Network analysis of suicide ideation and depressive-anxiety symptoms among adolescents

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Abstract

Background: The co-occurrence of depression and anxiety in adolescents is common and associated with suicide ideation. This study aimed to investigate the symptom-level relationship between suicide ideation and comorbidity of depression and anxiety.

Methods: R was used for network analysis of depressive and anxiety symptoms from 716 adolescents (PHQ-9 $\geq 5$ and GAD-7 $\geq 5$). Participants were grouped into the suicide ideation group and the non-suicide ideation group. Network differences were compared between these two groups.

Results: “Restlessness”, “Sad mood”, and “Trouble relaxing” were the most prominent central symptoms in this depressive-anxiety symptom network. “Restlessness”, “Nervousness”, and “Motor” were the bridge symptoms in this network. “Sad Mood” directly related to “Suicide Ideation” and explained the highest variance. The network structure was significantly different in network properties between adolescents who had suicide ideation and those who did not. “Restlessness” was the most central symptom in adolescents with suicide ideation. “Sad Mood” was the central and bridge symptom in adolescents with suicide ideation.

Conclusion: “Restlessness” and “Sad Mood” might be interesting avenues for reducing depression and anxiety symptoms in adolescents with suicide ideation.

Trial registration: The study received ethical approval from the Second Xiangya Hospital of Central South University on March 31, 2022. The number of Institutional Review Boards approval was 004.

1. Introduction

Suicide is the second most common cause of death among adolescents (Bilsen, 2018). It is a continuum of behaviour from suicide ideation through an attempt to completion (Silverman et al., 2007). Suicide ideation is the idea of the possibility of death or a plan to end one's life (WHO, 2019). Unfortunately, suicide ideation is common among teenagers (Uddin et al., 2019). A study estimated the global population prevalence of suicide ideation in adolescents aged 12–17 years, which indicated the average point prevalence of suicide ideation was 14.0% of teenagers from 82 countries (Biswas et al., 2020). The point prevalence of suicide ideation among Chinese adolescents was 18.2% and suicide became the leading cause of death in Chinese youths (Gong et al., 2020; Wang et al., 2008). Since suicide ideation is a risk factor for suicidal behaviour, identifying suicide ideation is a critical strategy for preventing youth suicidal behaviour (Glenn and Nock, 2014). Moreover, Suicide ideation was considered to be associated with numerous negative behavioural and mental health outcomes for young people, such as aggressive or violent behaviour (Miotto et al., 2003), poor academic achievement (Richardson et al., 2005), increased risk of substance abuse or addiction (Bousoño et al., 2017), lower self-esteem (Nguyen et al., 2019), and poor supportive social relationships (Springer et al., 2006). Therefore, it is important to prevent and intervene in suicide ideation since frequent suicide ideation has extremely negative impacts on the adolescent's life (Gijzen et al., 2021).
The role of depressive and anxiety symptoms was crucial in the development of adolescent suicide ideation and behaviour (Joiner et al., 2004). It is clear that depression can predict suicide ideation (Klonsky, 2016). Anxiety is another potential risk factor for adolescent suicide ideation (Batterham et al., 2013). Adolescents trapped in anxiety symptoms may turn to suicide to escape anxiety (Taylor et al., 2011). Moreover, anxiety was independently and positively associated with suicide ideation after controlling the diagnosis of mood disorders in a psychiatric sample (Machell et al., 2016). Although the current evidence indicates that anxiety and depression are independently associated with suicide ideation, research on the impact of comorbidity of depression and anxiety on suicide ideation is limited. Notably, anxiety and depression may have intricate etiological connections (Mathew et al., 2011).

Meanwhile, since the symptoms of anxiety and depression usually co-occur, people are more likely to receive a diagnosis of both conditions simultaneously (Schlechter et al., 2021). Comorbidity of anxiety and depression tends to have more severe consequences than when it occurs alone (Coryell et al., 1992). Moreover, similar to the increased pattern in suicide ideation, the comorbidity of depression and anxiety increases dramatically during adolescence (Konac et al., 2021; Uddin et al., 2019). Therefore, it is important to explore the relationship between comorbid depressive-anxiety symptoms and suicide ideation.

