SSM - Population Health 25 (2024) 101567

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: www.elsevier.com/locate/ssmph

Network analysis of depression and anxiety symptoms and their associations with mobile phone addiction among Chinese medical students during the late stage of the COVID-19 pandemic

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ARTICLE INFO

Keywords:
Depression
Anxiety
Mobile phone addiction
Medical students
Network analysis
COVID-19

ABSTRACT

Network analysis provides a novel approach to discovering associations between mental disorders at the symptom level. This study aimed to examine the characteristics of the network of depression and anxiety symptoms and their associations with mobile phone addiction (MPA) among Chinese medical students during the late stage of the COVID-19 pandemic. A total of 553 medical students were included. Depression and anxiety symptoms and MPA were measured by the nine-item Patient Health Questionnaire (PHQ-9), the seven-item Generalized Anxiety Disorder Scale (GAD-7), and the Mobile Phone Addiction Index (MPAI), respectively. Central and bridge symptoms were identified with centrality indices and bridge centrality indices. Network stability was examined using the case-dropping procedure. "Uncontrollable worry", "restlessness" and "nervousness" were the central symptoms in the depression and anxiety network. "Restlessness" and "motor" were the most central bridge symptoms linking depression and anxiety. "Concentration", "anhedonia" and "sleep" were most strongly associated with MPA. "Uncontrollable worry", "restlessness", "nervousness," and "motor" may be the symptoms for interventions to target in medical students with comorbid depression and anxiety. From a network perspective, depressive symptoms may be more important than anxiety symptoms in medical students with MPA.

1. Introduction

The COVID-19 pandemic gained global recognition as an important public health event (Cucinotta & Vanelli, 2020). Public health was significantly impacted by the pandemic (Al-Jbouri, Mashkury, & Al-Ameri, 2022; Chen et al., 2021). The pandemic influenced college students' mental health and caused a significant increase in the prevalence rates of depression and anxiety (Li, Wang, Wu, Han, & Huang, 2021). Compared with college students with other majors, medical students experienced higher prevalence rates of depression and anxiety, eliciting widespread attention from researchers during the COVID-19 pandemic (Li, Zhao, Chen, Peng, & Lu, 2022; Paz et al., 2022; Peng et al., 2023). The pandemic interrupted clinical training and laboratory experiments, with a switch to online learning (Paz et al., 2022). The disruption of medical education and practice training led medical students to worry about their course progress, some medical students were exposed to high-risk surroundings, and there was a lack of coping strategies available during this exceptional period; these factors all were detrimental to mental health (Alsoufi et al., 2020; Lyons, Wilcox, Leung, & Dearsley, 2020; Paz et al., 2022). A systematic review showed that the pandemic influenced the mental health of Chinese medical students, especially increasing their depression and anxiety levels (Paz et al., 2022). Another Chinese study including 1041 medical students found that 26.8% of them had increased depression severity, and 20.2% had increased levels of anxiety (Zhang, Peng, Zhang, & Li, 2021). Depression and anxiety are two separate disorders but have genetic and neurobiological similarities (Gorman, 1996; Hettema, 2008). Comorbidity of the two disorders also results in greater health impairment than either disorder alone, such as greater resistant to treatment, disabilities, and a higher risk of suicide (Tiller, 2013). A meta-analysis that included 66 studies with 88336 people showed that not only did all types of diagnosed anxiety disorders and depressive disorders predict each other, but the symptoms of anxiety and depression also predicted each other (Jacobson & Newman, 2017). The close correlation between the two

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https://doi.org/10.1016/j.ssmph.2023.101567
Received 20 August 2023; Received in revised form 18 November 2023; Accepted 19 November 2023
Available online 23 November 2023

disorders highlights the importance of studying their mutual characteristics. However, few studies have focused on their relationship at the symptom level. Therefore, to help prevent and treat clinically significant distress in medical students, it is helpful to understand relationship between depression and anxiety at the symptom level.

