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ORIGINAL RESEARCH

Echoes of Strain: A Two-Year Longitudinal Study on the Impact of China's Zero-COVID Policy on College Students' Insomnia and Depressive Symptoms

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Purpose: In China, stringent and long-lasting infection control measures, which were called "dynamic zero-COVID policy", have significantly affected the mental health of college students, particularly concerning depressive and insomnia symptoms. This study aims to investigate how depressive and insomnia symptoms evolved among Chinese college students throughout the pandemic, including the beginning and end of the dynamic zero-COVID policy period.

Patients and Methods: We conducted a 2-years longitudinal survey involving 1102 college students, collecting data at three key time points. Depressive symptoms were assessed using the Patient Health Questionnaire-9, and insomnia symptoms were measured with the Youth Self-rating Insomnia Scale-8. Three contemporaneous symptom networks and two cross-lagged panel networks were constructed.

Results: In the current sample, the prevalence of clinically significant depressive symptoms was 6.1%, 8.9%, and 7.7% during the first, second, and third waves, respectively. The prevalence of clinically significant insomnia symptoms was 8.1%, 13.0%, and 14.1%. Over time, the severity of depressive and insomnia symptoms and network density increased, persisting at least one year after the pandemic and control measures ended. "Difficulty initiating sleep" bridged the two disorders, while "anhedonia" played a pivotal role in triggering and sustaining other symptoms.

Conclusion: This study underscores the lasting impact of the evolving zero-COVID policy on depressive and insomnia symptoms among college students, elucidating the underlying interaction mechanisms. There is a pressing need for a more comprehensive evaluation of the implementation of restrictive public policies, taking into account their potential long-term consequences.

Keywords: insomnia, depression, dynamic zero-COVID policy, network analysis

Introduction

Since the onset of COVID-19 in December 2019, extensive studies have highlighted significant impacts of the pandemic on the mental well-being of college students, particularly in terms of insomnia symptoms[1] and depressive symptoms.[2] A systematic review encompassing 1,441,828 participants during the pandemic revealed a pooled prevalence of mild depressive symptoms and insomnia symptoms among college students at 34% (95% CI = [30–38%]) and 33% (95% CI = [22–44%]), respectively,[2] markedly higher than in the general population.[3] On May 4, 2023, the World Health Organization declared that COVID-19 no longer qualifies as a "public health emergency of international concern". Nevertheless, some studies have suggested that the pandemic's enduring adverse effects may persist even after the its conclusion.[4,5] Particularly in the context of China, scholars argue that the stringent and protracted public health measures enforced by the Chinese government to combat COVID-19 necessitate consideration of their long-term impact on mental

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health.[6,7] Consequently, in this study, we conducted a two-year longitudinal survey of a cohort of college students to examine changes in their depressive and insomnia symptom patterns in relation to the trajectory of the pandemic.

Insomnia in the Younger Demographic

Insomnia within the younger demographic is primarily characterized by sleep deprivation, difficulty initiating sleep, and difficulty maintaining sleep.[8] Adolescents and young adults, especially during their college years, are particularly susceptible to experiencing the initial onset or worsening of insomnia symptoms.[9] A nationwide survey conducted in Norway revealed that 30.5% college students reported sleep difficulties meeting the criteria for insomnia as outlined in the DSM-5. Furthermore, this prevalence has shown an upward trend over the past eight years.[10] Chronic sleep deprivation or a lack of opportunities for sleep can have adverse effects on cognitive functions, including impaired concentration, compromised memory, and heightened irritability.[11,12] Consequently, insomnia is often associated with daytime fatigue, diminished academic performance, and reduced overall quality of life.[13]

Depression and Its Association with Insomnia

Depression, as another psychiatric issue significantly affecting the mental well-being of college students, has been shown to be closely associated with insomnia. Numerous studies have illuminated the bidirectional relationship between insomnia symptoms and the risk of depression.[14] Specifically, in most cases, depression co-occurs with various sleep disturbance symptoms, and sleep-related items constitute essential criteria in diagnosing major depression according to most depression rating scales.[15] On the other hand, insomnia can also be the risk and maintaining factor for depression. Williams et al[16] argued that the impairment of interpersonal relationships and academic performance resulting from insomnia could contribute to the initiation and perpetuation of depression among college students. Additionally, the feelings of hopelessness and helplessness experienced by insomniac students during sleepless nights may further exacerbate their depressive symptoms.[17] Benca and Peterson further found that individuals with insomnia symptoms are up to 10 times more likely to experience depression compared to those without such symptoms.[18] However, the underlying mechanisms linking these two mental health challenges in college students remain unclear, and given the impact of the pandemic on the mental well-being of college students, this relationship might become even more intricate.

Pandemic and "Dynamic Zero-COVID Policy" in China

In late December 2019, a series of cases of the "2019 novel coronavirus" emerged in China, eventually escalating into a global public health emergency. To combat the virus's spread, the Chinese government implemented a comprehensive infection control strategy known as the "dynamic zero-COVID policy". Given that schools presented high-risk environments for infection, college students faced stringent control measures, including campus closures, disruptions to classroom instruction, and restrictions on social activities.[19] Such strict measures had a particularly adverse effect on adolescents and young adults' mental health.[7] Zhou et al reported that, during the pandemic, the prevalence of insomnia symptoms among Chinese adolescents and young adults surpassed that in the United States and also exceeded that in the general Chinese population.[20] They further found that insomnia symptoms in Chinese adolescents and young adults may be caused by their depressive symptoms. Deng et al noted that the prevalence of depressive and insomnia symptoms in higher education students had risen compared to pre-pandemic levels in similar populations.[2]

In December 2022, as China emerged from the peak of the pandemic, the government relaxed infection control measures, and officially concluded the "dynamic zero-COVID policy" on January 8, 2023.[21] However, the end of the pandemic does not equate to the cessation of its impact on individuals' mental health. While some studies in Western countries, such as the UK, the US, and Brazil, have shown that short-term home quarantine does not have long-term effects on individuals' mental health, some students even reported improvements in sleep quality due to school suspensions.[22–24] These studies, however, have been shaped by experiences with time-limited natural disasters and have not fully accounted for the long-term effects of China's enduring and stringent control strategy.[6] Liu et al found that, in China, during the prolonged COVID-19 lockdowns, depressive symptoms were mediated by anxiety levels and varied depending on individuals' emotional adaptation capacities.[25] They further demonstrated that depressive symptoms and academic motivation followed distinct trajectories over time, influenced by personal achievement goals, individual

factors, and their interaction with academic performance.[26] These findings highlight the evolving nature of depressive symptoms among college student in China. A survey of Chinese students indicated that their interest in real-world events, social skills, and their sense of the value of life had declined over time during the implementation of the dynamic zero-COVID policy.[27] Some scholars even predicted that the negative impact of the COVID-19 on mental health could persist for more than 20 years.[6] Nevertheless, few studies have explored how individuals' mental status has evolved in the post-pandemic era. Hence, in the present study, we aim to investigate changes in depression and insomnia symptoms among Chinese college students as the pandemic trajectory unfolds. Additionally, we seek to elucidate the temporal interrelationships between these two symptom communities within the context of the post-pandemic era.

