Network analysis of suicide ideation and depression–anxiety symptoms among Chinese adolescents

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ABSTRACT

Background The co-occurrence of depression and anxiety among adolescents is typically associated with suicide ideation.

Aims The study aimed to investigate the symptom-level relationship between suicide ideation and the comorbidity of depression and anxiety.

Methods 1501 adolescents aged 12–19 years were assessed using the Patient Health Questionnaire (PHQ-9) and the Generalized Anxiety Disorder Scale, and 716 adolescents who scored ≥5 on both scales were selected as participants. Network analysis was used to identify the network structure of depressive symptoms and anxiety symptoms. Participants were categorised into either the suicide ideation or non-suicide ideation groups based on their scoring on the suicide-related item in PHQ-9. A comparison was made between the depression–anxiety symptom networks of the two groups.

Results 'Restlessness', 'sad mood' and 'trouble relaxing' were the most prominent central symptoms in the depression–anxiety symptom network, and 'restlessness', 'nervousness' and 'reduced movement' were the bridge symptoms in this network. 'Sad mood' was found to be directly related to 'suicide ideation' with the highest variance. The network structure was significantly different in properties between the suicide ideation group and the non-suicide ideation group, with 'restlessness' and 'sad mood' exhibiting significantly higher influence in the network of the suicide ideation group than that in the non-suicide ideation group.

Conclusion Restlessness and sad mood could be targeted for the intervention of depression–anxiety symptoms among adolescents with suicide ideation.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Depression and anxiety comorbidities are significant risk factors for adolescent suicide ideation.

WHAT THIS STUDY ADDS

⇒ The network of depression and anxiety symptoms in adolescents with comorbid depression and anxiety along with suicide ideation differs from that in adolescents without suicide ideation.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Restlessness and sad mood may be focal points for managing symptoms of depression and anxiety in adolescents with suicide ideation.

INTRODUCTION

Suicide ideation, defined as thoughts of taking one's own life, is common among teenagers. The global prevalence of suicide ideation among adolescents is 18.0%, making suicide the second leading cause of death in this age group.[1] Moreover, suicide ideation has been linked to poor academic performance, aggressive or violent behaviours and an increased risk of substance abuse.[2–4]

Therefore, it is crucial to identify, prevent and address suicide ideation to enhance overall well-being and prevent suicide in adolescents.

For adolescents, the risk of suicide ideation and depression–anxiety comorbidity increases dramatically, making symptoms of depression and anxiety crucial in identifying suicide ideation.[5] Previous studies have shown that depression and anxiety are independently associated with suicide ideation and predict suicide ideation in adolescents.[6 7] Despite this, there is still limited research on the impact of comorbid depression and anxiety on suicide ideation among adolescents. Considering that depression and anxiety comorbidity may increase the risk of suicide, it is vital to examine the relationship between depression–anxiety symptoms and suicide ideation.

Network analysis can categorise mental disorders into clusters and identify interactions within and between clusters, enabling the exploration of the relationship between symptoms in comorbid depression and anxiety. A network analysis investigated the association between depression and anxiety symptoms in Chinese adolescents using the

Center for Epidemiological Studies Depression Scale and the Generalized Anxiety Disorder Scale (GAD-7). The analysis revealed that 'depressed affect' was a prominent central and bridge symptom.[8] Cai et al assessed depression and anxiety symptoms in Chinese adolescents using the Patient Health Questionnaire (PHQ-9) and GAD-7, and found that 'sad mood', 'irritability', 'worry too much' and 'guilt' were the central symptoms, while 'guilt', 'sad mood' and 'suicide ideation' were the bridge symptoms.[9] These studies highlight the potential of network analysis in identifying key symptoms and understanding their interconnectedness within the depression–anxiety comorbidity.

Based on the above findings, using network analysis to explore the relationship between suicide ideation and depression–anxiety symptoms may help to identify central symptoms, thereby facilitating the development of individualised interventions for suicide ideation. The study aimed to identify the depression–anxiety symptoms contributing to suicide ideation among adolescents and to investigate the specific structure of the depression–anxiety symptom network among adolescents with suicide ideation.

