



Centrality and bridge symptoms of anxiety, depression, and sleep disturbance among college students during the COVID-19 pandemic—a network analysis

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Abstract

Symptoms of depression and anxiety usually co-occur and are inextricably linked to sleep disturbance. However, little is known about the symptom-to-symptom relationships among these three mental disorders. Hence, to improve our understanding of concurrent depression, anxiety, and sleep disturbance, we used the network analysis approach to construct an interplay relationship among the above three mental disorders and identify which specific symptoms bridge these aggregations. We collected data from a large sample ($N=6710$, male=3074, female=3636; $mean_{age} = 19.28$) at a university. We estimated the symptom network structure of depression, anxiety, and sleep disturbance as assessed by the Patient Health Questionnaire-9, Generalized Anxiety Disorder-7, and Youth Self-Rating Insomnia Scale during the COVID-19 lockdown. We further investigated four goals: first, identifying the individual core symptoms in the network by the index of “expected influence”; second, determining the bridge symptoms that play roles in linking different mental disorders by the index of bridge expected influence (1-step); third, examining the robustness of all results; and fourth, providing an overall structure that may or may not differ by sex. The network structure was stable, accurate, and predictable. Items referring to sleep dissatisfaction, poor sleep quality, and uncontrollable worry were potentially core symptoms in the interplay among depression, anxiety, and sleep disturbance. Sleep, guilt, restlessness, irritability, and feeling afraid can function as bridges among depression, anxiety, and sleep disturbance, which is clinically relevant and theoretically important. The results suggested that the network structures significantly differed between the female and male networks. Robustness tests also revealed that the results were reliable.

Keywords Depression · Anxiety · Sleep disturbance · Network · Comorbidity

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Introduction

Sleep or nocturnal rest is critical for growth and development in human beings (Nunn et al., 2016). Human health, well-being, and functioning are directly impacted by sleep deprivation that does not provide adequate rest (Itani et al., 2016; Tomaso et al., 2021). Lack of sleep, difficulty falling asleep, and/or remaining asleep are typical symptoms of sleep disturbances (American Psychiatry Association, 2013) and are highly associated with depression and anxiety disorders (Zhou et al., 2020). Significantly, the outbreak of COVID-19 has placed a considerable burden on the mental health of the entire population (Altena et al., 2020), and a systematic review revealed that the prevalence of sleep disturbance was 17.65–81% in the general population (Lin et al., 2021). For Chinese university students, the prevalence of poor sleep quality and sleep disturbances has been calculated as 30% (Li et al., 2020) and 25.7% (Li et al., 2018), respectively. Hence, given the essential nature of sleep and the potential terrible consequences caused by sleep disturbances, the mechanisms underlying the psychiatric disorders associated with sleep disturbances among college students should be explored.

As is well known, college students' daily routine was converted by implementing containment measures during the COVID-19 pandemic period, including taking online courses instead of offline teaching, playing video games without hanging out, and suspending part-time jobs or taking internships online. The most straightforward and transparent consequence of the containment measure is a boosted trend of sleep disturbance among college students (Li et al., 2020), and female college students report more sleep problems (Wang et al., 2022). College students have to face the academic load and the challenges of career planning and interpersonal relations construction, which means taking on more adult-like responsibilities with a paucity of adulthood skills and cognitive maturity (Pedrelli et al., 2015). In addition, tremendous pressure and time-intensive tasks force college students to squelch their spare time and can be deleterious to college students' sleep quality (Wang et al., 2022). In common sense, poor sleep quality simply represents day naps, tiredness, or fatigue. However, from the cognition perspective, poor sleep quality is positively associated with functional impairment (Graham & Kyle, 2017), subjective cognitive concerns (Joo et al., 2021), hyperactive/impulsive symptoms (Gregory et al., 2017), and more executive dysfunction (Gloger & Suhr, 2020). Moreover, from the perspective of emotion, sleep disturbance is highly relevant to anxiety and depression disorders (Zou et al., 2020). Worse, sleep disturbance increases the risk of self-injurious behavior (Liu et al., 2017). In summary, sleep is a vital psychophysiological process for physical and mental health, and

sleep disturbance can bring serious consequences to individuals, especially college students, who should be given special attention.

A meta-analysis including 64 studies with 100,187 participants indicated that depression and anxiety symptoms among college students were 33.6% and 39%, respectively (Li et al., 2022). Moreover, a national cross-sectional survey in China revealed that the prevalence of depression and anxiety during the COVID-19 pandemic increased to 47.5% and 51.6%, respectively, among college students (Wu et al., 2020). Notably, depression and anxiety symptoms commonly co-occur in the same person rather than arising independently (Schlechter et al., 2021). That is, most people diagnosed with a depressive disorder are simultaneously diagnosed with an anxiety-related disorder, which was called "comorbidity" in clinical studies (Meehl, 2001). Individuals who reported both depressive and anxiety disorders showed cognitive decline, more sleep difficulties (Deng et al., 2021), and a higher rate of heart disease (Deschenes et al., 2020), which greatly impacts life quality (Samaranayake et al., 2014). It must be mentioned that the comorbidity of anxiety and depression was as high as 24.5% among college students during the COVID-19 pandemic (Wu et al., 2020), which has to be taken seriously.