Current Study and Relevant Research

Given the unprecedented nature of the two-year strict containment measures adopted by the Chinese government in modern public health policy, previous studies offer limited information. Developing a well-structured model may lack sufficient theoretical support. Therefore, we employed a data-driven method, the network analysis approach, to explore notable findings.

The network analysis approach is a novel method that conceptualizes mental health problems as a system in which symptoms reinforce or inhibit each other. This method provides two crucial pieces of information for clinical practice: bridge symptoms and central symptoms.[28] In network theory, a bridge symptom act as a mediator, serving as a channel between two disorders. This means that the triggering of any single symptom belonging to one disorder can activate symptoms belonging to another disorder by activating the bridge symptom, thus maintaining the comorbidity of different disorders. Targeted interventions on bridge symptoms may effectively alleviate the comorbidity of two disorders. Moreover, a central symptom is one that can most effectively activate surrounding symptoms. Changing a central symptom can lead to the greatest change in other symptoms. Prioritizing the central symptom in psychotherapy may alleviate a patient's overall disorder to the greatest extent possible.[29–31] Sometimes, the central symptom and the bridge symptom may be the same one.

Several studies have employed network analysis method to investigate the characteristics of depression and insomnia symptoms during the COVID-19 pandemic. Bai et al identified "sleep maintenance problems" as the core symptom in the depression-anxiety-insomnia symptom network, significantly associated with the quality of life among residents of Macau.[32] Similarly, Cha et al argued that "difficulty staying asleep" may act as a trigger for other depressive symptoms.[33] Among patients diagnosed with major depressive disorder, "worrying about sleep" emerged as the bridge connecting insomnia, depressive symptoms, and other psychosocial factors.[34] A study focusing on clinicians discovered that "interference with daytime functioning", "sleep dissatisfaction", and "noticeability of sleep problems by others" held significant influence in the insomnia-anxiety-depression network model.[35] Collectively, these investigations substantiate the exacerbation of depression and sleep-related issues during the COVID-19 pandemic, highlighting a reciprocal association between the two. Furthermore, a common thread across these studies underscores the dominance of insomnia symptoms, with these being core symptoms in each case.

Nevertheless, to our knowledge, no longitudinal network-based studies have delved into whether this insomnia-dominated vicious cycle persists over time. Additionally, it remains unclear whether individuals' deteriorated mental states due to COVID-19 experience relief one year after the epidemic has abated. This study aims to address these gaps through a comprehensive two-year follow-up analysis.

For the purpose of our study, we conducted a two-year follow-up survey involving a cohort of Chinese college students. We gathered data from three distinct time points with one year between each data collection: October 2021, November 2022, and November 2023. The first data collection occurred as students returned to school, experiencing the initial impact of the dynamic zero-COVID policy. The second time point represents the final month of China's pandemic control policy, while the third time point reflects the situation one year after the policy's end. To characterize the various stages of the pandemic's progression, we will refer to the period from the first to the second time points as the "outbreak period" and the period from the second to the third time points as the "receding period" in our subsequent analyses. A portion of the data from the first time point has already been published in a study that examined emotional problems among adolescents of different ages at the onset of the outbreak.[36] In the current study, our objective was to elucidate the

network structures of depression and insomnia during these three distinct stages of the pandemic and investigate how various depression and insomnia symptoms mutually influenced one another throughout this process.

Materials and Methods

Participants and Procedure

The data for this study were obtained at three time points from Northeast Agricultural University in Heilongjiang province, China. We performed the power analysis based on the recommendations of Constantin et al.[37] According to a previous study that included only symptoms of depression and insomnia,[38] the mean network edge weight (ie, the effect size) was set at 0.04 and the symptom number was set at 15 (9 depression symptoms and 6 insomnia symptoms). The sensitivity (the proportion of edges in the true network structure that was correctly estimated to be nonzero) was set at 0.6 and the desired power value was set at 0.8. The recommended minimum sample size was calculated to be 873. The number of students included in each data collection was 6709, 3343, and 1907, respectively. After merging the three datasets based on student identification numbers, we finally included the data of 1102 participants (53.4% females, M_{age} = 18.16, SD_{age} = 0.81) for the follow-up analysis. The actual sample size met the requirement obtained from the power analysis. Data collection utilized the Wenjuanxing online questionnaire platform (https://www.wjx.cn). Questionnaire links were randomly distributed to students at school. Thus, all participants in the outbreak period were quarantined in college dormitories with their roommates. Since the university established provisional committees to handle infection-related issues, any case of infection or any physical discomfort experienced by a student would be reported. None of the participants in this study exhibited any observable physical discomfort. Therefore, the current sample can be considered generally physically healthy. Prior to assessment, participants provided electronic signed informed consent. Ethical approval was obtained from the ethical committee of Beijing Normal University (Reference number: 202112220084).

Measures

Patient Health Questionnaire-9 (PHQ-9)

The Patient Health Questionnaire-9 (PHQ-9), initially developed by Kroenke et al, is a validated instrument used to assess depressive symptoms experienced within the past two weeks.[39] The Chinese version, revised by Chen et al, demonstrated good psychometric properties.[40] The study conducted by Wei et al further indicated that the Chinese version of the PHQ-9 exhibits good measurement invariance across gender and age groups.[41] In the current study, the PHQ-9 exhibited good internal consistency, with a mean Cronbach's α value of 0.88.