METHODS
Study subjects
The data were collected from 1501 teenagers from 10 middle schools in Changsha, Hunan, China, via cluster sampling from February to May 2021. After excluding 43 incomplete responses, 1458 valid questionnaires were included for further screening. The inclusion criteria were: (1) aged 12–19 years; (2) with normal physical development and no medical conditions; (3) with mild to severe depression and anxiety symptoms, as indicated by a PHQ-9 score ≥5 and a GAD-7 score ≥5. Finally, 716 participants meeting the inclusion criteria were included in the network analysis. Based on the score of the suicide-related item in PHQ-9 (0 or non-0), participants were divided into two groups: the non-suicide ideation group (n=307)

and the suicide ideation group (n=409). For the enrolment flowchart, refer to figure 1. The informed consent was obtained from all participants and their parents.

Measurements
Demographic characteristic
Social demographic variables, such as gender, age, place of residence (rural/urban), whether the individual was the only child in the family and family income, were inquired.

Patient Health Questionnaire-9
The Chinese version of the PHQ-9 has been widely used and previously validated with good psychometric properties among Chinese adolescents (Cronbach's alpha >0.84).[10] The questionnaire assesses the depression symptoms over the past 2 weeks, evaluating nine main symptoms: anhedonia, sad mood, sleep disturbance, lack of energy, loss of appetite, guilt, trouble concentrating, reduced movement and suicide ideation. Items in PHQ-9 are rated on a 4-point Likert scale from 0 to 3 (0=not at all, 1=several days, 2=more than half the days, 3=nearly every day), with higher scores indicating more severe depression symptoms. We used the last item, 'Thoughts that you would be better off dead/of hurting yourself'', to assess suicide ideation. Participants who scored '1', '2' or '3' for this item were considered to have suicide ideation.

Generalized Anxiety Disorder Scale-7
We used the Chinese version of the GAD-7 to assess seven anxiety symptoms: nervousness, uncontrollable worrying, excessive worry, trouble relaxing, restlessness, irritability and feeling afraid. Items in GAD-7 are rated on a 4-point Likert scale from 0 (not at all) to 3 (nearly every day) with higher scores representing more severe anxiety symptoms. The scale has shown excellent internal consistency among Chinese adolescents, with a Cronbach's alpha of 0.92.[11]
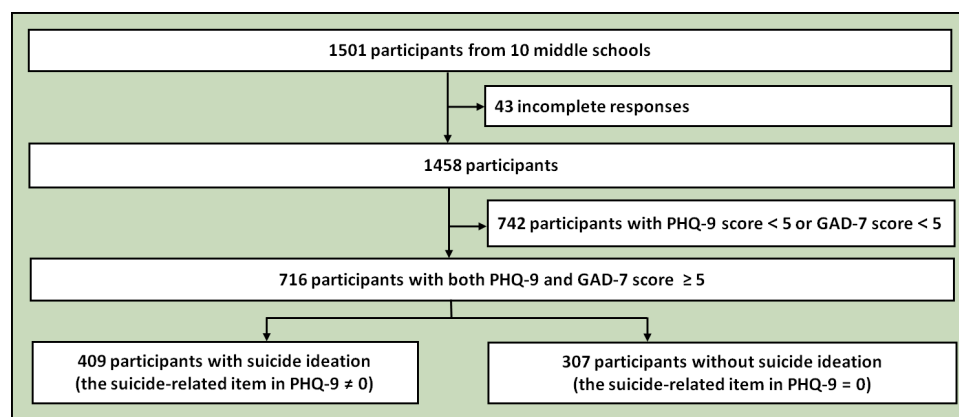

Figure 1 The flowchart of the participant enrolment procedure. GAD-7, Generalized Anxiety Disorder Scale; PHQ-9, Patient Health Questionnaire.

Table 1 Characteristics of the PHQ-9 and GAD-7 item-level symptoms of the participants

Items	Reference name		Mean	SD
PHQ-9				
Little interest or pleasure in doing things	P1	Anhedonia	1.62	0.86
Feeling down, depressed or hopeless	P2	Sad mood	1.57	0.83
Trouble falling or staying asleep, or sleeping too much	P3	Sleep disturbance	1.51	1.03
Feeling tired or having little energy	P4	Lack of energy	1.68	0.88
Poor appetite or overeating	P5	Loss of appetite	1.43	1.03
Feeling bad about yourself	P6	Guilt	1.58	0.94
Trouble concentrating on things	P7	Trouble concentrating	1.31	1.01
Moving or speaking so slowly	P8	Reduced movement	1.15	1.03
Thoughts that you would be better off dead/of hurting yourself	P9	Suicide ideation	0.93	1.01
GAD-7				
Feeling nervous, anxious or on edge	G1	Nervousness	1.76	0.82
Not being able to stop or control worrying	G2	Uncontrollable worrying	1.65	0.85
Worrying too much about different things	G3	Excessive worry	1.75	0.85
Trouble relaxing	G4	Trouble relaxing	1.43	0.90
Being so restless that it is hard to sit still	G5	Restlessness	1.23	0.96
Becoming easily annoyed or irritable	G6	Irritability	1.62	0.92
Feeling afraid as if something awful might happen	G7	Feeling afraid	1.36	1.00