Since symptoms of depression and anxiety may be associated with risk factors or causes of comorbidity, network analysis was used to investigate symptom-symptom relationships in depressive-anxiety comorbidities (Liu et al., 2022). Network analysis considers mental disorders as different clusters, where different symptoms can interact within the same cluster and between different clusters (Borsboom, 2017). Several past network analysis studies investigated the correlation of symptom-to-symptom relationships between depression and anxiety in Chinese adolescents. For example, a study examined the association between depressive and anxiety symptoms by Center for Epidemiological Studies Depression Scale (CES-D) and Generalized Anxiety Disorder Scale-7 (GAD-7) (Liu et al., 2022). The results demonstrated that depressed affect was the most central symptom and the bridge symptom in a large Chinese adolescent sample. Another study examining depressive symptoms by Patient Health Questionnaire-9 (PHQ-9) and anxiety symptoms with GAD-7 indicated symptoms of “Sad mood”, “Irritability”, “Worry too much”, and “Guilty” were the central symptoms. Additionally, “Guilty”, “Sad mood”, and “Suicide ideation” were the bridge symptoms in a sample of Chinese adolescents (Cai et al., 2022).

To better understand how the symptom-level correlation between anxiety and depression increases the risk for suicide ideation, we conducted the network analysis of co-morbidity of depressive and anxiety symptoms associated with suicide ideation. Network analysis offers new insight into how depression and anxiety can affect suicide ideation, which indicates the symptom level correlation between depression and anxiety can affect the development of suicide ideation. Accessing suicide ideation-related networks may be conducive to creating individualized interventions for suicide ideation. Using network analysis to investigate the relationship between depressive and anxiety symptoms and suicide ideation, it is possible to identify which specific symptoms are central to increased suicide ideation. Changing the state of the central symptoms in a suicide ideation-related network may also change the other symptoms (Papini et al., 2020). Although numerous risk factors for suicide have been identified through network analysis, few
studies have focused on the difference in depressive and anxiety symptoms between adolescents with and without suicide ideation using network analysis. Comparing these two networks may provide a more in-depth understanding of the unique features of suicide ideation in adolescents.

There are three aims of this study. First, the researchers aimed to examine whether the results of symptom-level relationships between depression and anxiety in Chinese adolescents are consistent with previous studies, since network analyses studies about trajectories of depressive and anxiety symptoms in Chinese adolescents sample are limited. Second, we aimed to assess which depressive and anxiety symptoms in the comorbidity network are the contributing factors to suicide ideation in adolescents by considering suicide ideation as a symptom of depression. According to the rationale of network analysis, suicide ideation in adolescents may be better understood by integrating it as a node in the network of depressive-anxiety symptoms (Gijzen et al., 2021). Finally, to further explore the association between suicide ideation and depressive-anxiety symptoms, we will investigate whether adolescents with suicide ideation have a different network structure in the depressive-anxiety symptoms network compared to adolescents without suicide ideation.

2. Method

2.1. Study sample

The current study collected data from 30 classes in 10 middle schools, which surveyed 1,501 teenagers in Changsha, Hunan Province, China. The current study was conducted by cluster sampling from February to May 2021. After eliminating 43 questionnaires with incomplete data, a total of 1,458 questionnaires were valid. The inclusion criteria were: (1) age between 12 and 19 years, (2) regular physical development, no major physical disease or organic brain disorder, (3) PHQ-9 ≥ 5 and GAD-7 ≥ 5. A total of 716 participants were included in the network analysis. Participants were allocated into two groups based on whether the suicide item in PHQ-9 (Thoughts that you would be better off dead/of hurting yourself in some way) is 0. Participants without suicide and self-injurious ideation were assigned to the non-ideation group (non-SI group) (n = 307), whereas those with suicide and self-injurious ideation were placed in the ideation group (SI group) (n = 409). The study received ethical approval from the Second Xiangya Hospital of Central South University. Informed consent was obtained from all the participants and their parents.

2.2. Measurements

The survey consisted of the PHQ-9 and the GAD-7. Demographic variables, including gender, age, residence (rural or urban), one-child family (“yes” or “no”), and family monthly income level (CNY), were collected.