Among the many factors related to depression and anxiety, mobile phone addiction (MPA) (or problematic smartphone use) has received increasing attention (Li, Li, Liu, & Wu, 2020). Mobile phone addiction (MPA) is a form of behavioral addiction in which individuals engage in activities centered around their phones and develop a craving for and dependency on their devices, which can result in various physical, psychological, and social challenges (Lopez-Fernandez, 2017; Zou et al., 2017). In recent years, some researchers have been concerned about increasing rates of MPA among medical students (Leow, Chiang, Chua, Wang, & Tan, 2023; Zhong et al., 2022), and many researchers have studied the impact of MPA on mental health (De-Sola Gutiérrez, Rodríguez de Fonseca, & Rubio, 2016; Huang, Wan, Lu, Ding, & Chen, 2022; Zhang et al., 2022). A meta-analysis including 33,650 college students found that MPA was positively associated with depression ($r = 0.36$, 95% CI: 0.32–0.40) and anxiety ($r = 0.39$, 95% CI: 0.34–0.45), providing strong evidence of the close relationships of MPA with depression and anxiety (Li et al., 2020). MPA may lead to anxiety and depression because people with MPA frequently disregard real-world social interactions, lead to frustration, reduced quality of personal relationships and social resources (Chen et al., 2016). The positive relationships of MPA with depression and anxiety have been widely studied (Li et al., 2020), but further examination of the underlying mechanisms is needed.

Network analysis in the field of psychopathology has recently emerged as a useful approach to understanding mental disorders (Borsboom, 2017). In network analysis, a mental disorder is viewed as a cluster of interacting symptoms (Hevey, 2018; Jin et al., 2022). Specific symptoms of mental disorders can affect how other symptoms emerge, and treating one symptom can reduce the intensity of other symptoms (Bringmann, Lemmens, Huibers, Borsboom, & Tuerlinckx, 2015). This approach can be used to quantitatively analyze and intuitively display the relationships among symptoms (Beard et al., 2016). It can be used to determine the most influential symptoms of the disorder and identify symptoms to target in interventions (Hofmann, Curtiss, & McNally, 2016), which addresses the limitations of traditional conceptualizations of psychopathology. Conventional conceptions of psychopathology treat the signs and symptoms of mental diseases as separate markers that point to a primary illness (Beard et al., 2016). Sum scores are used to describe the severity of psychopathology because the symptoms are viewed as interchangeable signs of the same underlying disease (Fried & Nesse, 2015). However, this approach may overlook the relationships among symptoms and obscure the essential differences between specific symptoms (Beard et al., 2016). In network analysis, symptoms are considered to be nodes and their interactions are viewed as edges (Hevey, 2018). Strength is one of the node centrality measures used to pinpoint the network's most influential symptoms and suggest potential clinical intervention targets (Beard et al., 2016; Borsboom & Cramer, 2013). Additionally, network analysis offers an original perspective on the mechanism of mental comorbidities (Jones, Ma, & McNally, 2021). When someone has a mental disorder, specific symptoms could raise their chance of developing other disorders; the symptoms most associated with other disorders are considered bridge symptoms (Borsboom & Cramer, 2013). As a result, it is essential to identify bridge symptoms because they may contribute to the emergence and persistence of psychiatric comorbidities.

To analyze the network structure of depression and anxiety in different populations, network analysis has been frequently applied, such as in Chinese college students (Bai, Cai, et al., 2021), German inpatients (Kaiser, Herzog, Voderholzer, & Brakemeier, 2021), and migrant Filipino domestic workers (Garabiles, Lao, Xiong, & Hall, 2019). Since earlier research had shown that the network of depression and anxiety was impacted by sample characteristics, socioeconomic status, and environmental variables (Bai, Xi et al., 2021; Jin et al., 2022), other populations may exhibit different characteristics of their network structure during different periods. To our knowledge, only one study in Switzerland used network analysis to explore the relationship between depression and anxiety among medical students (Ernst et al., 2021). Furthermore, a study reported that during the COVID-19 pandemic, medical students used their mobile phones more frequently (Santander-Hernandez, Peralta, Guevara-Morales, Diaz-Velez, & Valladares-Garrido, 2022). Additionally, some studies have reported that people under stress because of the COVID-19 pandemic experienced higher levels of depression and anxiety when they overindulged in media (Daimer, Mihatsch, Neufeld, Murray, & Knolle, 2022). Therefore, since medical students are both a student group and a population closely related to the COVID-19 pandemic, the structure of the depression and anxiety network and its association with MPA is worthy of study. This study is aimed to identify the central and bridge symptoms of depression and anxiety among Chinese medical students and their association with MPA during the COVID-19 pandemic to identify symptoms to target for the future prevention of depression and anxiety among medical students during major public health events similar to the COVID-19 pandemic.