GAD-7, Generalized Anxiety Disorder Scale; PHQ-9, Patient Health Questionnaire; SD, standard deviation.

Statistical analysis
Demographic data analysis
The data analyses were conducted using SPSS V.20 software. The χ^2 test was used to compare gender, age composition, place of residence, being an only child and family income between the non-suicide ideation group and the suicide ideation group.

Network estimation
R (V.4.1.2; R Core Team, 2020) was used for data analysis and graphical visualisation. Gaussian graphical models (GGMs) were used to establish the network structure between symptoms of depression and anxiety.[12] GGM is an undirected network where nodes represent symptoms and edges represent the partial correlation coefficient between two symptoms after controlling for all other covariates in the network. The GGM was calculated using a non-parametric Spearman correlation matrix and regularised through the graphical lasso. In network analysis, nodes with stronger connections to other variables are positioned at the centre, while those with weaker connections are placed on the periphery.[13] In this model, blue edges represent positive associations and red edges represent negative associations, with thicker lines indicating stronger correlations. Based on the number of items in PHQ-9 and GAD-7, two clusters were identified: one representing depression symptoms with nine nodes and the other representing anxiety symptoms with seven nodes.

The R-package 'qgraph' (V.1.6.5) and 'network-tools' were used to measure the centrality of the network.[14 15] Centrality represents the strength and closeness of a connection between nodes and was used to characterise the network structure between depression and anxiety symptoms, with higher centrality indices indicating greater criticality and influence of the node. To measure the importance of a symptom in the network, centrality strength was used to determine the connectivity between nodes by summing the absolute weights of these connections. Since centrality strength may lead to misinterpretation of a node's impact in a cluster when negative pairwise associations are present, we further used expected influence as an indicator to access network centrality, considering both positive and negative correlations without using the absolute value of edges. Bridge centrality was also used to assess the association between the two clusters. Bridge centrality represents the importance of a node connecting to all nodes in another cluster, with higher values indicating greater importance of the node. The bridge-expected influence was computed to access the bridge centrality, which indicated the sum connectivity of a node with other clusters.

