Original Article

Network structure of emotional and behavioral problems, loneliness, and suicidal thoughts in adolescents at the school closure and reopening stage in China

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Background: Public restriction and school closure policies during the pandemic may have long-term effects on adolescents' mental health, and adolescents' feelings and needs may change as the pandemic progresses. This study was conducted to explore the network structure and differences in emotional and behavioral problems (EBPs), loneliness, and suicidal thoughts in adolescents during different pandemic periods in China.

Methods: Based on two cross-sectional studies conducted in Taizhou, China, during school closure (April 16 to May 14, 2020) and reopening (May 25 to July 10, 2021) using online questionnaire, a total of 14,726 adolescents (school closure: 6,587, school reopening: 8,139) were recruited. EBPs were evaluated based on the student version of the Strengths and Difficulties Questionnaire (SDQ). Loneliness and suicidal thoughts were measured by item 20 and item 9 of the Chinese version of the Children's Depression Inventory (CDI), respectively. Network analysis was used to estimate the network connections and properties between EBPs, loneliness, and suicidal thoughts.

Results: The prevalence of psychosocial problems significantly increased at the school reopening compared with the school closure: EBPs: 36.8% *vs.* 31.6%; loneliness: 40.3% *vs.* 33.9%; suicidal thoughts: 40.8% *vs.* 15.4%. Suicidal thoughts showed the closest connections with being unhappy and lonely. Being bullied was strongly connected with conduct problems of lying and stealing. The links between hyperactivity symptoms and the other domains of EBPs were stronger after the school reopened. Being unhappy and showing the hyperactivity symptoms of "nonpersistent, distractible, and fidgety" presented high network and bridge (increasing transference from one symptom domain to another) centrality. Loneliness showed high expected influence and bridge centrality.

Conclusions: This study highlighted the high prevalence of EBPs, loneliness, and suicidal thoughts in Chinese adolescents. It also presented the network structure of these psychological problems over different pandemic stages. It is recommended that psychological support should be provided for adolescents, especially focusing on the central and bridge symptoms highlighted in this study.

Keywords: Network analysis; emotional and behavioral problems (EBPs); loneliness; suicidal thoughts; bullying

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Introduction

Adolescents have experienced substantial challenges as a result of the coronavirus disease 2019 (COVID-19) pandemic, including social distancing, school closures, home quarantine, negative information overload, missed in-person contact with peers and teachers, and family stress (e.g. parent mental health, family relationship problems, and personal space), which can impair mental health (1,2). A study in Hubei province, China, found that 22.28% of adolescents suffered from depression during the outbreak of the pandemic (3). Similarly, another study in China reported that 43.7% of junior and senior high school students indicated mild to severe depressive symptoms (4). However, the prolonged effect of the pandemic and prevention-related measures such as school closures on adolescents' mental health was largely unknown.

From childhood to adolescence, suicide attempts in the USA peaked in mid-adolescence before declining with the transition into young adulthood (5). The prevalence of suicide attempts in Chinese adolescents was around 3.1% before the pandemic (6). There have been rising concerns about adolescents experiencing social distancing during the pandemic, alongside concerns about increases in suicidal ideation. Given the complexity of the ongoing pandemic, credible assessments of suicidal thoughts and adequate interventions are required to reduce the risk of suicidal behavior and committed suicide.

To date, many previous studies have investigated the relation between emotional and behavioral problems (EBPs) and suicidal thoughts (7,8). Based on the cognitive-motivational-relational theory of emotion, emotional problems have negative effects on motivation and cognitive processes associated with suicide attempts (7). Destructive behavioral disorders may increase the likelihood of suicide by 3- to 6-fold in adolescents without psychiatric symptoms (8). Besides, emotional problems were associated with a range of adverse outcomes including substance abuse, physical health problems, and educational failure (9). Hyperactivity was a risk factor for later development of adolescents, and caused a high likelihood of violence and other conduct problems, substance abuse, and low self-esteem (10). In addition, adolescents who were isolated from their peer group tended to present EBPs (11). Peer attachment played a key role in explaining adolescents' behavioral problems such as substance abuse and aggressive behavior (12,13). Epidemiological studies have indicated that children and adolescents are particularly vulnerable to EBPs during the pandemic due to a variety of challenges posed by the COVID-19 crisis (14-16).

Loneliness has drawn particular attention in the context of the pandemic. Researchers cautioned that long-time social isolation limits adolescents' in-person contact with peers and teachers, aggravating loneliness (17). An early study indicated that around half of young adults reported high levels of loneliness during lockdown (18). Loneliness may lead to negative mental health outcomes such as depression, behavioral problems, and suicide (19-21). However, there is a lack of literature about the co-occurrence and the interactions between EBPs, loneliness, and suicidal thoughts among adolescents and their dynamic changes during different pandemic periods. To further

Highlight box

Key findings

- The prevalence of emotional and behavioral problems (EBPs), loneliness, and suicidal thoughts in Chinese adolescents was higher after the school reopened.
- Suicidal thoughts had the strongest connection with being unhappy and lonely.
- Being bullied was closely linked with conduct problems of lying and stealing.
- Being unhappy and having hyperactivity symptoms showed high network and bridge centrality.
- Loneliness also showed high network and bridge centrality in both stages.