The research on the comorbidity of anxiety and depression is opulent in revealing risk factors, symptoms, and effects (Kessler et al., 2015). However, the essential role of sleep disturbance is easily ignored. Sleep disturbance is considered a consequence of mental health problems, and individuals suffering from depression and anxiety usually experience sleep problems, including initial sleep or getting up earlier (American Psychiatry Association, 2013). In contrast, sleep can also contribute to the formation of mental disorders, in that poorer sleep quality is a significant factor in the onset of depression/anxiety symptoms (Adams & Kisler, 2013). However, there is little conclusive evidence about how sleep disturbance, depression, and anxiety are linked together, even though a body of studies has focused on factors that influence anxiety, depression, and sleep problems (Javakhishvili & Widom, 2022; Park et al., 2019; Peretti-Watel et al., 2020). The meta-analytic review of randomized controlled trials confirmed a bidirectional relationship between sleep and psychiatric disorders (i.e., anxiety and depression disorders) (Scott et al., 2017). Nonetheless, few studies have focused on the interrelationships among anxiety, depression, and sleep disturbance.

Recently, researchers proposed a new perspective, the symptom network approach of psychopathology (Borsboom & Cramer, 2013), to better understand the concurrence of depression, anxiety, and sleep disturbance. According to network analysis (Borsboom, 2017), symptoms do not arise from potential causes but rather reinforce (or inhibit) each

other, eventually leading to the establishment of whole mental disorders and influencing daily function (van den Bergh et al., 2021). Previous theoretical studies have shown that identifying bridge symptoms in psychopathology networks can reveal fecund information because it promotes clarifying symptoms that put patients at higher risk of comorbidity (Borsboom & Cramer, 2013). For instance, Wang et al. (2021) applied the symptom network approach and revealed that the most central symptoms were panic (i.e., anxiety) and wakefulness (i.e., sleep) in anxiety, depression disorders, and sleep disturbance, and that those symptoms had the greatest potential to affect an individual's mental state among HIV patients in China. In comparison, no study has explored the interrelationships among anxiety, depression, and sleep disturbance among college students who have experienced lockdown during the current COVID-19 pandemic from the perspective of a symptom network.

In summary, even under nonpandemic circumstances, college students can experience considerable sleep disturbance, anxiety, and depressive symptoms (Beiter et al., 2014; Li et al., 2018). Moreover, the situation only has worsened during the COVID-19 pandemic. Although several studies have reported increased sleep disturbance, anxiety, and depression disorders during the COVID-19 pandemic (Li et al., 2020; Wu et al., 2020), studies on the mechanisms underlying the anxiety and depression disorders associated with sleep disturbance are limited. Therefore, the primary goal of this study was to explore the core and bridge symptoms in the network structure of anxiety, depression, and sleep disturbance among Chinese college students under the lockdown of the pandemic. To do so, we applied a symptom network approach, including the four main statistical steps. First, the extended Bayesian information criterion (EBIC) (Chen & Chen, 2008) and graphical least absolute shrinkage and selection operator (LASSO) network models were used (Epskamp et al., 2018) to establish the depression–anxiety–sleep symptom network structure and seek the strongest edges (i.e., partial correlations). Then, the *expected influence* index was calculated to identify the most central nodes (i.e., core symptoms). Third, the *bridge* function was used to seek the potential target symptoms for intervention. Finally, to ensure that the obtained results are reliable and trustworthy, we ran centrality stability, edge accuracy and bootstrapped difference tests for centrality and edges. Given the sex difference between males and females in anxiety and depression disorders and sleep disturbance (Li et al., 2022; Wu et al., 2020), another goal of the present study was to identify sex differences in the depression–anxiety–sleep symptom network structure.

Methods

Participants

This current large-scale ($N=6710$, male=3074, female=3636; $mean_{age}=19.28$, $SD_{age}=1.99$) study adopted convenience sampling and was conducted at a university in *** from 27 September to 12 October 2021. All participants must have been students under lockdown at that university for at least one month to be eligible.

The questionnaires were posted on Wenjuanxing (<https://www.wjx.cn/>), an online platform. The participants provided their electronic informed consent prior to participation in this study. Given the sensitive nature of some questions, the mental health center where the middle author works provided timely online interventions for subjects who needed professional counseling services. The research was examined and approved by the ethics committee of *** University (Reference number: 202,112,220,084).

Measurements

Generalized anxiety disorder scale (GAD-7)

The GAD-7 is a brief measure of anxiety symptom severity with 7 items (Spitzer et al., 2006). The Chinese version of the GAD-7, which assesses the frequency of the seven anxiety symptoms over the previous two weeks on a scale from 0 (not at all) to 3 (nearly every day), proves to be valid and reliable (Gong et al., 2021). Higher scores indicate more severe anxiety symptoms. The GAD-7 has high internal consistency ($\alpha=0.93$) in the present study.