Network stability and accuracy
The R-package 'bootnet' (V.1.4.3) was used to assess the stability and accuracy of the network.[12] We used non-parametric bootstrapping to estimate the accuracy of edge weights with 95% confidence intervals (CIs). The case-dropping bootstrap procedure was used to calculate
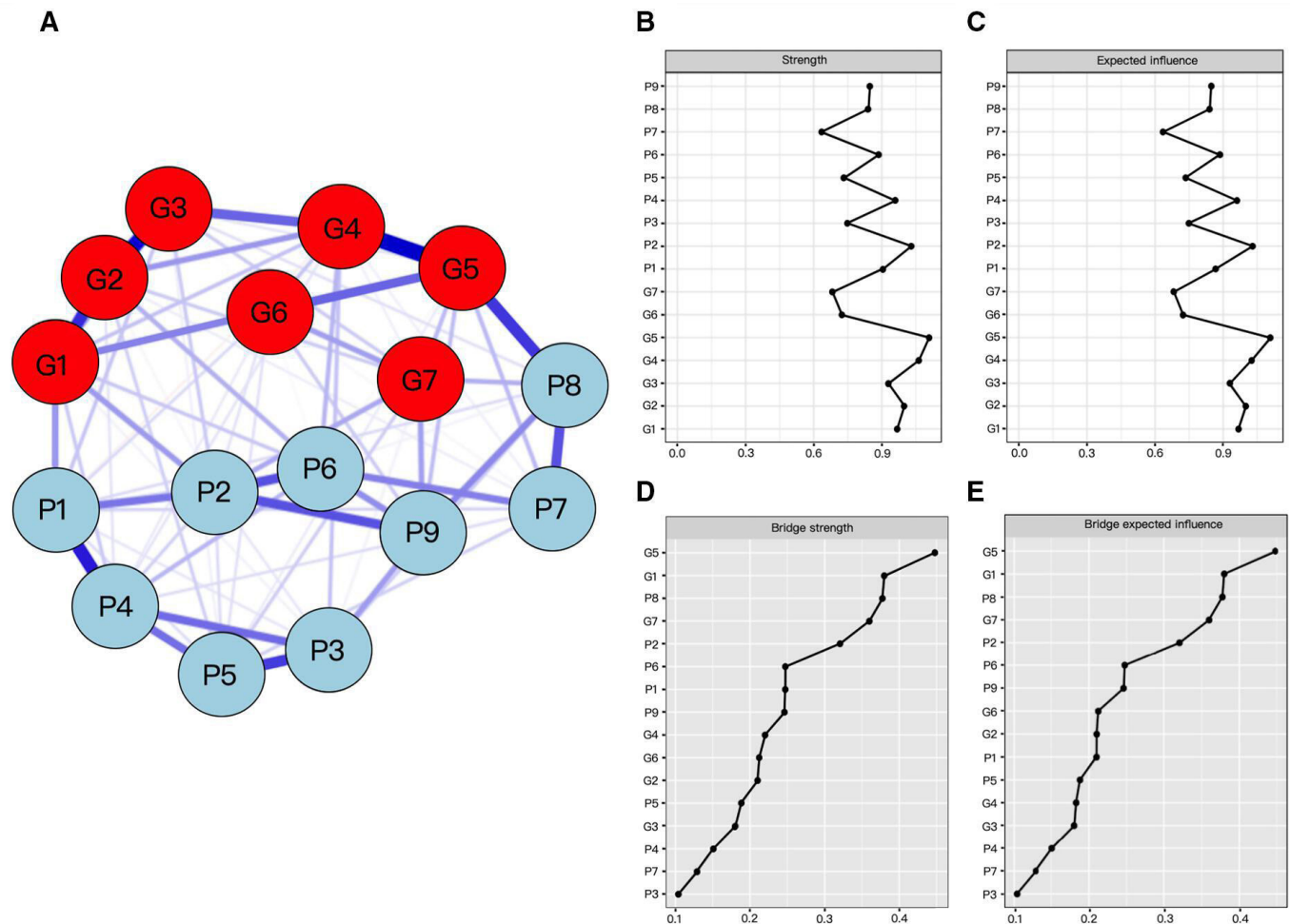
Figure 2 (A) Network structure of depression and anxiety symptoms among adolescents (n=716). Nodes are coloured according to their clusters, with blue nodes indicating depressive symptoms and red nodes indicating anxiety symptoms. Blue edges represent positive associations. Red edges represent negative associations. Thicker edges represent a greater association between two nodes, while thinner edges represent a weaker association. (B) Strength; (C) expected influence; (D) bridge strength; (E) bridge-expected influence. G1, nervousness; G2, uncontrollable worrying; G3, excessive worry; G4, trouble relaxing; G5, restlessness; G6, irritability; G7, feeling afraid; P1, anhedonia; P2, sad mood; P3, sleep disturbance; P4, lack of energy; P5, loss of appetite; P6, guilt; P7, trouble concentrating; P8, reduced movement; P9, suicide ideation.

the correlation stability coefficient, which should be >0.25 and preferably be >0.5 to indicate favourable stability of centrality indicators. The differences in the expected influence and the bridge-expected influence of network properties were assessed using bootstrapped difference testing over 1000 iterations.

Flow network analysis of suicide ideation
The 'flow' graphical function in 'qgraph' was used to assess symptoms directly connected to suicide ideation.[14] In this analysis, 'suicide ideation' was positioned to the left, and other depression and anxiety symptoms were positioned vertically to the right. The edges between suicide ideation and other symptoms were either direct or indirect.

Relative importance of risk factors in suicide ideation
The R-package 'relaimpo' was used to determine the relative importance of contributing factors to suicide ideation obtained through the flow network analyses.[16]

Comparison of networks related to suicide ideation
The network structure was compared between the suicide ideation and non-suicide ideation groups using the R-package 'Network Comparison Test', a permutation-based hypothesis test for network structure invariance.[17] The depression–anxiety symptom networks of these two groups were built and compared using the bootstrap method at a significance level of 0.05.

