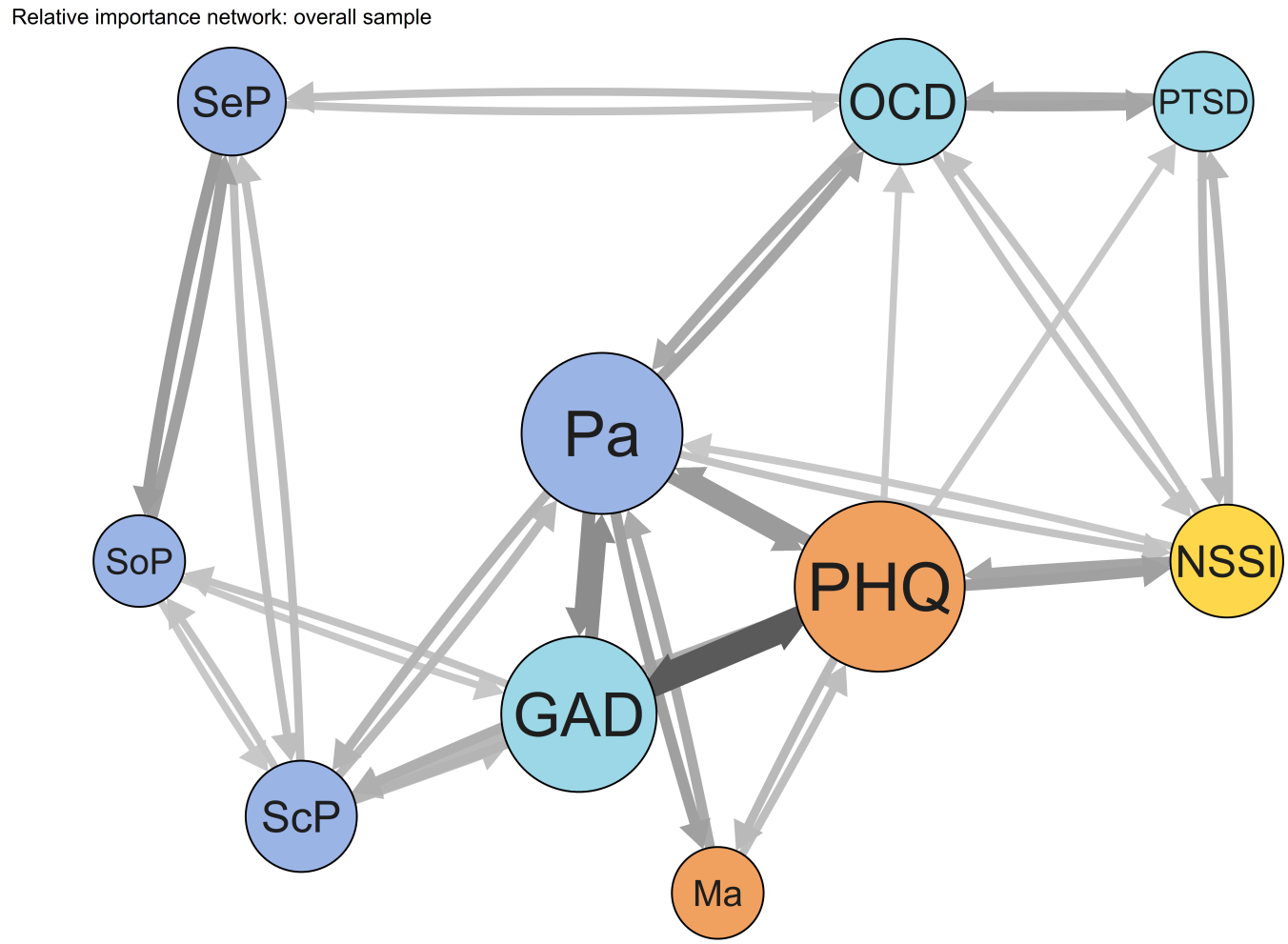


Figure 3

Directed relative-importance network for the overall sample.

Arrows represent directed explained-variance contributions derived from nodewise relative-importance models. Arrow width and saturation are proportional to the contribution magnitude, and node size reflects total incoming explained variance. NSSI, non-suicidal self-injury; PHQ, depressive symptoms; GAD, generalized anxiety; Pa, panic; SeP, separation anxiety; SoP, social anxiety; ScP, school avoidance; OCD, obsessive-compulsive symptoms; PTSD, post-traumatic stress symptoms; Ma, manic symptoms.

Supplementary Files

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