Youth Self-Rating Insomnia Scale (YSIS-8)

The Youth Self-rating Insomnia Scale (YSIS-8), developed by Buysse et al, is a 5-point Likert questionnaire designed to assess sleep disturbance experienced within the past month, with higher scores indicating poorer sleep quality.[42] Previous research has demonstrated the validity and reliability of the Chinese version of the YSIS-8.[43] In the current study, the YSIS-8 exhibited high internal consistency, as evidenced by a Cronbach's α value of 0.86.

Statistical Analysis

Descriptive Statistics and t-Test

Descriptive statistical analyses and network analyses were performed using R version 4.2.2.[44] Descriptive statistics and paired-sample *t*-tests were performed on the three waves to identify changes in depression and insomnia symptoms during the outbreak and the receding period one year after the epidemic.

Network Analysis

Prior to conducting network analysis, all items were evaluated for informativeness and redundancy following the recommendations of Marchetti[45] and Mullarkey.[46] The item check was conducted using the R package networktools 1.5.0.[47]

To establish three contemporaneous network structures, we employed the extended Bayesian Information Criterion (EBIC) and graphical least absolute shrinkage and selection operator (LASSO) network model proposed by Epskamp and

Fried.[48] The network estimation and visualization were conducted using the R packages bootnet 1.4.3[49] and qgraph 1.6.9,[50] respectively.

Node centrality, as represented by expected influence (EI), was calculated by summing the weights of all edges connected to a specific symptom across the entire network. This value reflects the symptom's overall influence within the network; for instance, the node centrality of "anhedonia" is determined by summing the coefficients of all edges linking it to other symptoms, indicating its general centrality and influence within the symptom structure. Bridge centrality, on the other hand, was assessed by calculating bridge expected influence (bridge EI), which measures a symptom's role in connecting distinct symptom clusters (eg, depression and anxiety). Specifically, for a symptom such as "anhedonia"—a depression symptom—bridge centrality was determined by summing the edge weights connecting "anhedonia" to anxiety symptoms, reflecting its importance in linking depressive and anxiety symptoms. As per Sánchez Hernández et al's criterion, symptoms with standardized bridge centrality values greater than 1 were identified as bridge symptoms.[51] The R package NetworkComparisonTest 2.2.1[52] was utilized to assess changes in network structure over the course of the pandemic.

Furthermore, to examine the relationships between specific symptoms over time, we conducted two cross-lagged panel networks (CLPN) using the glmnet package.[53] For directed CLPNs, there are two centrality indices: in expected influence (IEI) and out expected influence (OEI). OEI is calculated by summing up all values of outgoing edges connected to the symptom, which signifies the extent to which one symptom predicts the others. IEI is calculated by summing up all values of incoming edges connected to the symptom, representing the extent to which the others predict one symptom. Given the availability and effectiveness of clinical interventions, priority should be paid to focusing on the symptoms with high OEI that activate other subsequent symptoms.

A more detailed description of the statistical procedures can be found in the Supplementary Material 1.

Sensitivity Analysis

During the two-year follow-up, some participants dropped out of the study prematurely. To assess the impact of this data loss on our primary findings, we conducted a systematic analysis of missing values, following the guidelines of Hair et al[54] and a similar approach to a previous study.[55]

First, we applied Little's Missing Completely at Random (MCAR) test to determine if the missing data were completely random. Second, we compared all items included in the formal analysis between participants who dropped out and those who remained, to identify any significant differences in key variables. Third, we selected an appropriate interpolation method based on the missing pattern and estimated three new networks at different time points using the interpolated datasets (comprising 7564 data points). We then calculated the similarity between the interpolated networks and the original networks. If no significant differences were found, we inferred that the use of interpolation or listwise deletion had no significant effect on the main findings of the current study.

Finally, we constructed three depression-insomnia networks using three distinct datasets. These datasets were composed of data from three surveys, which included 5607, 2241, and 805 data points from participants who dropped out. We then compared these results with the analysis of the subset of matched data points, which consisted of 1102 observations. To do this, we generated weighted connected edge coefficient matrices for each network and examined their correlations. Drawing from previous research,[45,56] we concluded that if the symptom network structure of the matched data was highly correlated with the symptom network structure of the respective wave of unused data, we could assert the robustness of our primary findings. SPSS 22 was used to conduct the MCAR test and interpolate missing data. All other analyses were performed in R version 4.2.2.

Results

Descriptive Information

Previous research has established diagnostic thresholds for the PHQ-9 and YSIS-8 at 10 and 22, respectively.[39,43] According to these criteria, the prevalence of clinically significant depressive symptoms among college students in this study was 6.1%, 8.9%, and 7.7% in the first, second, and third waves. Whilst the prevalence of clinically significant insomnia symptoms was 8.1%, 13.0%, and 14.1%. The *t*-test results revealed that the mean score of PHQ-9 increased

Figure 1 (**A**). The distributions of depression scores across three time points. The dashed line, marked at 10, represents the diagnostic threshold of the PHQ-9. (**B**). The distributions of insomnia scores across three time points. The dashed line, marked at 22, signifies the diagnostic threshold of the YSIS-8. Each data point represents a student's score. Prevalence rates for depression/insomnia, along with the total number of participants in each wave, are denoted above the plot. The legend presents color codes denoting various severity levels of depression/insomnia, accompanied by the respective proportions of each severity category in Wave 1, Wave 2, and Wave 3.

significantly from the first wave ($M = 11.76$) to the second wave ($M = 12.14$) ($t = 4.02$, $p < 0.001$). The PHQ-9 score did not change significantly from the second wave ($M = 12.14$) to the third wave ($M = 11.91$) ($t = 1.73$, $p = 0.08$). The mean score of YSIS-8 increased significantly from the first wave ($M = 12.43$) to the second wave ($M = 13.37$) ($t = 7.21$, $p < 0.001$). The YSIS-8 score did not change significantly from the second wave ($M = 13.37$) to the third wave ($M = 13.54$) ($t = 0.93$, $p = 0.35$). The distributions of PHQ-9 and YSIS-8 scores for all participants at three time points are shown in Figure 1.

In accordance with the requirement for item heterogeneity in the network approach,[46,47] YSIS1 and YSIS2, which assessed overall sleep quality rather than specific symptoms, were excluded from further analyses. The remaining items fulfilled the requirements for informativeness and redundancy. Table 1 presents the means, standard deviations, skewness, kurtosis, and predictabilities (R^2) of all symptoms.

Contemporaneous Network Structures

Figure 2A–C, depicts the depression-insomnia symptom networks at three different time points. The weighted adjacency matrices containing all edge weights can be found in Tables S1–S3 in the supplementary materials. The expected influence (EI) and bridge EI values for each node are presented in Figure 2D and E.