RESULTS
Characteristics of the participants
Of the 716 participants, 36.6% were boys and 63.4% were girls, with an average age of 15.02 (1.80) years. Their sociodemographic characteristics are presented in online supplemental table s1. There were no significant statistical differences between the non-suicide ideation group (n=307) and the suicide group (n=409) in terms of
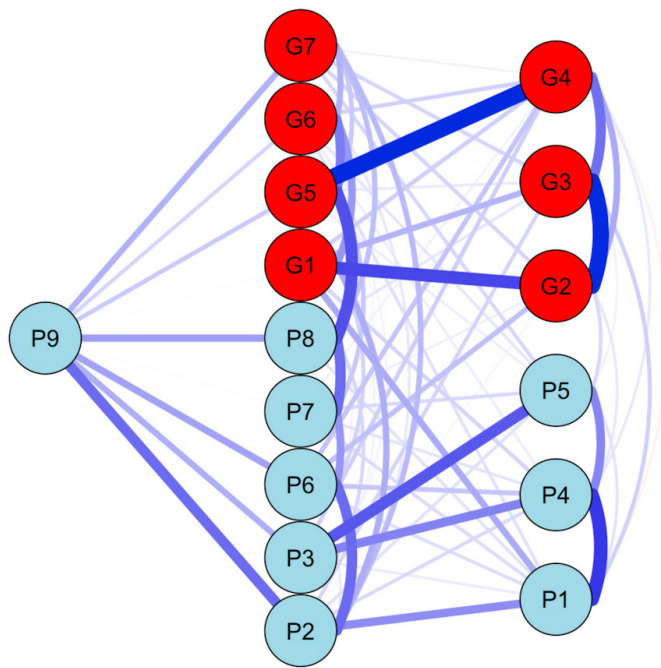
Figure 3 Flow network of suicide ideation. Blue edges represent positive associations. Red edges represent negative associations. G1, nervousness; G2, uncontrollable worrying; G3, excessive worry; G4, trouble relaxing; G5, restlessness; G6, irritability; G7, feeling afraid; P1, anhedonia; P2, sad mood; P3, sleep disturbance; P4, lack of energy; P5, loss of appetite; P6, guilt; P7, trouble concentrating; P8, reduced movement; P9, suicide ideation.

gender, age, place of residence, being an only child and family income.

Item-level description of PHQ-9 and GAD-7
The average scores of PHQ-9 and GAD-7 were 12.77 (5.56) and 10.80 (4.51), respectively. Details of the PHQ-9 and GAD-7 assessments are presented in table 1.

Estimation of the depression–anxiety symptom network
The structure of the depression–anxiety symptom network in adolescents with depression and anxiety is shown in figure 2A. The network consisted of 120 regularised partial correlations, with 77 edges showing positive associations. Correlation matrices are displayed in online supplemental table s2.

For network centrality, 'restlessness' in the anxiety cluster was the most central symptom, followed by 'sad mood' in the depression cluster and 'trouble relaxing' and 'uncontrollable worrying' in the anxiety cluster. Therefore, these four symptoms may be central to the association between depression and anxiety symptoms. The node 'trouble concentrating' in the depression cluster had the lowest strength and expected influence (figure 2B,C).

The most prominent bridge symptoms were 'restlessness' and 'nervousness', which had significantly stronger associations with depressive symptoms than other anxiety symptoms. 'Reduced movement' showed the highest

bridge-expected influence among the depression symptoms, while 'sleep disturbance' was the weakest bridge in depression symptoms connected with the anxiety cluster (figure 2D,E).

The results demonstrated a narrow range of 95% CIs of edge weights, indicating stability in most edges and centrality (online supplemental figure s1). The stability coefficients for the expected influence and the bridge-expected influence were 0.67 and 0.52, respectively, indicating acceptable network stability (online supplemental figure s2).

Flow network of suicide ideation
The flow network of suicide ideation is presented in figure 3. The strongest edges were shown between 'suicide ideation' and 'sad mood', 'guilt', 'reduced movement', 'feeling afraid', 'restlessness', 'sleep disturbance' and 'irritability', indicating a direct association between 'suicide ideation' and these symptoms, except for 'trouble relaxing', 'excessive worry', 'uncontrollable worrying', 'loss of appetite', 'lack of energy' and 'anhedonia', which was comparable with the bootstrapped CIs of edges.