Patient health questionnaire (PHQ-9)

The PHQ-9 is a questionnaire-based depression scale used to assist primary care practitioners in diagnosing depression and monitoring treatment (Kroenke et al., 2001). Each item of the PHQ-9 scores from 0 (not at all) to 3 (nearly every day), with a summed score ranging from 0 to 27 for the nine items. Higher scores indicate more severe depressive symptoms. The Chinese version of the PHQ-9 has been well validated as an efficient tool for screening depression among the general Chinese population (Ye et al., 2020). The PHQ-9 has high internal consistency ($\alpha=0.90$) in the present study.

Youth SelfRating Insomnia Scale (YSIS-8)

The YSIS-8 is a self-report questionnaire consisting of 8 questions about insomnia symptoms, waking symptoms and daytime consequences within the past month (Buysse et al., 2006). Eight symptoms, including difficulty initiating sleep

(DIS), difficulty maintaining sleep (DMS), early morning awakening (EMA), unrefreshing sleep, poor sleep quality, sleep insufficiency, sleep dissatisfaction, and interference of sleep difficulties with daytime functioning, were developed based on previous studies (American Psychiatry Association, 2013; Liu et al., 2019). Sleep quality ranges from 1 (very good) to 5 (very poor), and sleep satisfaction ranges from 1 (very satisfied) to 5 (very unsatisfactory). The remaining 6 items are rated on a 5-point scale from 1 = never, 2 = rarely (< 1 time/week), 3 = sometimes (1–2 times/week), 4 = often (3–5 times/week), to 5 = almost every day (6–7 times/week). Summing the scores on the 8 items yields a total YSIS-8 score ranging from 8 to 40. A higher total YSIS score indicates greater insomnia severity during the past month. The Chinese version of the YSIS-8 has been well validated as a simple and reliable scale for assessing adolescent insomnia severity (Liu et al., 2019). The YSIS-8 has high internal consistency ($\alpha = 0.92$) in the present study.

Statistical analysis

Network estimation

The present study conducted all analyses using *R* (version 4.1.1) (R Core Team, 2021). Based on previous studies (Mullarkey et al., 2019), we used the function *descrTable* in *R* package *compareGroups* (Subirana et al., 2014) to examine item informativeness (i.e., standard deviation (*SD*) of the item) and the function *goldbricker* in the *R* package *networktools* (version 1.3.0) (Jones et al., 2021) to examine redundancy (i.e., < 25% of significantly different correlations).

Extended Bayesian information criterion (EBIC) (Chen & Chen, 2008) and graphical least absolute shrinkage and selection operator (LASSO) network models were used (Epskamp et al., 2018) to establish the depression–anxiety–sleep symptom network structure. The *R* package *qgraph* (version 1.6.9) (Epskamp et al., 2012) was used to estimate and visualize the network. The principle behind this is that partial correlation analyses after controlling all other variables were computed to build the association of each pairwise continuous variable (i.e., symptom) and form a network analysis (Opsahl et al., 2010). A *node* represents a variable or symptom in the network analysis, and each pairwise association between variables or symptoms was defined as an *edge*. Thicker edges indicate higher correlations. Blue and red edges reveal positive and negative correlations, respectively (Epskamp et al., 2018; Epskamp et al., 2012).

In the field of network analysis, three centrality indices, strength (i.e., the sum of the absolute edge weights connected to a specific node), closeness (i.e., the inverse of

summing all the shortest path lengths from one node to all other nodes), and betweenness (i.e., the importance of a symptom as a “connector” to other symptoms based on how frequently a node lies on all the shortest paths between other nodes), must be computed to explore the importance of individual symptoms within the network (Haslbeck & Waldorp, 2020). Previous research has shown that assessments of closeness and betweenness are unreliable in determining nodes’ importance (Bringmann et al., 2019; Epskamp et al., 2016). Moreover, traditional indices such as strength centrality may not accurately predict node influence on a network containing both positive and negative edges. Robinaugh et al. (2016) demonstrated that expected influence is a more appropriate index in such cases. Hence, expected influence was chosen as the metric in the current study.

Network stability and accuracy

We used the *R* package *boonet* (version 1.4.3) (Opsahl et al., 2010) to assess the robustness of the results and the network’s stability and accuracy. First, nonparametric bootstrapping was used to estimate the accuracy of the edge weights by computing confidence intervals (*CI*s). New datasets based on 95% *CI*s were created by randomly resampling observations in the data. Second, a case-dropping bootstrap procedure was performed to compute a correlation stability coefficient (*CS-C*) to assess network stability. *CS-C* values indicated the maximum proportion of samples that could be removed, while correlations between the original centrality indices (i.e., strength, closeness, betweenness) and centrality indices based on the case-subset network were maintained above 0.7 with a 95% probability. As recommended previously (Epskamp et al., 2018), a *CS-C* should not be lower than 0.25 and is preferably above 0.5. Finally, differences in network properties (i.e., edge weights, node strengths) were evaluated by *bootstrapped difference tests* (Epskamp et al., 2018).