2.2.1. The Patient Health Questionnaire-9 (PHQ-9)
Depression symptoms in the past two weeks were assessed with the Chinese version of the PHQ-9 (Kroenke et al., 2003; Yang et al., 2015). PHQ-9 is a four-point Likert scale ranging from 0 (not at all) to 3 (nearly every day), with higher scores indicating more severe depression symptoms. The internal consistency for PHQ-9 was good (> 0.84) in the Chinese adolescent sample (Leung et al., 2020).

### 2.2.2. Suicide ideation

Item 9 of the PHQ-9 was used to assess suicide ideation (0 = Not at all, 1 = Several days, 2 = More than half the days, 3 = Nearly every day). Adolescents who scored “1”, “2” or “3” were considered to meet the criteria for suicide ideation.

### 2.2.3. The Generalized Anxiety Disorder Scale (GAD-7)

Anxiety symptoms were assessed via the Chinese version of the seven-item GAD-7 (He et al., 2010; Spitzer et al., 2006). The scale is scored in four-point Likert from 0 (not at all) to 3 (nearly every day), with higher total scores representing more severe anxiety symptoms. The scale has demonstrated excellent internal consistency in the Chinese adolescent sample, with Cronbach's alpha being 0.92 (Leung et al., 2020).

### 2.3. Statistical analysis

#### 2.3.1. Network estimation

R (Version 4.1.2; R Core Team, 2020) was used for data analysis and graphical visualization. Gaussian graphical models (GGM) were used to establish the symptom-symptom network structure between depression and anxiety (Costantini et al., 2015). GGM is an undirected network, with nodes representing symptoms and edges representing partial correlation coefficient between two symptoms after controlling all other covariates in the network. The GGM was calculated using a non-parametric Spearman correlation matrix and regularized via the graphical lasso (Friedman et al., 2008). In the network analysis, nodes with stronger connections to other variables are in the center of the network, while nodes with weaker connections are positioned at the edge of the network (Castro et al., 2019). The color of edges reveals the negative or positive association between two nodes. For example, blue edges represent positive associations, red edges represent negative associations, and thick lines indicate stronger correlations (Epskamp et al., 2012). According to the items of the PHQ-9 and GAD-7, there are two clusters representing depression and anxiety disorders, respectively, with nine nodes in the depression cluster and seven in the anxiety cluster.

To measure the centrality of the network, R-package qgraph (Version 1.6.5) (Epskamp et al., 2012) and “networktools” (Jones et al., 2021) were used. Centrality represents the strength and closeness of a connection between a node and other nodes, with higher centrality indices indicating the more important and influential the node is in the network (Castro et al., 2019). Network centrality indices were used to characterize the network structure between depressive and anxiety symptoms in adolescents. To measure the importance of a symptom in the network, centrality strength was commonly utilized to determine how
well-connected a node is to other nodes by summing the absolute weights of these connections. However, centrality strength may misinterpret the impact of a node in the cluster when negative pairwise associations exist (Castro et al., 2019). Therefore, we used the expected influence as an indicator to access the network centrality by considering both positive and negative correlations without the absolute value of edges. Apart from network centrality, bridge centrality was used to assess the association between the two symptoms. Bridge centrality represents the importance of symptoms in one cluster connecting to all symptoms in a different cluster, with higher values indicating a greater impact on activating two clusters by connecting the two communities (Jones et al., 2021). The bridge expected influence was conducted to access the bridge centrality in the network, which indicates the sum connectivity of a node with other clusters.

2.3.2. Network stability and accuracy

R-package bootnet (Version 1.4.3) was used to assess the stability and accuracy of the network (Epskamp et al., 2018). First, we used non-parametric bootstrapping to estimate the accuracy of edge weights with 95% confidence intervals (CIs). Second, a case-dropping bootstrap procedure was used to calculate a correlation stability coefficient (CS-C). The CS-C should not be greater than 0.25 and preferably greater than 0.5, indicating the stability of centrality indicators (Epskamp et al., 2018). Finally, expected influence and bridge expected influence differences in network properties were assessed using bootstrapped difference testing (Epskamp et al., 2018). A total of 1000 iterations were used throughout the bootstrapping procedures.