Relative importance of risk factors of suicide ideation
Through estimation of the relative importance of the contributing factors to suicide ideation obtained through flow network analyses, 'sad mood' was the most significant factor to suicide ideation (relative contribution=7.62%, 95% CI: 4.69% to 11.24%). The relative importance rates of the contributing factors are shown in online supplemental table s3.

Comparison of the depression–anxiety network between the suicide ideation and non-suicide ideation groups
The estimated networks of non-suicide ideation and suicide ideation groups are shown in figure 4A,D, the exact edge weights are presented in online supplemental tables s4 and s5, and the network stability of suicide ideation and non-suicide ideation groups is shown in online supplemental figures s3 and s4. According to our results, most edges and the centrality stability were acceptable.

The network comparison test showed significant differences in network properties (global strength) between the suicide ideation and non-suicide ideation groups (test statistic S=1.31, p<0.001). In the non-suicide ideation group, 'uncontrollable worrying', 'nervousness' and 'anhedonia' exhibited high network-expected influence (figure 4B), while in the suicide ideation group, the expected influence of the above symptoms was lower compared with other symptoms. 'Restlessness' and 'sad mood' had a relatively high influence on suicide ideation networks (figure 4E). Regarding bridge centrality, 'reduced movement', 'nervousness' and 'restlessness' demonstrated higher bridge-expected influence in the non-suicide ideation group (figure 4C), and 'sad mood' was found to be another bridge symptom in the suicide ideation group (figure 4F).
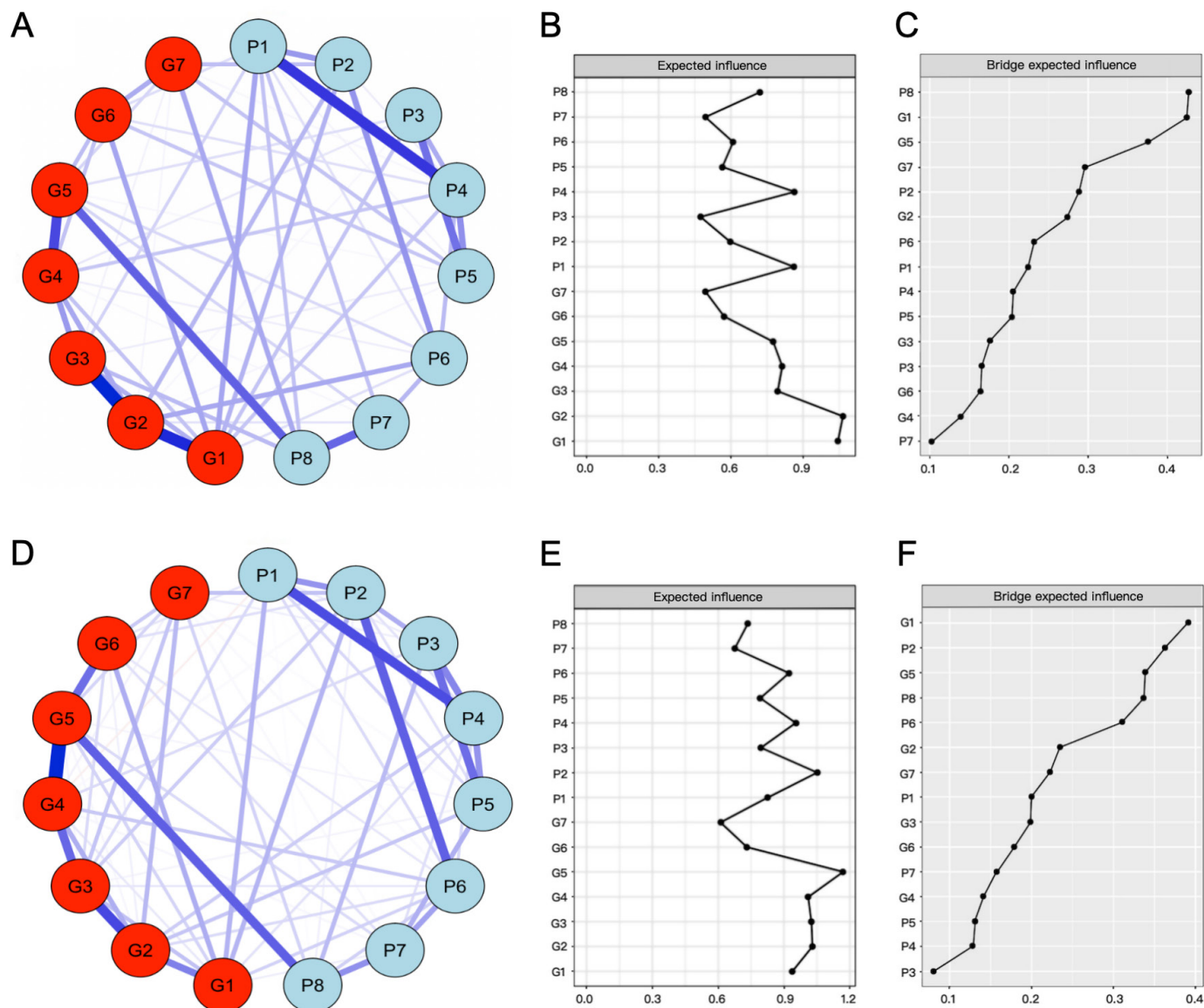
Figure 4 (A) Network structure of depressive–anxiety symptoms among the non-suicide ideation group. (B) Expected influence of the non-suicide ideation group. (C) Bridge-expected influence of the non-suicide ideation group. (D) Network structure of depressive–anxiety symptoms among the suicide ideation group. (E) Expected influence of the suicide ideation group. (F) Bridge-expected influence of the suicide ideation group. G1, nervousness; G2, uncontrollable worrying; G3, excessive worry; G4, trouble relaxing; G5, restlessness; G6, irritability; G7, feeling afraid; P1, anhedonia; P2, sad mood; P3, sleep disturbance; P4, lack of energy; P5, loss of appetite; P6, guilt; P7, trouble concentrating; P8, reduced movement; P9, suicide ideation.