Table 1 Descriptive Information

Time	Item	M	SD	Skewness	Kurtosis	Predictability (R^2)
Wave 1	PHQ1	0.45	0.68	1.50	2.00	0.51
	PHQ2	0.38	0.61	1.66	2.91	0.55
	PHQ3	0.32	0.65	2.14	4.19	0.46
	PHQ4	0.45	0.63	1.40	2.24	0.50
	PHQ5	0.36	0.64	1.94	3.98	0.36
	PHQ6	0.27	0.57	2.28	5.17	0.53
	PHQ7	0.42	0.70	1.73	2.75	0.40
	PHQ8	0.19	0.49	3.02	10.03	0.44
	PHQ9	0.08	0.34	5.04	29.06	0.33
	YSIS3	1.52	0.82	1.55	1.81	0.51
	YSIS4	1.34	0.71	2.40	6.01	0.35
	YSIS5	1.35	0.73	2.32	5.42	0.34
	YSIS6	1.60	0.97	1.61	1.86	0.56
	YSIS7	1.79	1.07	1.23	0.63	0.57
	YSIS8	1.46	0.83	1.93	3.41	0.53
Wave 2	PHQ1	0.49	0.74	1.58	2.17	0.59
	PHQ2	0.35	0.61	1.83	3.54	0.62
	PHQ3	0.47	0.77	1.75	2.55	0.58
	PHQ4	0.50	0.75	1.55	2.01	0.67
	PHQ5	0.35	0.66	2.05	4.07	0.48
	PHQ6	0.29	0.61	2.40	6.13	0.57
	PHQ7	0.37	0.68	2.01	3.80	0.50
	PHQ8	0.21	0.53	2.97	9.48	0.52
	PHQ9	0.10	0.37	4.61	24.81	0.32
	YSIS3	1.74	0.99	1.24	0.79	0.61
	YSIS4	1.45	0.79	1.89	3.34	0.44
	YSIS5	1.41	0.78	2.08	4.32	0.47
	YSIS6	1.68	1.01	1.44	1.28	0.59
	YSIS7	1.89	1.14	1.10	0.19	0.64
	YSIS8	1.56	0.91	1.65	2.09	0.60
Wave 3	PHQ1	0.35	0.63	1.83	3.13	0.69
	PHQ2	0.31	0.58	2.01	4.29	0.68
	PHQ3	0.33	0.65	2.22	5.00	0.58
	PHQ4	0.43	0.69	1.73	2.90	0.68
	PHQ5	0.34	0.66	2.10	4.17	0.51
	PHQ6	0.25	0.56	2.55	6.85	0.62
	PHQ7	0.29	0.60	2.25	5.10	0.60
	PHQ8	0.19	0.51	3.01	9.70	0.53
	PHQ9	0.14	0.45	3.67	14.86	0.50
	YSIS3	1.63	0.87	1.29	1.09	0.61
	YSIS4	1.50	0.81	1.63	2.31	0.54
	YSIS5	1.46	0.81	1.93	3.68	0.53
	YSIS6	1.73	1.01	1.30	0.93	0.71
	YSIS7	1.84	1.10	1.15	0.43	0.70
	YSIS8	1.61	0.92	1.51	1.73	0.75

Based on the criterion of EI > 1, the most central symptoms in the depression-insomnia network during the first wave were YSIS3 ("Difficulty initiating sleep"), PHQ1 ("Anhedonia"), and YSIS7 ("Unrefreshing sleep"). In the second wave, the most central symptoms were PHQ4 ("Energy"), YSIS7 ("Unrefreshing sleep"), and YSIS3 ("Difficulty initiating sleep"). Finally, in the third wave, YSIS8 ("Daytime functioning impairment") emerged as the most central symptom (see Figure 2D).

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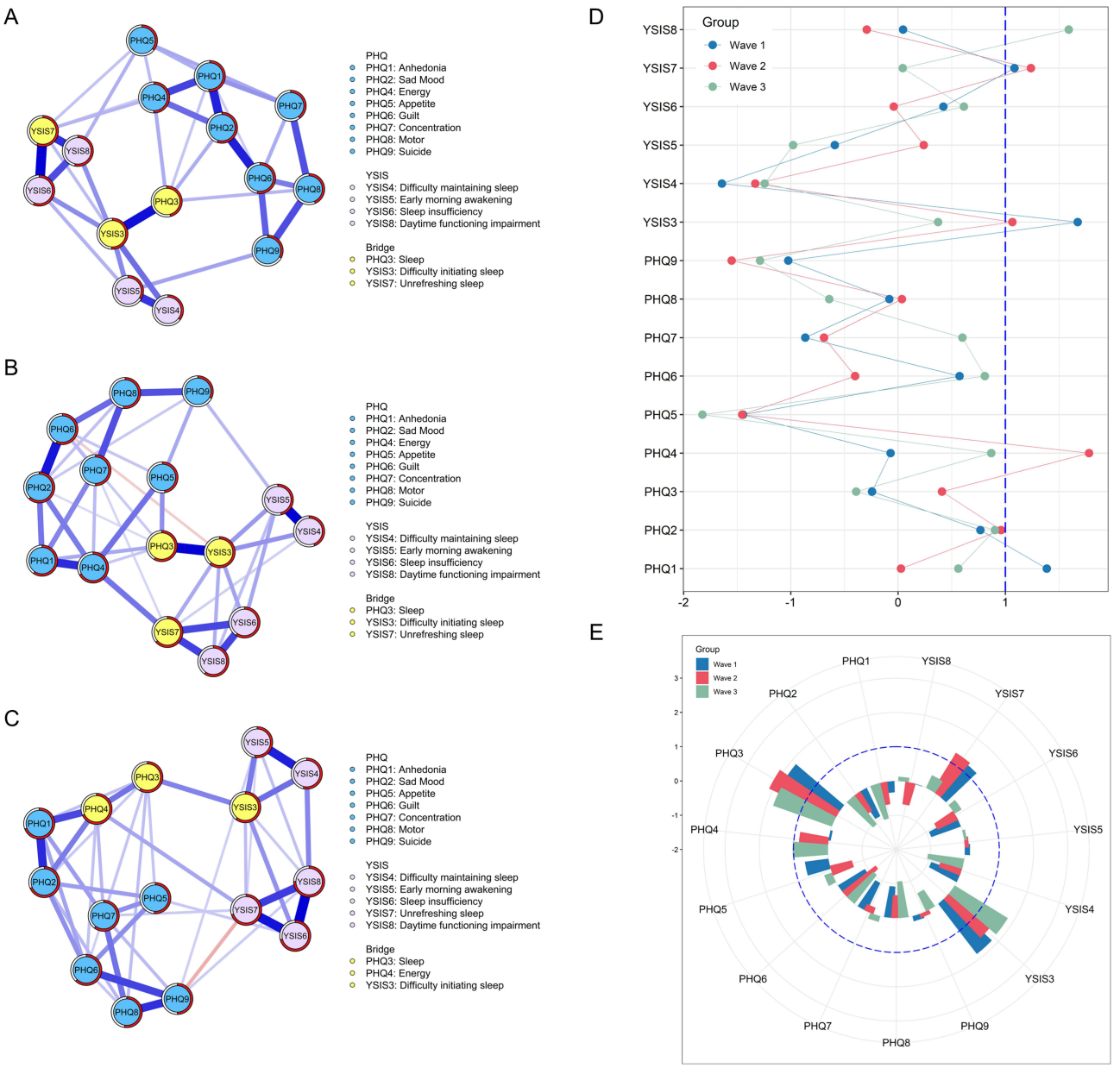