2. Methods

2.1. Study setting and participants

The survey was conducted online at China Medical University from March to April 2021. The "Questionnaire Star" program was used to link questionnaires with WeChat (Bai, Xi et al., 2021; Jin et al., 2022). In China, WeChat is a popular messaging app with over 1.2 billion monthly active users (Jin et al., 2022). Students were eligible to participate if they could read and write Chinese, completed the questionnaire independently and were willing to participate in the survey. Before the survey, each participant signed an online informed consent form. Due to the "Questionnaire Star" program characteristics, a questionnaire could not be submitted unless all questions were answered, so there were no missing data in this survey. However, to increase the data's authenticity, data from questionnaires with durations shorter than 3 min were not included. The institutional review board of China Medical University approved this study, and all research procedures followed the ethical guidelines.

2.2. Measurements

The nine-item Patient Health Questionnaire (PHQ-9), which consists of nine questions rated on a scale from 0 (not at all) to 3 (almost every day), was used to evaluate depressive symptoms (Kroenke, Spitzer, & Williams, 2001). A higher score indicates a higher severity of depression. The Generalized Anxiety Disorder scale (GAD-7), which consists of seven items rated on a scale from 0 (not at all) to 3 (almost every day), was used to measure anxiety symptoms (Spitzer et al.). Higher scores indicate a higher severity of anxiety. A total score equal to or greater than 5 on either measure is considered indicative of depression (on the PHQ-9) or anxiety (on the GAD-7). If a participant had PHQ-9 and GAD-7 scores equal to or greater than 5, they were deemed to have comorbid depression and anxiety. The Mobile Phone Addiction Index (MPAI) was used to measure MPA (Hai, Lu-ying, Chun-yan, & He-ming, 2014), which has been widely used among college students and has shown good reliability and validity (Feng et al., 2022; Liu et al., 2021; Shi, Zhai, Li, Shi, & Fan, 2021). The MPAI was first developed by Leung based on the MPPUS and translated into Chinese by Hai Huang (Hai et al., 2014; Leung, 2008). Each of the 17 items on the MPAI is rated on a scale from 1 (almost never) to 5 (always), with 5 being the highest score. An MPAI score ≥ 51 is considered to indicate mobile phone addiction. A higher overall score indicates more severe MPA.

2.3. Statistical analyses

2.3.1. Network estimation

R (version 4.2.1) was used to perform all analyses. The extended Bayesian information criterion (EBIC) model and the graphical Gaussian model (GGM) with the visual least absolute shrinkage and selection operator (LASSO) from the R packages "qgraph" and "bootnet" were used to determine the polychoric correlations between depressive and anxiety symptoms (Epskamp et al., 2012, 2018). A link between two nodes is an edge, and each node in the network model represents a particular symptom. The partial correlation coefficient between any two nodes is represented by each edge (Epskamp et al., 2012). Blue edges reflect positive associations; red edges represent negative associations. Thicker edges suggest stronger relationships.

2.3.2. Centrality and stability

Expected influence (EI) was determined by the centralityPlot function in the R package "qgraph" and used to quantify the central symptom in the network (Epskamp et al., 2012). A higher EI of a node indicates that it is a more central symptom in the network. The bridge expected influence (bEI), calculated with the bridge function in the R package "networktools", also quantifies the bridge symptoms between the communities of depression and anxiety (Jones et al., 2021). A node with a higher bEI between two mental disorders indicates a greater chance of comorbidity of the two mental disorders. Using the R program "mgm," the predictability of each node was calculated; this measure reflects how well a particular node can be predicted by all other nodes (Haslbeck & Waldorp, 2018). Predictability is expressed as a ring-shaped pie chart around each node in the network, and a fuller ring indicates higher predictability values. The flow network was also created using the flow function in the R package "qgraph" to pinpoint specific depressive and anxiety symptoms positively related to MPA (Epskamp et al., 2012; Jin et al., 2022).

The R package "bootnet" was used to evaluate the network model's stability and accuracy using 1000 bootstraps for each node (Epskamp et al., 2018). Both the expected influence and the bridge expected influence were calculated using the correlation stability (CS) coefficients. Values above 0.25 indicate adequate stability, whereas values above 0.5 suggest good stability.

2.3.3. Network comparison

Following previous studies (Hou, Bi, Jiao, Luo, & Song, 2020; Jin et al., 2022), sex differences in network characteristics were investigated. The Network Comparison Test (NCT) in the "NetworkComparisonTest" R package was used to evaluate the global strength and each strength of each edge to compare the networks between the two sexes using 1000 permutations (Van Borkulo et al.).