What is known and what is new?

- There was a strong connection between loneliness, EBPs, and suicidal thoughts.
- Suicidal thoughts showed the closest connections to being unhappy and lonely. The impact of the pandemic and prevention-related measures on psychological interaction patterns was varying.

What is the implication, and what should change now?

- It is recommended that psychological support should be provided for adolescents, especially focusing on the central and bridge symptoms highlighted in this study.

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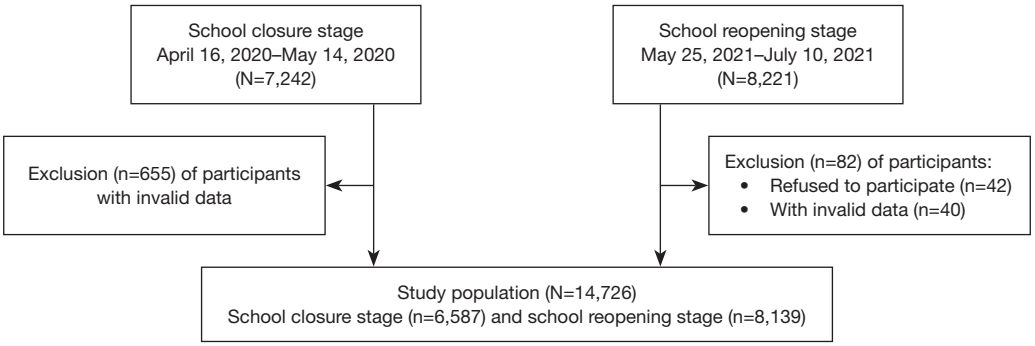

Figure 1 Flow chart.

understand these phenomena, the current study applied the statistical approach of network analysis.

Network analysis can be used to identify shared connections in a highly multivariate data set. In terms of symptom patterns, network modeling is useful to provide visual and quantitative information by graphically mapping the connections between symptoms and highlighting central symptoms (22). The central symptoms in a network are closely connected to other symptoms and could be prognostic indicators. Interventions could target central symptoms to reduce or prevent the activation of additional symptoms (23). Network analysis is also a novel approach to understanding the mechanism of co-occurrence among different domains of symptoms (24,25). Bridge symptoms are defined as those that increase the risk of transferring from one domain to another (25). As such, it can help identify clinical and public health targets to prevent the co-occurrence of mental health problems.

Two cross-sectional surveys were conducted to investigate the prevalence of EBPs, loneliness, and suicidal thoughts among Chinese adolescents in Taizhou during the school closures and reopening stage. Using network analysis, this research aimed to explore the network structure of EBPs, loneliness, and suicidal thoughts, and to explore the differences between the networks obtained during different pandemic periods. It further aimed to explore the interactions between symptom domains of EBPs, loneliness, and suicidal thoughts over the two stages, and to identify the central symptoms and bridge symptoms. Following the literature reviewed on the relationships between emotional problems, peer problems, hyperactivity, conduct problems, loneliness, and suicidal thoughts, we hypothesized that suicidal thoughts would be mostly connected with emotional problems and loneliness, and that emotional problems and loneliness would be the central symptoms of the psychosocial network in adolescents. However, we were not able to provide a clear hypothesis regarding the differences in these symptoms between the school closure and the reopening stage due to the lack of enough evidence. We present this article in accordance with the STROBE reporting checklist (available at https://tp.amegroups.com/article/view/10.21037/tp-23-33/rc).

Methods

Study population

Two population-based cross-sectional studies were conducted in junior and senior high schools in Taizhou, Zhejiang province, China. The first survey was conducted during the school closure stage from April 16 to May 14, 2020. The second survey was conducted during the school reopening stage from May 25 to July 10, 2021. Cluster sampling was adopted, and 24 and 36 junior and senior high schools were randomly selected in two stages, which covered public and private schools. Two classes were randomly sampled from each grade in each school. All students were invited to complete an online questionnaire through the Wenjuanxing platform (http://www.wjx.cn). Eligibility criteria were: (I) students in junior or senior high school; (II) able to read, understand, and complete the questionnaire independently; and (III) online informed consent provided. A total of 7,242 and 8,221 eligible students were invited in the two stages, with the participation rates of 100% and 99.49%, respectively. After the exclusion of 655 and 40 invalid questionnaires which missed school information or took more than one hour to complete from the two stages, a total of 14,726 participants were included in the analyses (6,587 from the school closure stage and 8,139 from the school reopening stage) (*Figure 1*). The study was conducted

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in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Ethics Committee of Taizhou Central Hospital (No. 2022L-01-17) and online informed consent was taken from all individual participants.