2.3.3. Flow network analyses of suicide ideation

Flow, a graphical function in R-package qgraph was used to evaluate the symptoms that were directly connected to suicide ideation. In this analysis, suicidal ideation was positioned to the left. Other depressive and anxiety symptoms were positioned vertically to the right. The edges between suicide ideation and these symptoms represented direct or indirect connections.

2.3.4. Relative importance of risk factors in suicide ideation

To determine the relative importance of the contributing factors to suicide ideation obtained through flow network analyses, we used the package Relaimpo (Groemping, 2006).

2.3.5. Network comparison of suicide ideation

The network structure between SI and non-SI groups was compared using the R-package Network Comparison Test, a permutation-based hypothesis test for network structure invariance (van Borkulo et al., 2017). The depressive-anxiety symptom networks of these two groups were built, estimated, and compared using the bootstrap method. The significance level was 0.05.

3. Results

3.1. Characteristics of the study sample
Of the 716 middle school students involved in this survey, 36.6% were boys and 63.4% were girls. The mean age of the sample was 15.02 years ($SD = 1.80$). Table 1 shows the socio-demographic characteristics of participants.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Variable</th>
<th>Percent%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>36.6</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>63.4</td>
</tr>
<tr>
<td>Age(years)</td>
<td>12–14</td>
<td>49.9</td>
</tr>
<tr>
<td></td>
<td>15–17</td>
<td>35.2</td>
</tr>
<tr>
<td></td>
<td>18–19</td>
<td>14.9</td>
</tr>
<tr>
<td>Residence</td>
<td>Urban</td>
<td>64.3</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>35.6</td>
</tr>
<tr>
<td>One-child family</td>
<td>YES</td>
<td>30.1</td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>69.9</td>
</tr>
<tr>
<td>Family monthly income level (CNY)</td>
<td>5000</td>
<td>39.3</td>
</tr>
<tr>
<td></td>
<td>5000–10000</td>
<td>38.1</td>
</tr>
<tr>
<td></td>
<td>10000</td>
<td>22.6</td>
</tr>
</tbody>
</table>

### 3.2. Item-level description of PHQ-9 and GAD-7

The means of PHQ-9 and GAD-7 total scores were 12.77 ($SD = 5.56$) and 10.80 ($SD = 4.51$), respectively. “Energy” had the highest mean score in PHQ-9 ($M = 1.68; SD = 0.88$), while “Suicide ideation” had the lowest mean score ($M = 0.55; SD = 0.88$). Other high score items included “Anhedonia”, “Guilty” and “Sad Mood”. For the GAD-7, “Nervousness” had the highest mean score ($M = 1.76; SD = 0.82$) and “Restlessness” had the lowest mean score ($M = 1.23; SD = 0.96$). “Worry too much”, “Uncontrollable worrying”, and “Irritability” were the other three items with an average score of over 1.5. Reference name, mean scores and standard deviations of PHQ-9 and GAD-7 items are presented in Table 2.
### Table 2
Characteristics of the PHQ-9 and GAD-7 item-level symptoms of the adolescents.