3. Results

3.1. Study sample

A total of 593 medical students were invited to participate this study; of these, 553 (333 females, 220 males) were included, for an effective response rate of 93%. The average age was 19.86 years (SD = 0.79 years). Depression and anxiety were separately defined as PHQ-9 and GAD-7 total scores >5, respectively. The prevalence of depression in our sample was 50.6% (95% CI = 46.5–54.8%), that of anxiety was 38.3% (95% CI = 34.3–42.4%), and that of comorbid depression and anxiety was 35.4% (95% CI = 31.4–39.4%). The mean GAD-7 score was 3.77 (SD = 4.14), and the mean PHQ-9 score was 5.32 (SD = 4.85) (Table 1). The prevalence of MPA was 30.9% (95% CI = 27.1–34.8%), and the mean score was 43.61 (SD = 13.06).

Table 1
Descriptive statistics of measurement items.

Item abbreviation	Item content	Mean (SD)	Expected influence	Predictability
PHQ-1	Anhedonia	0.75 (0.68)	−0.802	0.548
PHQ-2	Sad mood	0.6 (0.69)	0.746	0.635
PHQ-3	Sleep	0.63 (0.75)	−1.365	0.467
PHQ-4	Fatigue	0.73 (0.70)	0.574	0.618
PHQ-5	Appetite	0.62 (0.72)	−1.214	0.522
PHQ-6	Guilt	0.58 (0.68)	0.177	0.632
PHQ-7	Concentration	0.65 (0.71)	−1.184	0.553
PHQ-8	Motor	0.46 (0.65)	−0.092	0.654
PHQ-9	Suicide	0.3 (0.59)	−1.591	0.574
GAD-1	Nervousness	0.64 (0.67)	0.770	0.732
GAD-2	Uncontrollable worry	0.52 (0.68)	1.795	0.769
GAD-3	Excessive worry	0.61 (0.71)	0.515	0.693
GAD-4	Trouble relaxing	0.59 (0.72)	0.005	0.667
GAD-5	Restlessness	0.44 (0.66)	1.227	0.737
GAD-6	Irritability	0.52 (0.67)	−0.271	0.634
GAD-7	Feeling afraid	0.45 (0.65)	0.710	0.722

SD: standard deviation; PHQ-9: the nine-item Patient Health Questionnaire; GAD-7: the seven-item Generalized Anxiety Disorder scale.

3.2. Network structure

The network of depression and anxiety symptoms among medical students during the COVID-19 pandemic is shown in Fig. 1. The ring pie chart around each node shows the predictability of each symptom. The average predictability was 0.634, meaning that surrounding nodes could typically explain 63.4% of each node's variance. In the symptoms of the depression network, the strongest edges (in descending order) were between PHQ-1 (anhedonia) and PHQ-4 (fatigue), between PHQ-1 (anhedonia) and PHQ-2 (sad mood), and between PHQ-4 (fatigue) and PHQ-5 (appetite). In the symptoms of the anxiety network, the strongest edges (in descending order) were between GAD-5 (restlessness) and GAD-7 (feeling afraid), between GAD-1 (nervousness) and GAD-3 (excessive worry), between GAD-1 (nervousness) and GAD-2 (uncontrollable worry), and between GAD-3 (excessive worry) and GAD-4 (trouble relaxing). In the symptoms of the depression and anxiety network, the strongest edges (in descending order) were between GAD-5 (restlessness) and PHQ-8 (motor), between GAD-1 (nervousness) and PHQ-6 (guilt), between GAD-2 (uncontrollable worry) and PHQ-2 (sad mood), and between GAD-7 (feeling afraid) and PHQ-9 (suicide).

The EI and bEI values of symptoms in the depression and anxiety network are shown in Fig. 2. The most central symptom was GAD-2 (uncontrollable worry), followed by GAD-5 (restlessness) and GAD-1 (nervousness) (Fig. 2, left). To understand the network of depression and anxiety symptoms in medical students, it is crucial to understand these three symptoms. The main symptoms bridging the depression and anxiety communities were GAD-5 (restlessness), PHQ-8 (motor), and GAD-2 (uncontrollable worry) (Fig. 2, right part).

The flow network of MPA with depressive and anxiety symptoms is shown in Fig. 3. Twelve symptoms were linked to MPA. The strongest edges of depression and anxiety symptoms with MPA included PHQ-7