In addition, predictability (i.e., R^2), which reflects how well all its neighboring nodes predict a specific node, was estimated using the *R* package *mgm* (version 1.2–12) (van Borkulo et al., 2022). Furthermore, to explore bridge symptoms in the network that played essential roles in connecting two or more psychiatric disorders (Haslbeck & Waldorp, 2020), the *bridge* function in the *R* package *networktools* (version 1.4.0) was used (Chen & Chen, 2008; Jones et al., 2021). Bridge centrality indices assessed bridge symptoms, including bridge strength, bridge closeness, bridge betweenness, and bridge expected influence (1-step). Following a previous study (Robinaugh et al., 2016), bridge symptoms were selected using the index of bridge expected influence (1-step), including both positive and negative associations.

Table 1 Basic information of scales and descriptive item statistics

Scale	Symptoms	Items	Mean (SD)	Predictability	
PHQ-9	Anhedonia	1. Little interest or pleasure in doing things	1.42 (0.67)	59%	
	Sad mood	2. Feeling down, depressed, or hopeless	1.35 (0.60)	63%	
	Sleep	3. Trouble falling or staying asleep, or sleeping too much	1.32 (0.64)	51%	
	Energy	4. Feeling tired or having little energy	1.43 (0.66)	60%	
	Appetite	5. Poor appetite or overeating	1.34 (0.65)	41%	
	Guilt	6. Feeling bad about yourself or that you are a failure or have let yourself or your family down	1.28 (0.59)	57%	
	Concentration	7. Trouble concentrating on things, such as reading the newspaper or watching television	1.37 (0.68)	47%	
	Motor	8. Moving or speaking so slowly that other people could have noticed? Or the opposite being so fidgety or restless that you have been moving around a lot more than usual	1.18 (0.50)	53%	
	Suicide	9. Thoughts that you would be better off dead, or of hurting yourself	1.09 (0.36)	43%	
	GAD-7	Nervousness	1. Feeling nervous, anxious or on edge	1.32 (0.59)	70%
		Uncontrollable worry	2. Not being able to stop or control worrying	1.26 (0.57)	73%
		Excessive worry	3. Worrying too much about different things	1.33 (0.61)	71%
		Trouble relaxing	4. Trouble relaxing	1.28 (0.57)	69%
		Restlessness	5. Being so restless that it is hard to sit still	1.16 (0.45)	62%
Irritability		6. Becoming easily annoyed or irritability	1.26 (0.55)	58%	
Feeling afraid		7. Feeling afraid as if something awful might happen	1.17 (0.46)	69%	
YSIS-8	PSQ	1. Poor sleep quality	1.67 (0.85)	82%	
	SD	2. Sleep dissatisfaction	1.69 (0.87)	83%	
	DIS	3. Difficulty initiating sleep	1.53 (0.84)	62%	
	DMS	4. Difficulty maintaining sleep	1.36 (0.75)	45%	
	EMA	5. Early morning awakening	1.38 (0.77)	47%	
	SI	6. Sleep insufficiency	1.57 (0.94)	60%	
	US	7. Unrefreshing sleep	1.77 (1.07)	61%	
	DFI	8. Daytime functioning impairment	1.46 (0.83)	61%	

SD, standard deviation; PHQ-9, the Patient Health Questionnaire-9; GAD-7, the Generalized Anxiety Disorder-7 questionnaire; YSIS-8, Youth Self-Rating Insomnia Scale

Comparisons based on sex

Following previous studies (Li et al., 2022; Wu et al., 2020), sex differences in network characteristics were assessed using the Network Comparison Test (NCT) in the *R* package *NetworkComparisonTest* (version 2.2.1) (van Borkulo et al., 2022). This test is employed on subsamples (female vs. male) with 1000 permutations to compare the global network strengths (absolute sum of all edge weights) and network structures (edge weight distributions) between the two networks. Furthermore, the strength of each edge connecting the two networks was determined using Holm–Bonferroni correlations for multiple comparisons.

Results

Descriptive statistics and items check

The means and standard deviations of the PHQ-9, GAD-7, and YSIS-8 items are reported in Table 1. Before performing network analysis, we checked for mean item level, item informativeness (i.e., item standard deviation), and item redundancy. All items were above the informativeness threshold (i.e., ± 2.5 *SD* below the mean level, PHQ-9: $M_{SD} = 0.59 \pm 0.10$; GAD-7: $M_{SD} = 0.54 \pm 0.06$; YSIS-8: $M_{SD} = 0.87 \pm 0.10$), and no item was considered statistically redundant (i.e., > 25%) by using the Fruchterman–Reingold algorithm. Hence, all items were included in the analysis.