Figure 2 Network structures are presented in parts (**A**–**C**). Positive associations between symptoms are represented by blue lines, while negative associations are indicated by red lines. The thickness of an edge corresponds to the strength of the association, and the size of the red ring indicates the predictability. (**A**), network structure in the first wave. (**B**), network structure in the second wave. (**C**), network structure in the third wave. EI values are shown in part (**D**). The x-axis represents the normalized EI values, with symptoms having an EI value greater than 1 considered key central symptoms. The blue dashed line marks an EI value of 1. Bridge EI values are presented in part (**E**). The y-axis represents the normalized bridge EI values, with symptoms exhibiting a bridge EI value greater than 1 considered key channel symptoms. The blue dashed line marks a bridge EI value of 1.

Regarding the bridge EI values (see Figure 2E), in the first and second waves, PHQ3 ("Sleep (Trouble falling or staying asleep, or sleeping too much)"), YSIS3 ("Difficulty initiating sleep"), and YSIS7 ("Unrefreshing sleep") were identified as bridge symptoms. In the third wave, the bridge symptoms were PHQ3 ("Sleep"), PHQ4 ("Energy"), and YSIS3 ("Difficulty initiating sleep").

Network Comparison

The results of the network comparison test are presented in Table 2 and Figure S1.

Table 2 Network Comparison Results (1000 Permutations)

	Edge Invariance	Global Invariance
Wave 1 - Wave 2	M = 0.141	S = 0.160
	p = 0.453	p = 0.055
Wave 2 - Wave 3	M = 0.215	S = 0.133
	p = 0.019	p = 0.029

Notes: M: The value of the maximum difference in edge weights. S: The value of difference in sum of all edge weights.

Network density showed an increasing trend from the first to the second wave, but this trend was not significant (S = 0.160, p = 0.055). A significant increase in the network global strength was observed from the second wave to the third wave (S = 0.133, p = 0.029). The edge invariance test between the second wave and the third wave was significant (M = 0.215, p = 0.019). Specifically, the association between PHQ3 ("Sleep") and YSIS3 ("Difficulty initiating sleep") in the second wave was significantly higher than in the third wave ($Weight_{wave2}$ = 0.382, $Weight_{wave3}$ = 0.186, $p < 0.01$).

The NCT also revealed that the EI value of PHQ4 ("Energy") increased significantly (p = 0.015) from the first wave to the second wave, and the EI value of YSIS8 ("Daytime functioning impairment") decreased significantly (p = 0.015) from the second wave to the third wave.

Temporal Network Structures

The CLPN structures are visualized in Figure 3. All edge weights are shown in LASSO cross-lagged regression matrixes in Table S4 and S5. The autoregression coefficient figure is presented in Figure S2. The strongest cross-lagged edge in the outbreak period was between PHQ1 ("Anhedonia") and PHQ3 ("Sleep"). In the receding period, the strongest edge was PHQ1-YSIS8 ("Anhedonia" - "Daytime functioning impairment").

As shown in Figure 4, centrality estimates indicated that PHQ3 ("Sleep") had the highest IEI in the outbreak period, and YSIS8 ("Daytime functioning impairment") had the highest IEI in the receding period. The symptom with the highest OEI was PHQ1 ("Anhedonia") in both outbreak and receding periods.

Network Accuracy and Stability

The results of case-dropping analysis are presented in Figure S3. The correlation stability coefficients (CS-Cs) of EI in three contemporaneous networks were 0.36, 0.36, and 0.44, respectively. The CS-Cs of IEI and OEI were as follows: outbreak period: $CS\text{-}C_{IEI}$ = 0.49, $CS\text{-}C_{OEI}$ = 0.28; receding period: $CS\text{-}C_{IEI}$ = 0.49, $CS\text{-}C_{OEI}$ = 0.31. These results indicated that the centrality indices in the current study showed moderate to strong stability. The edge confidence interval

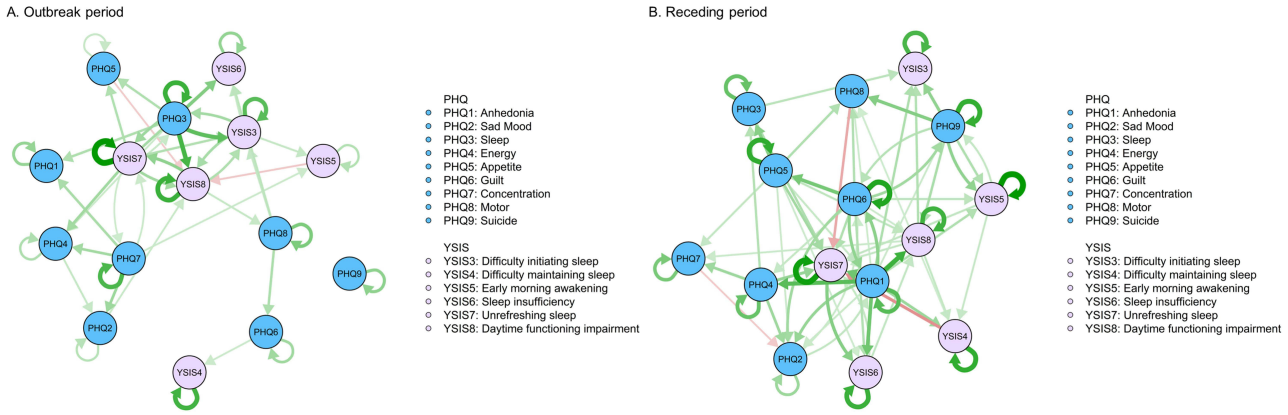

Figure 3 Cross-lagged panel network structures. Each curved arrow "loop" reflects an autoregressive association. Green lines indicate positive relations, whereas Orange lines signal negative relations, and line thickness and boldness reflect the strength of associations. (**A**), CLPN in the outbreak period. (**B**), CLPN in the receding period.