Assessment of sociodemographic and psychosocial characteristics

Demographic information included adolescents' age, sex (boys or girls), school type (public or private school), family economic status (high, medium, and low levels based on subjective appraisals), father's and mother's educational attainment (primary school or lower, middle or high school, and college or higher), relationships with mother and father (good, normal, and bad), study time at home on average each day in the last month (including time for online courses), screen entertainment time on average each day in the last month (including mobile phones, TVs, computers, etc., except online courses), and whether having difficulty in studying.

Assessment of suicidal thoughts and loneliness

Suicidal thoughts and loneliness were measured by two items from the Chinese version of the Children's Depression Inventory (CDI) (26). Q1: I do not think about killing myself; I think about killing myself, but would not do it; I want to kill myself. Q2: I do not feel lonely; I feel lonely many times; I always feel lonely. Each item consisted of three options, scored from 0 to 2, and the adolescents were asked to choose the best statement that described their feelings and thoughts during the past 2 weeks.

Assessment of EBPs

EBPs were evaluated based on the student version of the Strengths and Difficulties Questionnaire (SDQ) (27). In this study, we included four subscales: conduct problems, emotional problems, hyperactivity, and peer problems over the past six months. Each subscale consisted of five statements scored from 0 to 2 (ranging from "Not true" =0 to "Certainly true" =2 with five reverse-scored items). The items of SDQ and their reference names are listed in Table S1. The total difficulties score was calculated by summing the scores from all the scales, with higher scores indicating more severe symptoms. This was then divided into 4 categories: 0–14 indicating close to average, 15–17 slightly raised, 18–19 high, and 20–40 very high. Cronbach's alpha was 0.83 and 0.84 at the two stages.

Preliminary statistical analyses

Continuous variables were presented as mean (standard deviation) and categorical variables as frequencies and percentages. Chi-square test and Student's *t*-test for independent samples were used to compare the categorical and normally distributed continuous variables between the school closure and reopening stages.

Network estimation and centrality

Network analysis was used for network estimation, network centrality, and network comparison. Pair-wise Spearman correlations were run and sparse Gaussian graphical models with graphical lasso were conducted to estimate the networks of the relation between EBPs, loneliness, and suicidal thoughts at the school closure and reopening stages. In a network, each item was considered as a node and the pair-wise correlations between these nodes were considered as edges, with thicker edges indicating stronger associations. The network was estimated via "bootnet" and visualized via the "qgraph" R package (28). Network structure was described by network centrality indices, including strength, betweenness, closeness, and expected influence (29,30). The higher centrality values indicated the more important symptoms that were connected to more numbers of other symptoms in the network. Strength was the sum of the absolute edge weights directly linked to a focal node in the network, and the node with high strength might lead to the activation of other nodes (30). Betweenness referred to the degree that a focal node lied on the shortest path between another two nodes, and the node with high betweenness might be a bridge that connects different symptom clusters of the network (30). Closeness was defined as the inverse of the average shortest path length from a focal node to other nodes. The node with high closeness might be most directly associated with more symptoms (30). Expected influence (EI) was a new index of strength that accurately calculated a node's linkage including positive and negative edges (31).

Apart from network centrality, bridge centrality indices were estimated, including bridge strength, bridge betweenness, bridge closeness, and bridge expected influence. Bridge centrality indicates the importance of a specific symptom in linking two dimensions of mental health symptoms (32). This was completed using the "networktools" R package (31). Stability of the network

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structure was evaluated by a bootstrap method with 1,000 replicates (33,34). Mean values and 95% confidence intervals of edge weights in the bootstrapped sample were plotted together with the edge weights in the current sample. Consistency of edge weights in the current and bootstrapped sample was used as an indicator of network stability. Network stability was assessed using a case-dropping subset bootstrap with 1000 replicates. A correlation stability (CS) coefficient was used to quantify stability of the network structure. A CS value greater than 0.5 indicates strong stability (28). The bootstrap of network stability was calculated via the "bootnet" R package (28).

Network comparison

The network difference between school closure and reopening stages was compared using permutation tests with 1,000 iterations via the "NetworkComparisionTest" R package (35). Network differences in edges were compared at the global and local levels. Global difference in invariant network structure was quantified by testing the largest difference in paired edges between two networks. Global difference in strength was measured by the difference of the weighted absolute sum of all edges in the network. Also, local differences were quantified by testing for invariance per edge strength. In addition, differences in network property were estimated separately. The level of significance was set at a P<0.05.

Results

Characteristics of the study population

Table 1 presents participant descriptive information. A total of 14,726 participants were included in this analysis. Specifically, 6,587 participants with an average age of 15.6±1.7 years were surveyed in the school closure group, while 8,139 participants with an average age of 15.3±1.4 years were surveyed in the school reopening group. There were 50.1% and 48.0% of girls in these groups, and nearly one-third studied in private schools. A small proportion reported low family economic status, low father's education, low mother's education, and poor relationships with parents. Mean study time at home was greater in the school reopening group, while screen entertainment time was lower. More than half of the sample had difficulty in studying. Compared with the school closure group, adolescents in the school reopening group were more likely to have suicidal thoughts (40.8% *vs.* 15.4%, P<0.001) and report loneliness (40.3% *vs.* 33.9%, P<0.001). The mean SDQ total score was higher at school reopening stage compared with school closure (12.6±6.0 *vs.* 11.8±5.8, P<0.001). The prevalence of slightly raised, high, and very high EBPs was 13.4%, 7.3%, and 11.0% at school closure, also significantly greater in the reopening group. Regarding SDQ subscales, adolescents were more likely to report conduct, emotional, and hyperactivity problems in the reopening group (all P<0.05).