<table>
<thead>
<tr>
<th>Item</th>
<th>Reference Name</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHQ-9</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little interest or pleasure in doing things</td>
<td>P1</td>
<td>1.62</td>
<td>0.86</td>
</tr>
<tr>
<td>Feeling down, depressed, or hopeless</td>
<td>P2</td>
<td>1.57</td>
<td>0.83</td>
</tr>
<tr>
<td>Trouble falling or staying asleep, or sleeping too much</td>
<td>P3</td>
<td>1.51</td>
<td>1.03</td>
</tr>
<tr>
<td>Feeling tired or having little energy</td>
<td>P4</td>
<td>1.68</td>
<td>0.88</td>
</tr>
<tr>
<td>Poor appetite or overeating</td>
<td>P5</td>
<td>1.43</td>
<td>1.03</td>
</tr>
<tr>
<td>Feeling bad about yourself</td>
<td>P6</td>
<td>1.58</td>
<td>0.94</td>
</tr>
<tr>
<td>Trouble concentrating on things</td>
<td>P7</td>
<td>1.31</td>
<td>1.01</td>
</tr>
<tr>
<td>Moving or speaking so slowly</td>
<td>P8</td>
<td>1.15</td>
<td>1.03</td>
</tr>
<tr>
<td>Thoughts that you would be better off dead/of hurting yourself in some way</td>
<td>P9</td>
<td>0.93</td>
<td>1.01</td>
</tr>
<tr>
<td><strong>GAD-7</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeling nervous, anxious or on edge</td>
<td>G1</td>
<td>1.76</td>
<td>0.82</td>
</tr>
<tr>
<td>Not being able to stop or control worrying</td>
<td>G2</td>
<td>1.65</td>
<td>0.85</td>
</tr>
<tr>
<td>Worrying too much about different things</td>
<td>G3</td>
<td>1.75</td>
<td>0.85</td>
</tr>
<tr>
<td>Trouble relaxing</td>
<td>G4</td>
<td>1.43</td>
<td>0.90</td>
</tr>
<tr>
<td>Being so restless that it is hard to sit still</td>
<td>G5</td>
<td>1.23</td>
<td>0.96</td>
</tr>
<tr>
<td>Becoming easily annoyed or irritable</td>
<td>G6</td>
<td>1.62</td>
<td>0.92</td>
</tr>
<tr>
<td>Feeling afraid as if something awful might happen</td>
<td>G7</td>
<td>1.36</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### 3.3. Depressive-anxiety symptom network estimation

The anxiety and depressive symptom network structure for adolescents with depression and anxiety is presented in Figure 1a. The network had 120 regularized partial correlations, with 77 edges showing positive associations. The “Restlessness” – “Trouble relaxing” edge in anxiety symptom clusters showed a strong connection, followed by edges for “Uncontrollable worrying” – “Worry too much” edge, and “Uncontrollable worrying” – “Nervousness”. The regularized partial correlation coefficients were 0.37, 0.34, and 0.27, respectively. Among the depressive symptoms, the “Anhedonia” – “Energy” edge showed the strongest connection, with a regularized partial correlation coefficient of 0.29. Within the entire symptom network, the “Motor” – “Restlessness” edge revealed the strongest correlation between
depressive and anxiety symptoms, with a regularized partial correlation coefficient of 0.25. Correlation matrices are displayed in supplementary materials (Table S1).

Figure 1. a) Network structure of anxiety and depression 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.

For network centrality with strength and expected influence, “Restlessness” in the anxiety cluster was the most central symptom, followed by the “Sad mood” in the depressive symptoms cluster and “Trouble relaxing”, and “Uncontrollable worrying” in the anxiety symptoms cluster. Therefore, these four symptoms were central to understanding the association between depression and anxiety symptoms in this sample. The node “Concentration” in the depressive symptoms cluster, had the lowest strength and expected influence of all the nodes (Fig. 1b,c).

Bridge symptoms differed from the central symptoms. Bridge strength and expected influence index revealed that the most prominent bridge symptoms were “Restlessness” and “Nervousness”, which had significantly stronger associations to the depressive symptoms cluster than other anxiety symptoms. “Motor” showed the highest bridge expected symptoms in depressive symptoms. “Concentration” was the weakest bridge in depressive symptoms connected with anxiety symptoms cluster (Fig. 1d, e).

The results demonstrated a narrow range of 95% CIs of edge weights, indicating most of the edges and centrality were stable (see Supplementary Material S1a). The stability coefficients for the expected influence and bridge expected influence were 0.672 and 0.517, indicating the stability of the network was acceptable (see Supplementary Material S1b).

3.4. Flow network of suicide ideation

Figure 2 illustrates the flow network of suicide ideation. The thickest edges were between “Suicide ideation” and “Sad Mood”, “Guilty”, “Motor”, “Feeling afraid”, “Restlessness”, “Sleep”, and “Irritability”. It seems that “Suicide ideation” was directly associated with all symptoms except “Trouble relaxing”, “Worry too much”, “Uncontrollable worrying”, “Appetite”, “Energy”, and “Anhedonia”. The results were comparable to the bootstrapped CIs of edges.