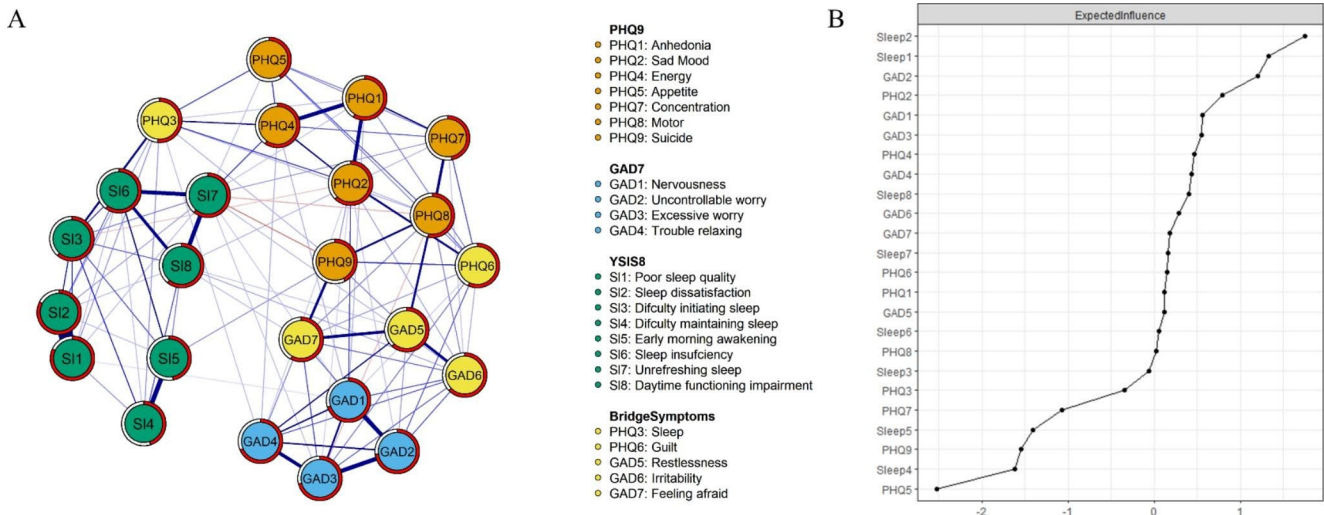


Fig. 1 A, The network structure of anxiety, depressive symptoms, and sleep disturbance among college students during the COVID-19 pandemic. B, Standardized centrality indices (i.e., ExpectedInfluence) of the network structure of anxiety, depressive symptoms, and sleep quality (Z scores)

Network estimation structure and local network properties

The network estimated on the PHQ-9, GAD-7, and YSIS-8 is shown in Fig. 1(Part A) and Fig. S1. Several points are worth mentioning. First, through the weighted adjacency matrix (see Table S1), we found that poor sleep quality (#YSIS-1; i.e., quality of sleep during the past month) with sleep dissatisfaction (#YSIS-2; i.e., satisfaction with sleep during the past month) and DMS (#YSIS-4; i.e., waking up frequently during the night) with EMA (#YSIS-5; i.e., waking up earlier and cannot return to sleep) had the first and second strongest associations. Second, local property analysis showed that symptoms of sleep dissatisfaction (#YSIS-2; i.e., satisfaction with sleep during the past month) were the most central node, followed by poor sleep quality (#YSIS-1; i.e., quality of sleep during the past month) and uncontrollable worry (#GAD-2; i.e., unable to stop or control worry). The symptoms with the lowest centrality included appetite (#PHQ-5; i.e., poor appetite or overeating), DMS (#YSIS-4; i.e., waking up frequently during the night), suicide (#PHQ-9; i.e., thoughts about killing or hurting yourself), EMA (#YSIS-5; i.e., waking up earlier and cannot get back to sleep), and concentration (#PHQ-7; i.e., trouble concentrating).

Bridge symptoms of anxiety, depressive symptoms, and sleep disturbance

The bridge expected influence was estimated in Fig. 1 and S2. The strongest bridge symptoms (Z score above 1) were sleep (#PHQ-3; i.e., trouble falling or staying asleep or sleeping too much), feeling afraid (#GAD-7; i.e., feeling

afraid as if something awful might happen), guilt (#PHQ-6; i.e., feeling bad about yourself or that you are a failure or have let yourself or your family down), restlessness (#GAD-5; i.e., being so restless that it is hard to sit still) and irritability (#GAD-6; i.e., becoming easily annoyed or irritable). The bridge expected influence of these items was significantly correlated with expected influence values ($r_s = 0.88$, $CI [0.74; 0.95]$).

Network stability and accuracy

The predictability index indicated that the neighboring nodes could account for 60% of the variance in each node ($M_R^2 = 0.60 \pm 0.11$), on average. SD (i.e., #YSIS-2, $R^2 = 0.83$), PSQ (i.e., #YSIS-1, $R^2 = 0.82$), uncontrollable worry (i.e., #GAD-2, $R^2 = 0.73$), excessive worry (i.e., #GAD-3, $R^2 = 0.71$), nervousness (i.e., #GAD-1, $R^2 = 0.70$), trouble relaxing (i.e., #GAD-4, $R^2 = 0.70$), feeling afraid (i.e., #GAD-7, $R^2 = 0.69$), sad mood (i.e., #PHQ-2, $R^2 = 0.63$), DIS (i.e., #YSIS-3, $R^2 = 0.62$), restlessness (i.e., #GAD-5, $R^2 = 0.62$), US (i.e., #YSIS-7, $R^2 = 0.61$), DFI (i.e., #YSIS-8, $R^2 = 0.61$), SI (i.e., #YSIS-6, $R^2 = 0.60$) and energy (i.e., #PHQ-4, $R^2 = 0.60$) had the highest predictability indices within the network (Table 1). Although, on average, half of each symptom's variance could potentially be explained by the other nodes, this also implied that the remaining variance was not explained by only considering the interplay among symptoms.