Network estimation

The estimated network structure is displayed in *Figure 2* and detailed edge weights are listed in Tables S2,S3. The network structure during school closure and reopening had some similarities regarding symptom connections (edge weights). Suicidal thoughts showed the strongest connections with being unhappy and lonely at both stages. Loneliness was positively correlated with suicidal thoughts, emotional problems of being unhappy, and peer problems of being solitary and unpopular. Also, being bullied was more strongly connected with conduct problems of lying and stealing than the other peer problems. Symptoms of emotional problems were closely interlinked, while some showed strong connections with symptoms of hyperactivity, such as worries with fidgety, and nervousness with distractible. Apart from the other symptoms of hyperactivity, being nonpersistent was closely linked to being unpopular among children, not getting on well with adults, and being disobedient.

Stability of the networks was evaluated using the bootstrap method at both stages. Results are shown at Figures S1,S2. The edge weights in the current sample were largely consistent with the bootstrapped sample, indicating that the network structure was stable (Figure S1). The CS exceeded 0.5 for both stages even using 30% of the cases, indicating a stable structure regardless of groups (Figure S2).

Network comparison

Network differences in symptom connections (edge weights) between school closure and reopening were examined. The global difference in network structure was statistically significant. The maximum difference (diff, contrast: school reopening—school closure) between the two stages in edge weights was between fights and lies symptoms (diff =0.12, P of permutation test =0.010), although no global difference in strength was found (global strength of school closure *vs.*

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Table 1 Participants characteristics

Characteristics	School closure (N=6,587)	School reopening (N=8,139)
Age, years	15.6±1.7	15.3±1.4
Girl	3,297 (50.1)	3,904 (48.0)
Private school	2,114 (32.1)	2,320 (28.5)
Economic status		
High	674 (10.2)	1,462 (18.0)
Median	5,462 (82.9)	6,178 (75.9)
Low	451 (6.8)	499 (6.1)
Father's education		
Primary school or lower	1,225 (18.6)	1,173 (14.4)
Junior or senior high school	4,649 (70.6)	5,888 (72.3)
College or higher	713 (10.8)	1,078 (13.2)
Mother's education		
Primary school or lower	1,650 (25.0)	1,530 (18.8)
Junior or senior high school	4,254 (64.6)	5,594 (68.7)
College or higher	683 (10.4)	1,015 (12.5)
Relationship with mother		
Good	5,231 (79.4)	6,604 (81.1)
Normal	1,230 (18.7)	1,372 (16.9)
Bad	126 (1.9)	163 (2.0)
Relationship with father		
Good	4,951 (75.2)	6,059 (74.4)
Normal	1,458 (22.1)	1,836 (22.6)
Bad	178 (2.7)	244 (3.0)
Study time at home, h	3.20±2.89	3.94±2.78
Screen entertainment time, h	3.00±3.05	2.60±2.51
Having difficulty in studying	3,569 (54.2)	4,571 (56.2)
Suicidal thoughts		
No	5,571 (84.6)	4,819 (59.2)
Yes, but would not do it	902 (13.7)	3,002 (36.9)
Yes	114 (1.7)	318 (3.9)
Loneliness		
No	4,353 (66.1)	4,858 (59.7)
Many times	1,880 (28.5)	2,796 (34.3)
Always	354 (5.4)	485 (6.0)
Total score for SDQ	11.8±5.8	12.6±6.0
Close to average (0 to 14)	4,504 (68.4)	5,140 (63.2)
Slightly raised (15 to 17)	880 (13.4)	1,219 (15.0)
High (18 to 19)	481 (7.3)	658 (8.1)
Very high (20 to 40)	722 (11.0)	1,122 (13.8)
SDQ subscales		
Conduct problems	2.1±1.6	2.2±1.6
Emotional problems	2.8±2.4	3.4±2.5
Hyperactivity	3.8±2.2	3.9±2.2
Peer problems	3.1±1.5	3.1±1.6

Continuous variables were presented as mean ± standard deviation and categorical variables as n (%). SDQ, the Strengths and Difficulties Questionnaire.

school reopening: 12.7 *vs.* 13.3, P=0.45). Additionally, local differences were found in several edges, and the statistically significant higher and lower correlations are visualized separately at *Figure 3* (P<0.05).