3.5. Relative importance of risk factors on suicide ideation

We estimated the relative importance of the contributing factors to suicide ideation obtained through flow network analyses. “Sad mood” was the largest relative contributing factor to suicide ideation (relative contribution = 7.617%, 95% CI 4.69–11.24). Table 3 shows the relative importance rates of these contributing factors including “Sad Mood”, “Guilty”, “Motor”, “Feeling afraid”, “Restlessness”, “Sleep”, and “Irritability”.

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Table 3
Explained Variance in Suicide Ideation by Symptoms of PHQ-9 and GAD-7.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Percentage (%)</th>
<th>95% Confidence intervals (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sad mood</td>
<td>7.61</td>
<td>4.69–11.24</td>
</tr>
<tr>
<td>Guilty</td>
<td>4.66</td>
<td>2.70–7.08</td>
</tr>
<tr>
<td>Motor</td>
<td>4.19</td>
<td>2.27–6.79</td>
</tr>
<tr>
<td>Feeling afraid</td>
<td>3.34</td>
<td>1.67–5.82</td>
</tr>
<tr>
<td>Restlessness</td>
<td>3.29</td>
<td>1.72–5.50</td>
</tr>
<tr>
<td>Sleep</td>
<td>2.99</td>
<td>1.40–5.04</td>
</tr>
<tr>
<td>Irritability</td>
<td>2.01</td>
<td>0.94–3.81</td>
</tr>
</tbody>
</table>

3.6. Comparison based on suicidal and self-injurious ideation

Figures 3a and 3b illustrate the estimated networks of non-SI and SI groups. Tables S2 and S3 provide a list of the detailed edge weights. We used the bootstrap method to access the stability of the networks of SI and non-SI groups (see Figs. S3 and S4). The results demonstrated the stability of most of the edges and centrality was acceptable.

Based on the Network comparison test, there were significant network properties (global strength) between SI and non-SI groups ($p < 0.001$). Figures 3c-f show the expected influence and bridge expected influence of each symptom in the SI and non-SI groups. In the non-SI group, “Uncontrollable worrying”, “Nervousness”, and “Anhedonia” exhibited high network expected influence. While in the SI group, the expected influence of these symptoms was relatively decreased compared with other symptoms. “Restlessness”, and “Sad Mood” was relatively high in ideation networks. Apart from network centrality, bridge centrality is also different between the two networks. “Motor”, “Nervousness”, and “Restlessness” demonstrated higher bridge expected influence in the non-SI group. Besides these three symptoms, “Sad Mood” was another bridge symptom in the SI group.

4. Discussion

The current study expands the result of the depressive-anxiety symptom network analysis among Chinese adolescents. Moreover, a focus on suicide ideation was added to this network. We investigated which depressive and anxiety symptoms are contributing factors of suicide ideation and compared the difference in comorbidity network structure between adolescents who had suicide ideation and who did not.
Network analysis of depressive-anxiety symptoms demonstrated that psychomotor symptoms were the central and bridge symptoms. “Restlessness” and “Trouble relaxing” was the most prominent central symptoms in this adolescent’s network, while “Restlessness”, “Nervousness”, and “Motor” were the bridge symptoms. Another depressive-anxiety symptom network analysis conducted during the COVID-19 outbreak and the after-peak stages in China showed similar results (Wang et al., 2020). The study indicated that psychomotor symptoms including motor, restlessness, and trouble relaxing maintained the most central symptoms in the network between the outbreak and after the peak. During COVID-19, Chinese middle school students take online courses at home due to temporary regulations of social distance or lockdown. Body-related activities of school-aged adolescents may be significantly reduced during this period since there are no physical education classes, no need to commute to school and no recess to play with classmates. Psychomotor symptoms have a unique significance in the pathophysiology, diagnosis, and therapy of depression (Schrijvers et al., 2008). Meanwhile, core symptoms of anxiety are associated with psychomotor functions, such as restlessness (Spitzer et al., 2006). Since we also recruited the adolescents after the peak stage, this could explain why “Motor” in depressive symptoms or “Restlessness” and “Trouble relaxing” in anxiety symptoms may increase the risk of activation of other depressive and anxiety symptoms in our sample. However, the previous network analysis of depressive and anxiety symptoms in Chinese adolescents did not show the same results (Cai et al., 2022; Liu et al., 2022). In contrast to prior studies, we excluded adolescents who did not have symptoms of depression and anxiety (PHQ-9<5 and GAD-7<5). The network structures of low-symptom adolescents and high-symptom adolescents were statistically different (Osborn et al., 2020). Our finding is consistent with previous findings of a comorbidity network of depressive and anxiety symptoms in an inpatient sample (Kaiser et al., 2021). In addition, we found a strong link between two psychomotor symptoms in anxiety clusters, which is “Restlessness” and “Trouble relaxing”. This finding is also consistent with the results of depressive and anxiety symptoms network analysis in Chinese patients with epilepsy (Wei et al., 2021). A similar network structure result was found in Chinese adolescents, which demonstrated that the association between 'Restlessness' and 'Trouble relaxing' is relatively strong in both the first and second surveys of depressive-anxiety symptom networks (Liu et al., 2022). Therefore, psychomotor symptoms were more likely to activate other symptoms in our depressive-anxiety symptom network.