The expected influence and predictability were unrelated to PHQ-9 item variability (PHQ-9: $r_s = 0.17$, $CI [-0.56; 0.75]$ and $r_s = 0.32$, $CI [-0.44; 0.81]$, respectively) and item mean (PHQ-9: $r_s = 0.30$, $CI [-0.46; 0.80]$ and $r_s = 0.46$, $CI [-0.29; 0.86]$, respectively). In contrast, predictability

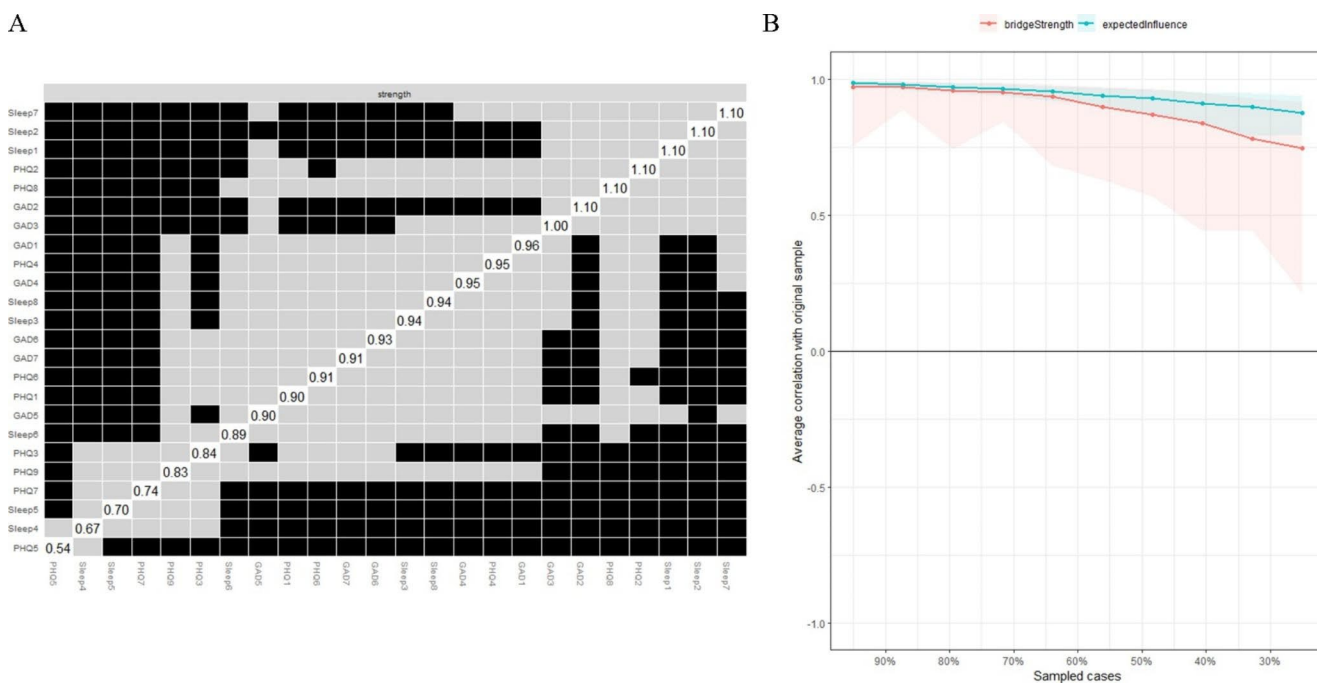


Fig. 2 A, estimation of edge weight difference by bootstrapped difference test. Nonparametric bootstrapped difference test for strength. Grey boxes indicate no significant difference, whereas black boxes indicate a statistically significant difference ($p < .050$). Diagonal values represent the strength score of each node. B, the stability of the network structure by case dropping subset bootstrapping

was positively related to GAD-7 item variability (GAD-7: $r_s = 0.86$, $CI [0.30; 0.96]$) and item mean (GAD-7: $r_s = 0.82$, $CI [0.18; 0.97]$); however, expected influence was unrelated to GAD-7 item variability (GAD-7: $r_s = 0.61$, $CI [-0.26; 0.93]$) and item mean (GAD-7: $r_s = 0.51$, $CI [-0.40; 0.91]$). Expected influence and predictability were positively related to sleep item mean (YSIS-8: $r_s = 0.77$, $CI [0.14; 0.96]$) and $r_s = 0.74$, $CI [0.08; 0.95]$, respectively). The expected influence and predictability were unrelated to the PHQ-9 and were unrelated to the sleep mean item (YSIS-8: $r_s = 0.41$, $CI [-0.42; 0.86]$) and $r_s = 0.3$, $CI [-0.51; 0.83]$, respectively).

The edge weights in the current sample were consistent with the bootstrapped sample, especially the connections with larger weights, indicating that the current network

structure was stable (**Part A of Fig. 2**). The bootstrapped difference tests revealed that a large proportion of the comparisons among edge weights were statistically significant (Supplementary Fig. S3, S4).