In the school reopening group, suicidal thoughts showed a weaker connection with being unhappy, but the edge weight was still large. Fears were more closely related to somatic symptoms such as headaches, stomach aches, or sickness. There were no significant differences in the connections between loneliness and other symptoms. Compared to the school closure group, emotional problems showed stronger connections with symptoms of hyperactivity in the school reopening group. There were increased connections between worries and distraction, and between being nervous in new situations and nonpersistent. The hyperactivity problem of restlessness was more closely related to stealing and having no friends.

Network centrality

Figure 4 shows the network and bridge centrality of each item at the two stages. Being unhappy and hyperactivity symptoms such as "nonpersistent, distractible, and fidgety" exhibited high network and bridge centrality at both stages. The high betweenness and bridge betweenness of these symptoms showed that they might play a key role

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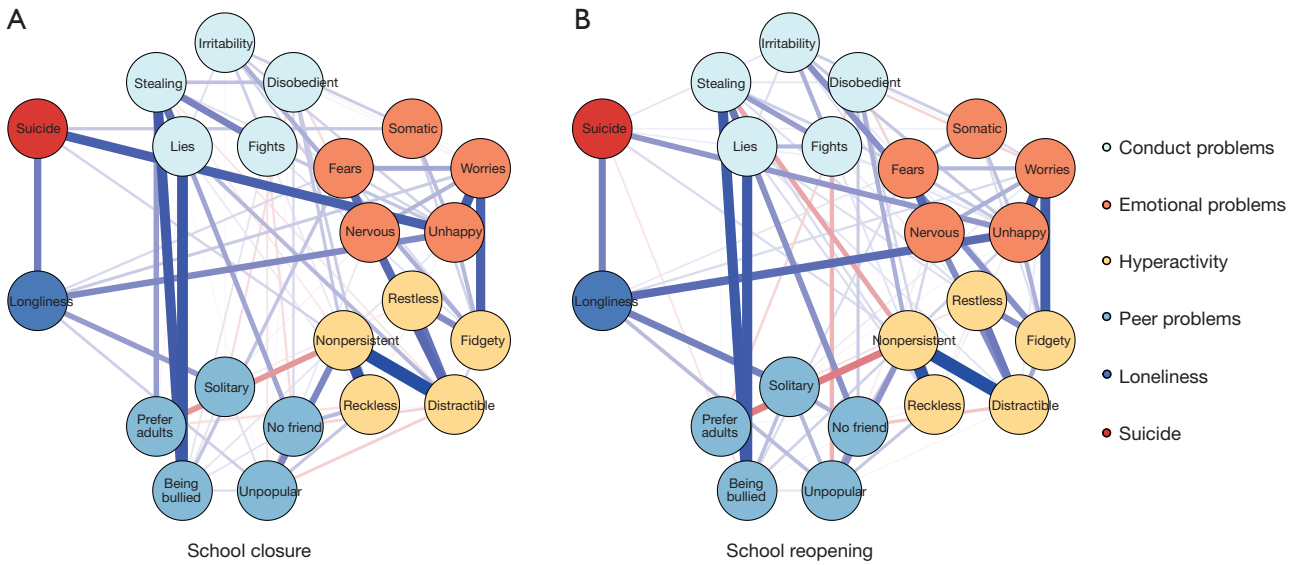

Figure 2 Symptom network at two stages. The light blue nodes denote the SDQ conduct problems, orange nodes denote emotional problems, yellow nodes denote hyperactivity, middle blue nodes denote peer problems, and blue and red nodes denote loneliness and suicide, respectively. The blue edges denote the positive correlations and the red edges denote the negative correlations. (A) School closure; (B) school reopening. SDQ, the Strengths and Difficulties Questionnaire.