DISCUSSION
Main findings
The findings of our network analysis revealed that 'restlessness' and 'sad mood' are central symptoms within the depression–anxiety network among adolescents, indicating their significant contribution to the comorbidity of these two conditions. 'Restlessness' has emerged as a significant symptom, playing a pivotal role in connecting with research findings during the coronavirus disease 2019 (COVID-19) pandemic that emphasised the impact of psychomotor symptoms on the risk of depression and anxiety.[18–21] This study adds to the existing literature by recognising 'sad mood' as a crucial factor that triggers other symptoms in the depression–anxiety network,[22–25] reaffirming its established importance

in diagnosing major depression according to the Diagnostic and Statistical Manual of Mental Disorders and its potential use as an indicator for the onset or recurrence of depressive episodes.

The differences in network structure between the groups with and without suicide ideation highlight the significance of 'restlessness' and 'sad mood' as potential intervention targets. This finding aligns with existing research indicating that symptoms of increased psychomotor activity, like restlessness, are a distinct and significant risk factor for suicidal ideation.[26] Adolescents with suicide ideation and a sad mood may be at higher risk of experiencing depression and anxiety symptoms. Studies have shown that individuals in a sad mood tend to focus on negative words rather than positive or

neutral ones, indicating a cognitive bias toward negativity.[27] This bias can lead to maladaptive thoughts associated with suicide ideation during depressive episodes.[28] The results of our study suggest that interventions targeting restlessness and the concomitant cognitive bias toward negative stimuli may be effective in reducing suicidal ideation in adolescents.

Limitations

Several limitations must be acknowledged when interpreting the findings of our study. The assessment of suicide ideation was based on a single item in PHQ-9, rather than an independent scale. The data were not collected from a clinical population but were based on self-reports from middle school students, limiting the generalisability of the conclusion. Several symptoms, such as restlessness, are common in other psychiatric disorders. Further research should include additional questionnaires to better understand how these symptoms relate to suicide ideation. Our cross-sectional study cannot establish a causal relationship between symptoms, which may limit the value of our study in inspiring interventions for depression–anxiety symptoms. Longitudinal studies using an independent scale for suicide ideation assessment are needed to investigate the causal relationship between suicide ideation and other depression–anxiety symptoms.

Implications

This study is the first network analysis to focus on suicide ideation and comorbid depression–anxiety symptoms among Chinese adolescents. Our findings provide a comprehensive analysis of the interconnectedness between depression, anxiety and suicidal ideation, offering specific interventions to reduce the risk of suicide among adolescents. By emphasising these key observations, our research contributes to a nuanced comprehension of the depression–anxiety–suicide ideation context.

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