Regarding network stability, the case-dropping bootstrap procedure showed that the expected influence (i.e., $CS-C=0.75$) and bridge expected influence (1-step) (i.e., $CS-C=0.28$) values remained stable after dropping different proportions of the sample (**Part B of Fig. 2**).

Sex differences

We tested whether global strength, structure and single edges differed by sex. Overall, the two networks appeared similar (**Fig. S5**). There were significant sex differences in

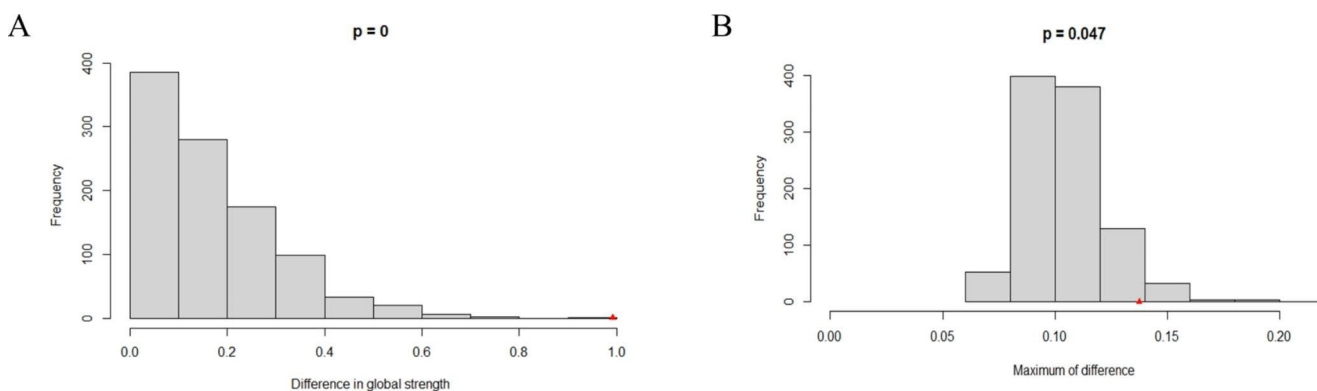


Fig. 3 A, the maximum difference in edge strength. B, the difference in global strength (right panel)

network global strength (females: 11.22 vs. males: 12.21; $S=0.99$, $p=.000$) and the network structure distribution of edge weights ($M=0.14$, $p=.047$) (all $p>.05$ after Holm–Bonferroni correction, **Fig. S6**), as shown in Fig. 3. Specifically, examining each node and the *expected influence* index shows that men’s strength was stronger than women’s strength for #PHQ-7 and #YSIS-7 ($p<.05$).

Finally, we tested whether males and females reported different symptom mean levels statistically. There were 20 of 24 symptoms with statistically significant (all adjusted p values ≤ 0.045) differences (**Table S2**). However, the magnitude of the differences was negligible to small (Cohen’s $d\leq 0.5$). Hence, the level differences of symptoms in females and males should be interpreted with caution.

Discussion

Using network analysis, the present study examined the relationships among sleep disturbance, depression, and anxiety among a large sample of college students during the COVID-19 pandemic. All results showed stability and accuracy, suggesting strong correlations between the internal symptoms of these three mental disorders.

From the node centrality, sleep dissatisfaction (#YSIS-2; i.e., satisfaction with sleep during the past month), poor sleep quality (#YSIS-1; i.e., quality of sleep during the past month), and uncontrollable worry (#GAD-2; i.e., unable to stop or control worry) were the highest strength values (Z score above 1), indicating those in the depression, anxiety, and sleep disturbance network structure, which should be noted. Sleep dissatisfaction refers to both the quality and quantity of sleep that cannot meet one person’s demands, such as adequate and regular sleep duration, a healthy sleep pattern, and high-quality sleep (Varghese et al., 2020). For college students, depression, anxiety, substance abuse, day naps, and rest time are prefiguring sleep dissatisfaction (Wilsmore et al., 2013). During the pandemic quarantine period, college students’ daily lives were replaced with taking online teaching and staying at home. Moreover, without hierarchical supervision from teachers or schools, students can easily become addicted to video games or mobile devices, and without peers’ companionship, college students may rely on substances to evade negative affection (Cuong et al., 2021). Therefore, superficially, the pandemic changed students’ daily lives. Nevertheless, college students’ regular sleep rhythm was devastated by the unrestricted usage of video games, mobile devices, and substances. To combat sleep dissatisfaction, regular physical activity might improve sleep quality (Baron et al., 2022).

In addition to sleep dissatisfaction, poor sleep quality is another conspicuous factor besetting college students. In its

literal meaning, poor sleep quality denotes that one person evaluates his or her sleep quality as poor or bad in the last month, which is positively associated with a higher prevalence of mental disorders and a longer duration of insomnia symptoms (Ohayon et al., 1997). Our view maintains that college students’ daily routine changes disturb their regular sleep patterns, which cannot be recovered or appeased by long sleep or day naps. Currently, the mainstream treatment to improve sleep quality is via mindfulness to release psychological stress (Lau et al., 2018).