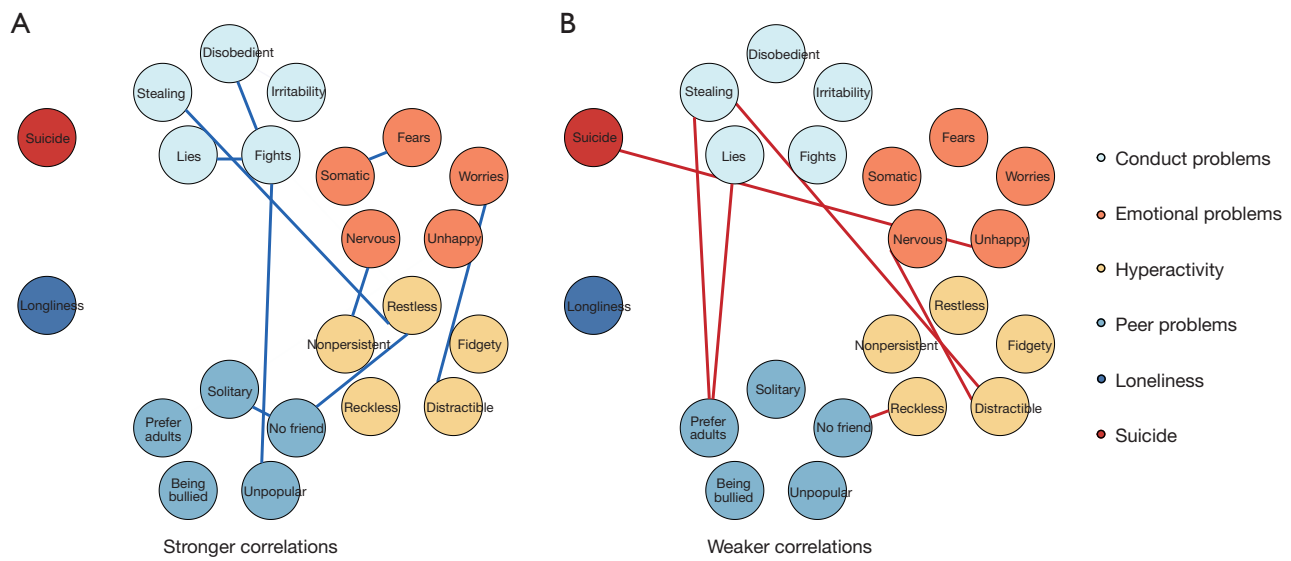

Figure 3 Edges exhibiting significant differences between two stages. The light blue nodes denote conduct problems of the SDQ subscale, orange nodes denote emotional problems, yellow nodes denote hyperactivity, middle blue nodes denote peer problems, and blue and red nodes denote loneliness and suicide, respectively. Additionally, the blue edges denote stronger correlations between subscales during school reopening compared with those during school closure; and red edges denote weaker correlations. (A) Stronger correlations during school reopening compared with those during school closure; (B) weaker correlations during school reopening compared with those during school closure. SDQ, the Strengths and Difficulties Questionnaire.

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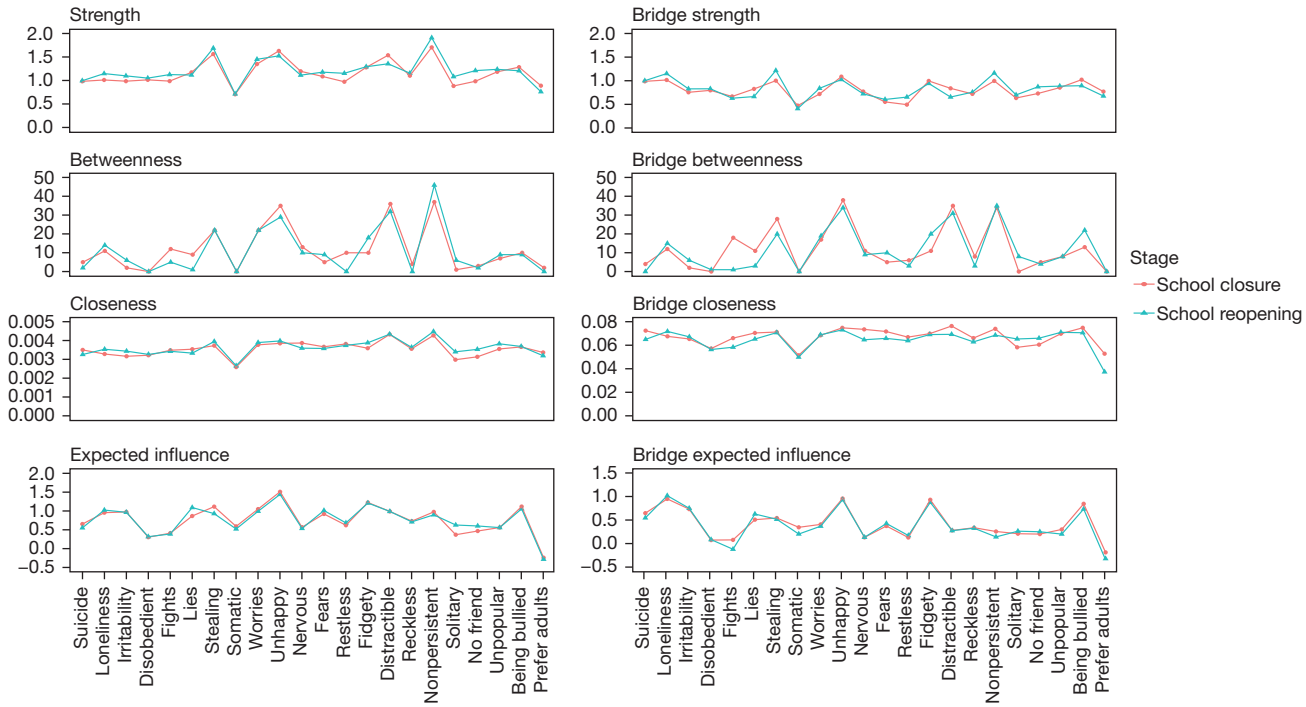

Figure 4 Network and bridge centrality.

as mediators in regulating the connections between the associated symptoms. Loneliness also showed high EI, bridge strength, bridge closeness, and bridge EI, and being bullied showed high EI and bridge EI at both stages. In addition, permutation tests showed that peer problems of solitary (diff $_{EI}$ =0.26, P<0.001) and no friend (diff $_{EI}$ =0.13, P=0.008) showed greater EI in the school reopening group compared to the school closure group.