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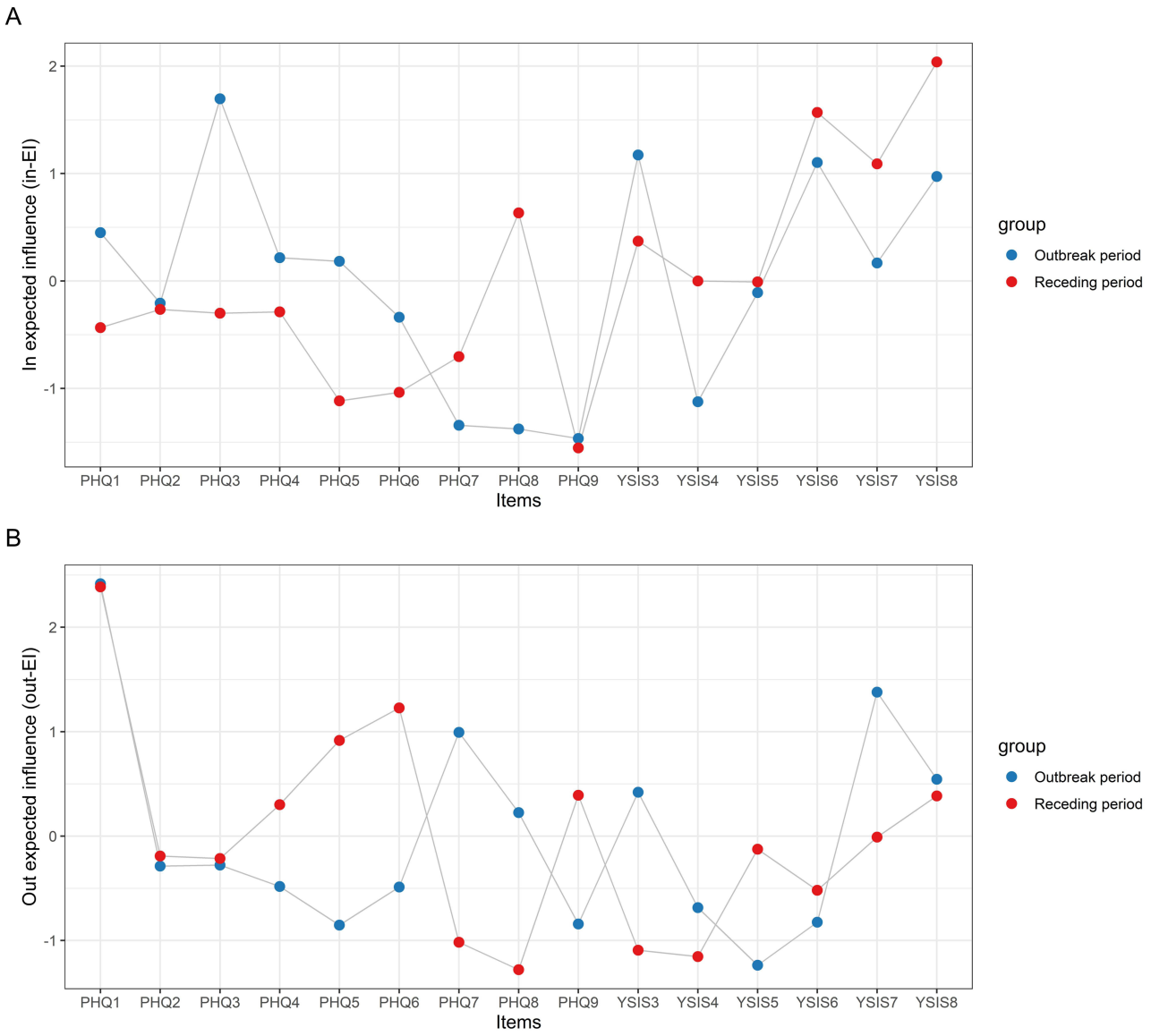

Figure 4 Centrality estimates of in-EI (**A**) and out-EI (**B**) using z values. Out-EI is calculated by summing up all values of outgoing edges connected to the symptom, which signifies the extent to which one symptom predicts the others. In-EI is calculated by summing up all values of incoming edges connected to the symptom, representing the extent to which the others predict one symptom.

plots displayed small to moderate confidence intervals around the edge weights, suggesting good accuracy for networks (see Figure S4). Furthermore, the edge weight difference tests revealed that strong edges were significantly thicker than most other edges (see Figure S5-S6), and the centrality difference tests indicated that the key symptoms exhibited significantly higher influence compared to other symptoms (see Figure S7-S8).

Sensitivity Analysis

The Little's MCAR test result was not significant ($\chi^2 = 162.83$, df = 153, $p = 0.28$), indicating that we cannot reject the null hypothesis that the data are missing completely at random. Second, we divided the sample into two groups based on whether data were missing in the second wave and performed *t*-tests on the levels of all items in the first wave between these two groups. Results showed no significant differences in most items in the first wave (t ranging from 0.15 to 1.64, p ranging from 0.10 to 0.88), except for item YSIS3 ("Difficulty initiating sleep", Mean $_{retention} = 1.48$, Mean $_{missing} = 1.55$, $t = 3.30$, $p < 0.01$, Cohen's $d = 0.08$) and YSIS4 ("Difficulty maintaining sleep", Mean $_{retention} = 1.32$, Mean $_{missing} = 1.39$, $t = 3.46$, $p < 0.01$,

Cohen's $d = 0.09$). Similarly, for participants with missing data at the third time point, there was no significant difference in any item score between the retention group and the missing group in wave 1 (t ranging from 0.21 to 1.65, p ranging from 0.10 to 0.83) or wave 2 (t ranging from 0.06 to 1.90, p ranging from 0.06 to 0.95). In summary, there were no significant differences in most item scores between the retention and missing groups. For the two significant comparisons, the effect sizes were small, lower than the "small effect" criterion of 0.2.[57] Therefore, we believe that the sample loss would not significantly affect the data distribution, and listwise deletions would not introduce a systematic bias sufficient to affect the main conclusions.