In addition to sleep problems, the other factor, uncontrollable worry, is deleterious to college students’ mental health. Uncontrollable worry is being unable to restrain or control worry cognitively (Hallion & Ruscio, 2013), which is also defined as pathological worry (Gorday et al., 2018). Our result is consistent with one previous study showing that alienation from peers is one etiology of uncontrollable worry (Curzik & Salkicevic, 2016). For college students, staying away from peers means alienation from emotional divulgence. Moreover, more fierce competition for jobs or further education and uncertainties followed by pandemics can drag college students into deep emotional turmoil. Unfortunately, college students are tyros in the confrontation of traumatic events, although, without peer companions, a warm and solid filial relationship may mollify worry.

Furthermore, the perspective of bridge expected influence (1-step) measures the symptoms that play a crucial role in coalescing depression, anxiety, and sleep disturbance. Sleep (#PHQ-3; i.e., trouble falling or staying asleep or sleeping too much) and feeling afraid (#GAD-7; i.e., feeling afraid as if something awful might happen) should be mentioned and discussed. The physical reaction to depression is mainly shown as difficulties initiating sleep, maintaining sleep, and fatigue. In a cognitive–emotion–behavior circulation (Weiner, 1980), we conjecture that sleep in the body directly reflects an irregular lifestyle and great pressure. When college students notice physical maladaptation without experience, college students may digress to either retain the same pattern or painstakingly revert to the original track. However, failures in lifestyle change may induce negative affection containing remorse, depression, surliness, or anger (Sarris et al., 2014). Additionally, cognitive bias may elicit college students to have a depressive status in which college students hold the belief that efforts to change are always in vain (Pang & Wu, 2021).

Referring to learned helplessness (Abramson et al. 1989), a person who endures unescapable negative events extensively will give up exerting efforts on the situation. College students are in a key developmental period to start a career, pursue further education, or cultivate a long-term intimate relationship. Nevertheless, in the pandemic, a profound adverse event, the main developmental task must be paused,

and with chronic resurgence, containment measures become a quotidian. Ambitious college students are naturally fearful about future awful events that divest auspiciousness and omens. Furthermore, in terms of cognition–emotion–behavior circulation (Weiner, 1980), accumulated fearfulness manifests in sleep disturbance, depression, and anxiety.

After delineating the importance of symptoms, strong associations between two specific nodes should be mentioned, as strong associations indicate that alleviating either symptom in the association means that two symptoms are improved accordingly, which can shed light on practice. From our findings, poor sleep quality (#YSIS-1; i.e., quality of sleep during the past month) with sleep dissatisfaction (#YSIS-2; i.e., satisfaction with sleep during the past month) and DMS (#YSIS-4; i.e., waking up frequently during the night) with EMA (#YSIS-5; i.e., waking up earlier and cannot get back to sleep) are the two strongest associations, implying that sleep problems should be main targets in treatments to release college students' mental distress. College students must sleep well to deal with daily routine work. In a cognition–emotion–behavior circulation (Weiner, 1980), college students have poor sleep quality behaviorally, including being unable to maintain sleep, sleep deeply or initiate sleep, which may hold antagonist affection toward sleep. Dissatisfaction with sleep, including distress, sadness, and hatred toward sleep, can decay sleep quality (Duran & Erkin, 2021). Hard-to-maintain sleep makes college students mentally excited after extended periods of mobile usage, playing video games, or watching television programs. Thus, excited college students cannot maintain deep sleep naturally, and it is difficult to get up earlier to resume activities (Mei et al., 2022).

Limitations

Based on a large sample plan, this study investigated the network characteristics of mental health symptoms of college students under close management during COVID-19. However, there are still several research limitations that need to be addressed. First, similar to most studies (Van den Bergh et al., 2021; Wang, 2022), this study was cross-sectional, which does not best explain longitudinal causality. Second, the study was conducted at a closed university, and thus, the results may not be generalizable to all groups in the new population.

Conclusions

In summary, network analysis provides new insights into the internal relationships among depression, anxiety, and

sleep disturbance. The results highlight that specific symptoms can function as bridges among anxiety, depression, and sleep complaints, which helps to explain their comorbidity and reciprocal influences. In particular, sleep, guilt, restlessness, irritability, and feeling afraid play unique roles as bridge symptoms. Although the current network does not consider the directionality between symptoms, it still contributes to comprehending college students' depression, anxiety, and sleep disturbance during the closed management of COVID-19. However, the network-comparison test results showed significant differences in global strength and edge weights between males and females in the network structure for depression, anxiety, and sleep disturbance. In future research, expanding the issue of directivity between symptoms is necessary. At the same time, it is also important to investigate the symptom network between closed management and after closed management and provide meaningful suggestions for clinical practices.

Code and Data Availability Analytic code and data for this work are available upon request.

Declarations

Ethical approval The research was examined and approved by the ethics committee of Beijing Normal University (Reference number: 202112220084).

Informed consent Informed consent was obtained from all individual participants included in the study.

Competing Interests The authors have no conflicts of interest regarding this research study.

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