Discussion

This is the first large-scale network analysis of the structure of adolescent EBPs, loneliness, and suicidal thoughts during different COVID-19 pandemic periods. Central and bridge symptoms were identified by focusing on their network interactions. The globally different network structure between school closure and reopening stages suggests the varying impact of the pandemic and prevention-related measures on psychological interaction patterns.

In this study, the prevalence of EBPs was 31.6% among adolescents during school closure. This was similar to a previous study which reported 30.9% EBPs in 1,293 students aged 7–17 years during the pandemic (36). It was notable that the prevalence of EBPs in this study was 36.8% during the school reopening period, particularly for emotional, conduct, and hyperactivity problems. These results suggest that harmful effects on mental health might last for a long time after the pandemic peak. Previous research indicates that the frequency of loneliness is age-dependent, peaking in adolescence and old age (37). One-third of adolescents in this study reported loneliness at school closure and 40.3% at school reopening. These results are consistent with two studies in which 27–36% of UK adults self-reported high levels of loneliness during the pandemic (38,39). Social distancing measures most severely hit young adults and might have potential long-term effects on the increase in loneliness (40). Our results also suggested that the level of loneliness that adolescents experienced during the pandemic did not turn out to be transient. In this study, the prevalence of suicidal thoughts was 15.4% during school closure and 40.8% at school reopening (severe suicidal ideation: 1.7% *vs.* 3.9%). These results were consistent with a recent study that found the suicide rate among Japanese children and adolescents increased in the second wave of the pandemic (July to October 2020) compare to the first wave (February to June 2020), with the incidence rate ratio 1.49 (95% CI: 1.12, 1.98) (41). The difference in prevalence of EBPs, loneliness, and suicidal thoughts in

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our study could be due to the far-reaching influences of COVID-19. During school closure, adolescents experienced a prolonged state of home isolation with high stress and anxiety, irregular rhythm of routine, and lack of in-person contact with peers and teachers (2). Short-term exposure to a harmful environment might not affect mental health immediately, but consequences of the accumulative risk might emerge after school reopening (42). Furthermore, adolescents might have a higher level of academic stress at school reopening, since the timing of the second survey was near the end of the school term.

Regarding the symptom network, suicidal thoughts had the strongest connections with being unhappy and lonely at both stages, which supported our hypothesis. Suicidal thoughts may be the result of a maladaptive attempt to deal with distressful emotions (43). The association between being unhappy and suicidal thoughts is supported by the cognitive-motivational-relational theory of emotion. Emotional problems have adverse effects on individual adaptive functioning and social interrelationships, and adolescents with emotional problems tend to have poor emotional regulation skills, which may further facilitate the occurrence of suicidal behaviors (44,45). The connection between loneliness and suicidal thoughts is consistent with the results of a meta-analysis indicating that loneliness is a significant predictor of suicidal ideation and behavior (46). The association was explained by the Interpersonal Theory of Suicide, which suggests that loneliness in the form of thwarted belongingness could induce suicidal thoughts (47). Other possible mechanisms are that loneliness affects biology including brain structure and processes, and also changes adolescents' conception of stressful events caused by the pandemic (48). The connection between fears and suicidal thoughts was stronger in the school reopening sample, although the difference was not significant. The difference might be caused by adolescents experiencing more fears of academic examination, social interaction with peers, and bullying. In the school reopening network, fears were more closely connected with somatic symptoms such as headaches, stomach aches, or sickness. Another possible explaination was that students might have more fear of COVID-19 after returning to school. Parents and teachers need to take notice of adolescents who frequently complain of physical problems as their emotional problems sometimes were manifested through somatic symptoms (49).

Similar to previous studies (20,21), the present study found that loneliness was strongly connected to being unhappy at both stages. Loneliness also displayed a strong association with peer problems of solitary and unpopular in this network, and the association was stronger in the school reopening group even if the difference was not significant. Adolescents seemed vulnerable to loneliness in the COVID-19 context (17), because of the insufficient peer support and in-person interactions which were particularly important during the development stage (50). Further on, peer problems of solitary and unpopular might be relevant intervention targets during periods when adolescents attend school. In addition, loneliness appeared to be a central symptom in the network, especially for bridge centrality, and the centrality was stronger in the school reopening group. Loneliness might raise the prevalence of suicidal thoughts by increasing the risk of depressive symptoms, with unhappiness being one of the most central symptoms of mental disorders after the COVID-19 outbreak (51). Further study is required to explore the potential mediation effect of depression in the relation between loneliness and suicidal thoughts.