To further validate our inferences, we estimated new networks using interpolated datasets. Considering the data distribution pattern and MCAR test results, we chose the expectation-maximization (EM) method to interpolate missing data. The correlation analysis results indicated that the interpolated network in the first wave was highly correlated with the original network ($r = 0.91$, $p < 0.001$), as was the second network ($r = 0.92$, $p < 0.001$) and the third network ($r = 0.91$, $p < 0.001$). We then conducted network comparison tests between the three original networks and the three interpolated networks, showing no significant difference in network density ($S_{wave1} = 0.13$, $p_{wave1} = 0.11$; $S_{wave2} = 0.57$, $p_{wave2} = 0.11$; $S_{wave3} = 0.88$, $p_{wave1} = 0.23$) or network structure ($M_{wave1} = 0.09$, $p_{wave1} = 0.92$; $M_{wave2} = 0.11$, $p_{wave2} = 0.95$; $M_{wave3} = 0.12$, $p_{wave3} = 0.99$) in all three waves.

Finally, we compared the network structure obtained from the missing data with the original network. Upon examining the data lost in the first wave, this study found that the network structure matrix obtained from the lost data closely resembled the network structure matrix of the matched data in the first wave ($r = 0.76$, $p < 0.001$). Similarly, highly similar network structure matrices were also observed for the lost data in the second wave ($r = 0.74$, $p < 0.001$) and the third wave ($r = 0.71$, $p < 0.001$). These results suggest that missing data had no significant impact on the key findings of the present study.

Discussion

Utilizing symptom network analysis and cross-lagged network analysis, this study aimed to illuminate the dynamics of changes in insomnia and depressive symptoms among college students following the conclusion of the pandemic. Several noteworthy results warrant discussion.

During the outbreak period, there was a significant increase in both depressive and insomnia symptom scores. This finding aligns with prior studies conducted in the context of the COVID-19 pandemic.[19] The enforced campus or dormitory confinement and the shift to online courses during the quarantine resulted in decreased physical activity levels and potential disruptions to college students' regular sleep routines due to unrestricted electronic device usage.[58] Previous research has suggested that insufficient physical activity worsens both depression and sleep quality,[59] while disrupted sleep routines contribute to increased sleep problems.[60] Additionally, a cross-lagged study indicated an increase in depression and sleep disturbances among college students during the quarantine,[61] further supporting the notion that quarantine measures may exacerbate depressive and insomnia symptoms. However, some studies have identified different phenomena. A survey in the UK found that residents' depression and anxiety peaked at the beginning of quarantine, declined gradually over the subsequent period, and stabilized after 16 weeks.[23] A study in Brazil reported that students who were home-quarantined during the outbreak went to sleep later but also woke up later, leading to an increase in overall sleep time. Some students who were sleep-deprived before quarantine experienced improved sleep quality as their sleep schedule became more flexible.[24] A study in the US found that while depression levels in college athletes increased with rising COVID-19 exposure levels, the cross-lagged relationship between insomnia and depressive symptoms was not affected by COVID exposure levels.[22] This difference may be attributable to varying quarantine conditions. China's dynamic zero-COVID policy implemented a "local quarantine" strategy for university students, where all were quarantined in school dormitories and required to follow a school schedule of online learning and mandatory physical health checks. In contrast, subjects in the UK and Brazil were home quarantined; they lived in relatively comfortable, familiar environments with their families. Fancourt et al suggested that individuals might have gradually adapted to the quarantine environment under such favorable living conditions, and emotional problems resolved as a result.[23] Niu et al also demonstrated that developing adaptive emotion regulation strategies is key to alleviating depressed mood during COVID-19.[62] Under the dynamic zero-COVID policy, Chinese students' poorer living conditions and stringent schedules may explain why their depression and sleep problems have become more severe.

Significantly, this study discovered that depressive and insomnia symptoms did not diminish one year after the conclusion of the dynamic zero-COVID policy. Instead, there was a notable increase in network density during this

receding period, suggesting that the control measures and the pandemic may have prolonged effects on college students' mental health. Post the removal of dynamic zero-COVID policies, college students may face increased vulnerability, potentially diminishing their perceived sense of security. Simultaneously, after two years of the pandemic, the academic and economic statuses of some college students were significantly impacted, heightening the difficulty of securing satisfactory employment.[63] Consequently, college students may perceive heightened stress levels during this period. Chronic stress has been linked to significant disruptions in sleep homeostasis[64] and induced sleep disturbances.[65] Moreover, heightened pressure and insecurity can exacerbate depression.[66] Thus, the continuing strengthening of the relationship between depression and insomnia after the quarantine is comprehensible.

Moreover, "difficulty initiating sleep" emerged as the bridge symptom across all three waves, underscoring the importance of addressing difficulty initiating sleep in understanding the comorbidity of insomnia and depression. Disrupted sleep routines and excessive electronic device usage due to quarantine measures likely contribute significantly to insomnia occurrence.[67] Consequently, an increased prevalence of insomnia was observed both during and after the lockdown.[68,69] Additionally, according to the hyperarousal model of insomnia, the connection between depression and insomnia can be attributed to shared neurobiological and behavioral deficits related to sleep-wake regulatory dysfunction, contributing to deficits in emotional reactivity.[70] Extensive research have concluded that emotion regulation deficits may act as a mediator in the bidirectional relationship between insomnia and depression. Palmer et al found that sleep problems in adolescents are linked to poor emotion regulation abilities, which subsequently increase susceptibility to affective disorders, including depression. This finding indicates that sleep disruptions impair emotional management, creating a pathway through which depressive symptoms may develop.[71] Similarly, Kirschbaum-Lesch et al demonstrated that emotion regulation deficits partially mediate the relationship between sleep issues and depressive symptoms in a clinical sample of depressed adolescents, suggesting that targeting emotion regulation could mitigate depressive symptoms associated with sleep difficulties.[72] During the COVID-19 pandemic, Niu highlighted that maladaptive emotion regulation strategies, such as rumination, reinforced the cyclical relationship between sleep and depression in college students. Poor sleep heightened depressive symptoms, which in turn exacerbated sleep issues, perpetuating a self-reinforcing cycle.[62] Additionally, O'Leary et al also proposed that poor sleep quality may directly lead to depressive symptoms through its adverse effects on emotion regulation.[73] Therefore, when college students struggle to fall asleep at night, their daily mood may be significantly influenced, potentially exacerbating depression symptoms. In line with this, a longitudinal study has demonstrated that "difficulty initiating sleep" may serve as a risk factor for the onset of depression.[74] Similarly, a recent meta-analysis indicated that depressed adolescents reported higher levels of difficulty initiating sleep, more wakefulness after falling asleep, and lower sleep efficiency compared to their healthy counterparts.[14] Hence, some intervention programs for difficulty in falling asleep, such as stimulus control or mindfulness practice, may work well for individuals affected by the comorbidity of depression and insomnia.[75,76]