"Sad Mood" is another central symptom in this network, which is consistent with the findings of (Cai et al., 2022) in their study of Chinese adolescent depressive and anxiety networks. Moreover, Similar results were found among adolescents in different countries. For example, a network analysis of depressed teenagers in the US showed that “Sad” was one of the most central symptoms and stay stable over the developmental period from 5 to 14 years old (McElroy et al., 2018). This finding indicated that “Sad Mood” is likely to be the key symptom to maintain the depressive-anxiety symptoms network among adolescents. For adolescents in Sub-Saharan Africa, “depressed mood” was one of the most central depression symptoms in the depressive-anxiety symptoms network (Osborn et al., 2020). These studies demonstrate that “Sad Mood” as the most central symptom of adolescent depression and anxiety networks have cross-cultural generalizability. Apart from community samples, similar results were found
Sad mood represents a negative affect state, which is a hallmark for a diagnosis of major depression based on DSM-5 and ICD-10. Sad mood has been proven to be superior in assessing the risk of an episode or relapse of depression compared to other depressive symptoms. For example, network analysis demonstrated that "Sad mood" was more central than the other 28 depressive symptoms in a large, depressed outpatients’ sample (Fried et al., 2016). The same results have been demonstrated in a longitudinal study with a community sample of adolescents (Georgiades et al., 2006). According to the concept of centrality in network analysis, "Sad mood" may activate other symptoms in the depressive-anxiety network. Therefore, this finding supports that the "Sad mood" is a risk factor for anxiety and depression.

Furthermore, “Sad Mood” was the central node between suicidal ideation and other depressive-anxiety symptoms, which was directly related to suicidal ideation. Moreover, “Sad Mood” was a central symptom in the SI group network, which was less important in the non-SI group network. Adolescents with suicidal ideation who experience a sad mood may be at an increased risk for activation of other anxiety-depressive symptoms. Meanwhile, as a unique bridge symptom in the network of adolescents with suicidal ideation, “Sad Mood” may increase the risk of anxiety. Suicidal ideation in adolescence may develop from a mildly depressed mood in response to acute stressors to a generalized sad mood (Prager, 2009). Based on the mood activation hypotheses and cognitive theory, vulnerable individuals in a sad mood are less likely to show protective bias in their attentional functioning (McCabe et al., 2000). This suggests that those vulnerable adolescents are more likely to neglect positive and neutral content words and bias toward negative-content words when they are in a sad mood (Lau et al., 2004). Meanwhile, sad mood may induce maladaptive cognitions, which are associated with suicidal ideation during depressive episodes (Antypa et al., 2010). Therefore, prevention and treatment of suicidal ideation could focus on reducing the maladaptive cognitions triggered by sad moods. Mindfulness-based therapy has been found to be effective in improving negativity bias (Raes et al., 2009). For example, mindfulness-based stress reduction has shown effectiveness in reducing suicidal ideation, anxiety, and depression (Serpa et al., 2014).