Network theory helps to understand the co-occurrence of symptoms between different mental health problems. After assessing interactions between the EBP subscales, it was found that symptoms of hyperactivity showed strong connections with emotional, peer, and conduct problems. In particular, the associations between distraction and worries, nonpersistent and nervous in new situations, as well as restlessness and stealing and no friends were stronger in the school reopening group. Hyperactivity symptoms of being fidgety, distractible, and nonpersistent showed high network and bridge centrality in the network structure at both stages. Our findings suggested that hyperactivity might activate symptoms of other domains of EBPs among adolescents. A recent large-scale genome-wide association study (GWAS) found common genetic variants between attention deficit hyperactivity disorder and anxiety disorders (52). Oppositional defiant disorder and conduct disorder are the most common psychiatric comorbidities in children with hyperactivity, occurring in 60% of patients (53). Adolescents with hyperactivity tend to demonstrate inattention, impulsivity, low frustration tolerance, and temper tantrums, which makes their peers dislike them (54).

In the current study, bullying rate was significantly greater in the school reopening group compared with the school closure group (20.1% *vs.* 15.9%, P<0.001). Being bullied appeared to be another central and bridge symptom in the network at the school reopening stage, and was strongly associated with the conduct problems of lies and stealing. Research suggests that children with a high

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level of behavioral problems are more likely to become a bully-victim (55). Conduct problems and bullying seem to be a manifestation of the same underlying neurobiological mechanism such as impairment in the anterior cingulate cortex or a difference in prefrontal cortical development (54). Bullied individuals can also experience externalizing symptoms including conduct problems, especially in boys (56). Additionally, children who bully and are bullied are most likely to suffer from conduct problems compared to pure perpetrators and pure victims (55). Therefore, Chinese parents and teachers should pay more attention to adolescents with conduct problems, which might be a sign of school bullying.

The centrality of nodes performed well in identifying specific symptoms that contributed most strongly to overall psychological status. Partially supporting our hypothesis, being unhappy, nonpersistent, distractible, and fidgety were central and bridge symptoms at both stages. Since the central symptoms remained consistent over time, the symptoms could be regarded as intervention targets for mental disorders. Besides the emotional problems screening, schools and researchers also should focus more attention on adolescents with hyperactivity problems which may activate symptoms of other domains. Loneliness showed high bridge centrality, especially at the school reopening stage. WHO has warned of the negative effect of COVID-19 related measures, such as school closures and social distancing, on loneliness, emotional problems, and suicidal behavior (57). Our results suggest that it would be beneficial to identify adolescents at risk of loneliness and low mood and deliver effective interventions, which theoretically should decrease the closely related risk of suicide. In addition, our results imply that the centrality of peer problems was enhanced after the school reopening. Parents and teachers should pay more attention to peer problems when students return to classrooms, especially school bullying. There are some preventive and coping recommendations against school bullying: (I) training teachers and school staff about strategies for preventing problems associated with bullying; (II) providing information about the behaviors that constitute bullying, the school's rules about bullying, and strategies for dealing with bullying for students and parents; (III) paying close attention to adolescents with conduct problems such as lying and stealing which have strong connections with being bullied; (IV) developing a school-based surveillance system to monitor bullying among adolescents. As China released measures to optimize COVID-19 response, schools are no longer closed and adolescents' life returns to normal. However, they still face looming challenges such as the health burden of post-COVID-19 condition and academic stress due to the long-term disruption to education. We hope that our findings are beneficial to the government, to schools, and to parents who should try their best to provide psychological support for adolescents, especially addressing the symptoms highlighted by our network analysis.

This research has two strengths. One is the use of a large sample size network analysis to identify central symptoms and bridge symptoms among EBPs, loneliness, and suicidal thoughts which provide potential key targets for mental interventions for adolescents during and after the COVID-19 pandemic. Another is that symptoms differences were evaluated and the dynamic process and interactions between EBPs, loneliness, and suicidal thoughts were investigated during two different pandemic stages, which helps to understand the long-term impact of COVID-19 on the psychological wellbeing of adolescents.

Several limitations also need to be noted in the current research. First, the level of EBPs was measured by a self-reported questionnaire rather than clinical diagnosis. Second, change was not investigated in our study, as this would require follow-up in the same individuals. However, our careful sampling procedure increased the probability that both groups of adolescents were equally representative of their denominator population. Third, we did not investigate casual relations, and more longitudinal studies are needed to clarify this. Fourth, the extent of loneliness and suicidal thoughts might not be sufficiently captured by a single item.

Conclusions

In conclusion, this study highlighted the high prevalence of EBPs, loneliness, and suicidal thoughts in Chinese adolescents, which were greater still in those experiencing school reopening compared to school closure. It also presented the variant network structure of these symptoms over different pandemic stages, and provides insights to understand interactions between specific symptoms. This study found that the central and bridge symptoms of being unhappy, nonpersistent, distractible, and fidgety to be particularly important in the symptom network. Being unhappy and lonely explained the most variance of suicidal thoughts, and lies and stealing were directly related to being bullied. These findings inform a potential approach for psychological interventions to reduce the co-occurrence of

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different mental health problems during adolescence.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://tp.amegroups.com/article/view/10.21037/tp-23-33/rc

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://tp.amegroups.com/article/view/10.21037/tp-23-33/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Ethics Committee of Taizhou Central Hospital (No. 2022L-01-17) and online informed consent was taken from all individual participants.

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