In the CLPN analysis, anhedonia emerged as the symptom exhibiting the highest OEI values during both the outbreak and receding periods. This finding suggests that anhedonia may play a significant role in triggering other symptoms, both during and after quarantine. Specifically, during the outbreak period, the most robust cross-lagged association was observed between "anhedonia" and "sleep", while after the removal of quarantine measures, the strongest connection was between "anhedonia" and "daytime functioning impairment". This observation implies that anhedonia could potentially instigate or exacerbate sleep-related issues. According to the definition provided by the American Psychiatric Association,[77] anhedonia is characterized as "the diminished interest or pleasure confronting stimuli that were once perceived as rewarding during the pre-morbid state". Prior research has indicated that individuals with high levels of anhedonia may exhibit a tendency to overestimate the likelihood of negative events occurring, as well as the effort required for action, while simultaneously neglecting the possibility of experiencing pleasurable outcomes.[78] Consequently, individuals suffering from both insomnia and elevated levels of anhedonia may be prone to overestimating the probability of experiencing difficulties in falling asleep and worrying about obtaining restful sleep during the night. These concerns may contribute to the onset or exacerbation of insomnia. In line with this, Tully et al have proposed that individuals with anhedonia are more likely to hold maladaptive beliefs about sleep, significantly hindering their ability to fall asleep at night.[79] A critical point to note, however, is that the core of depressive symptoms is generally considered to consist of two components: anhedonia (low positive affect) and depressed mood (high negative affect). In the current study, however, only anhedonia exhibited a strong predictive effect. Similar conclusions have been drawn in previous studies. For

example, Niu et al highlighted that anhedonia can influence cognitive and affective processes that impact the encoding and retrieval of episodic memories, particularly under conditions of sleep disruption. This suggests that the presence of anhedonia may exacerbate the negative impact of poor sleep on mood by altering cognitive functions related to memory, thereby intensifying depressive symptoms.[80] Similarly, Rizvi et al emphasized that anhedonia's impact extends beyond general mood deterioration to affect motivation and reward processing, potentially creating a feedback loop that exacerbates sleep disturbances.[81] Therefore, the results of this study suggest that anhedonia represents a promising target for addressing the comorbidity of depression and insomnia.

Limitations

Some limitations require acknowledgment. Firstly, data collection occurred at three specific time points: the inception of the infection control policy, the final month of its implementation, and one year thereafter. The absence of information preceding the pandemic limits the robustness of attributing changes and developments in depression and insomnia solely to the influence of infection control measures. Further exploration of data from countries without dynamic zero policies could help validate the findings.

Secondly, infection with COVID-19 may impact depressive and insomnia symptoms. However, in the present study, we did not include the item related to COVID-19 infection in the first two surveys and the last survey for different reasons. The first two surveys were conducted in the "dynamic zero-COVID" context. During this period, all universities in China established specialized provisional committees to handle infection-related issues, and all students participated in daily nucleic acid tests. Any case of infection was immediately quarantined and publicized within the school, and we were promptly informed of the infected student's identification number. Therefore, we could ensure that neither wave 1 nor wave 2 participants had been infected with COVID-19. The last survey took place one year after the end of the "dynamic zero-COVID" policy. A surge in infections occurred in the winter of late 2022 to early 2023 following the abrupt termination of the zero-COVID policy.[82] However, after the policy ended, the Chinese government ceased providing nucleic acid testing services to the public. Many people experienced symptoms such as fever and cough, but most recovered on their own without receiving any COVID-19 testing; even the Chinese government could not confirm how many people had been infected with COVID-19.[83] During this wave, the primary virus affecting the Chinese population was the Omicron variant, which has symptoms similar to seasonal influenza.[84] Thus, for individuals experiencing symptoms of infection, it is difficult to distinguish whether they were infected with COVID-19 or some other viral disease. Considering these factors, we deemed it unreliable to ask participants to self-assess whether they had been infected with COVID-19. Future studies may consider partnering with the medical system to collect data from clinically tested COVID-infected individuals to separately examine changes in symptoms between those infected and those uninfected with COVID-19.

Thirdly, while this research has demonstrated that the pandemic's influence persists for at least one year, the precise duration of its effects and the enduring impact of quarantine measures remain uncertain. Further research is imperative to identify the long-lasting effects of these factors. Additionally, the present sample consisted of a general college student population, rather than individuals with confirmed medical diagnoses. Further research is necessary to ascertain the generalizability of the current findings to clinical populations.

Conclusions

This study employed a network analysis approach to investigate the characteristics and changes in depressive and insomnia symptoms among college students during and after the pandemic. We found that depressive and insomnia symptoms among college students were exacerbated during the outbreak and continued at least one year after its end. "Difficulty initiating sleep" emerged as a pivotal pathway connecting depressive and insomnia symptoms. Furthermore, the CLPN analysis revealed that "anhedonia" exhibited the strongest triggering effect and mainly influenced insomnia symptoms. These results suggest that the pandemic and concurrent infection control measures may have enduring effects on depressive and insomnia symptoms among college students, and highlight the importance of considering anhedonia when devising effective interventions to address the comorbidity of depression and insomnia.

Data Sharing Statement

Data are available upon request from the correspondence author.

Ethics Approval and Informed Consent

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. This study was reviewed and approved by the ethical committee of Beijing Normal University (Reference number: 202112220084).

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Disclosure

The authors declare no competing interests in this work.

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