Compared with the non-SI group, “Restlessness” was the most central symptom in the SI group network, which corresponds with the most prominent central symptoms identified in the comorbidity network. Agitated depression is a subtype of major depressive disorder (MDD), with the co-occurrence of depression and psychomotor agitation in an episode (Spitzer et al., 1978). One of the excitatory psychomotor symptoms is restlessness (Akiskal et al., 2005). As a typical symptom of agitated depression, suicidal ideation could be independently predicted by psychomotor activation during MDD (Akiskal et al., 2005). Meanwhile, restlessness is a core symptom of anxiety disorders. Adolescents with anxiety disorders may exhibit emotional processing biases, such as interpreting ambiguous situations as threatening or being attracted by threatening information, which may lead them to experience more negative arousal states including restlessness and trouble relaxing (Osborn et al., 2020). This emotional-processing bias for negative stimuli is also a characteristic of suicidal ideation (Harfmann et al., 2019). Therefore, restlessness may increase the risk of activation of other anxiety and depression symptoms in adolescents with suicide ideation. Physical therapy and pharmacologic treatment, such as rTMS,
ziprasidone and haloperidol, were found to be effective in reducing psychomotor symptoms (Citrome et al., 2004; Heath et al., 2018). With the decrease of the central symptom in the depressive-anxiety network, suicidal ideation may also be alleviated.

There are several limitations in this study. First, suicide ideation was measured by one question in PHQ-9 rather than a suicidal ideation scale. Second, it is a cross-sectional study to estimate the undirect network. As these edges do not show a causal relationship between symptoms, it reduces the effectiveness of application in clinical intervention and treatment. Researchers could conduct a longitudinal study with a suicidal ideation scale to investigate the causal relationship between suicide ideation and other symptoms of anxiety and depression in the future.

5. Conclusions

This is the first network analysis to focus on suicide ideation and comorbid depression and anxiety symptoms in Chinese teenagers. The current findings demonstrated that “Sad Mood” was a central node directly related to suicide ideation. Meanwhile, it was the central symptom both of the suicide ideation network and the depressive-anxiety symptom network. “Restlessness” as one of the psychomotor symptoms was the bridge symptoms in these two networks. The results suggested that “Restlessness” and “Sad Mood” might be intriguing avenues for reducing depression and anxiety symptoms in adolescents with suicide ideation. With the interesting understanding of the interactions between suicide ideation and comorbidity of depressive and anxiety symptoms, the study provides a novel symptom-level perspective for the prevention, identification, and intervention of suicidal ideation.

Declarations

Ethics approval and consent to participate

The study received ethical approval from the Second Xiangya Hospital of Central South University on March 31, 2022. The number of Institutional Review Boards approval was 004. Informed consent was obtained from all the participants and their parents.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.
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Authors’ Contributions

SX and YJ: Conceptualization, Writing – original draft, analysis; XW: Conceptualization, Writing – original draft; WO, MM, GL, XZ, YQ, YLi, LL, MH, SY, YLu, YC and JL: Investigation, Data curation; BL and YZ: Conceptualization, Writing – review and editing, Supervision. All authors read and approved the final manuscript.

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Figures

Figure 1

a) Network structure of anxiety and depression 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.
Figure 2

*Flow Network of Suicide Ideation. Blue edges represent positive associations. Red edges represent negative associations.*
Figure 3

a) Network structure of depressive-anxiety symptoms among the non-SI group. b) Network structure of depressive-anxiety symptoms among the SI group. c) Expected influence of the non-SI group. d) Bridge expected influence of the non-SI group. e) Expected influence of the SI group. f) Bridge expected influence of the SI group. P1, Anhedonia; P2, Sad Mood; P3, Sleep; P4, Energy; P5, Appetite; P6, Guilty; P7, Concentration; P8, Motor; G1, Nervousness; G2, Uncontrollable worrying; G3, Worry too much; G4, Trouble relaxing; G5, Restlessness; G6, Irritability; G7, Feeling afraid.

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