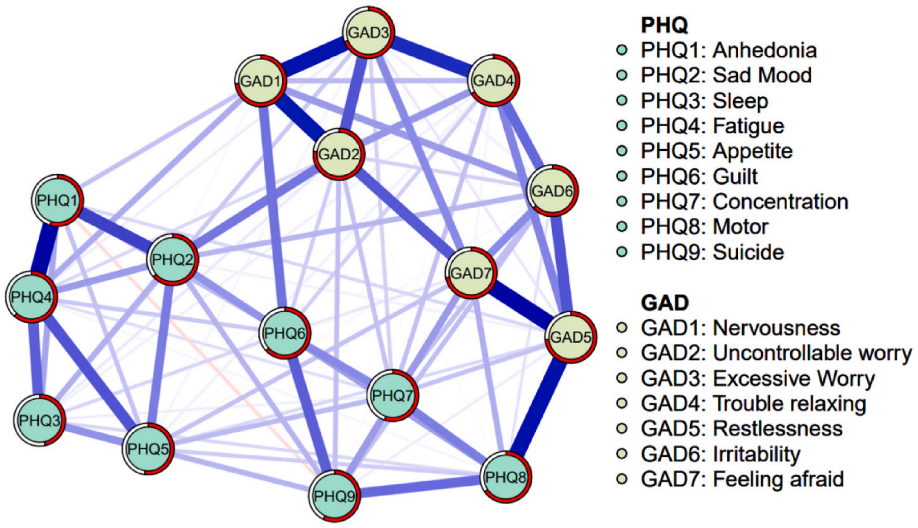

Fig. 1. Network structure of depression and anxiety symptoms in medical students during the late stage of the COVID-19 pandemic.

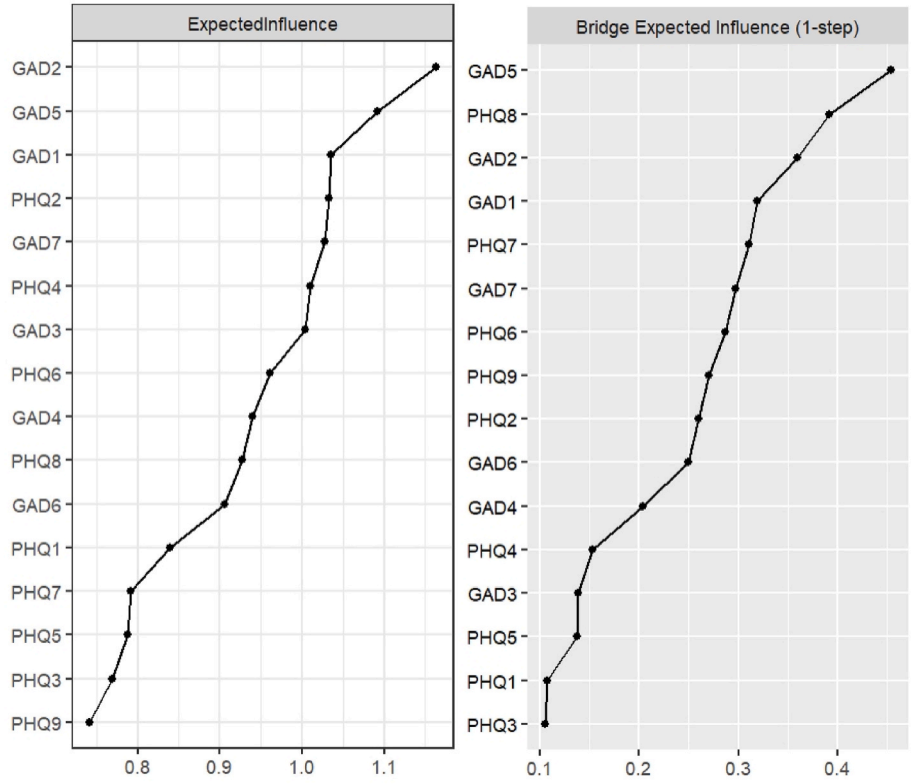

Fig. 2. Centrality indices: expected influence and bridge expected influence values.

(concentration), PHQ-1 (anhedonia) and PHQ-3 (sleep).

3.3. Network stability

The symptoms in the depression and anxiety network had good stability. Fig. 4 shows that the stability of the EI CS-coefficient was 0.673, and the bEI CS-coefficient was 0.517, indicating that the network did not significantly change when 67.3% of the sample was dropped. The central symptoms were significantly different from the other nodes, according to the bootstrapped stability test for EI (Fig. S1).

3.4. Comparisons of network structure between the sexes

Fig. S2 shows the network structures of males and females. Male and female networks did not significantly differ in terms of global strength (male: 7.525, female: 7.496; $S = 0.028$, $p = 0.866$) or the distribution of edge weights in the network ($M = 0.275$, $p = 0.289$) according to the network comparison test (Fig. S3).

4. Discussion

To the best of our knowledge, this is the first study to use network analysis to examine the symptoms of depression and anxiety among

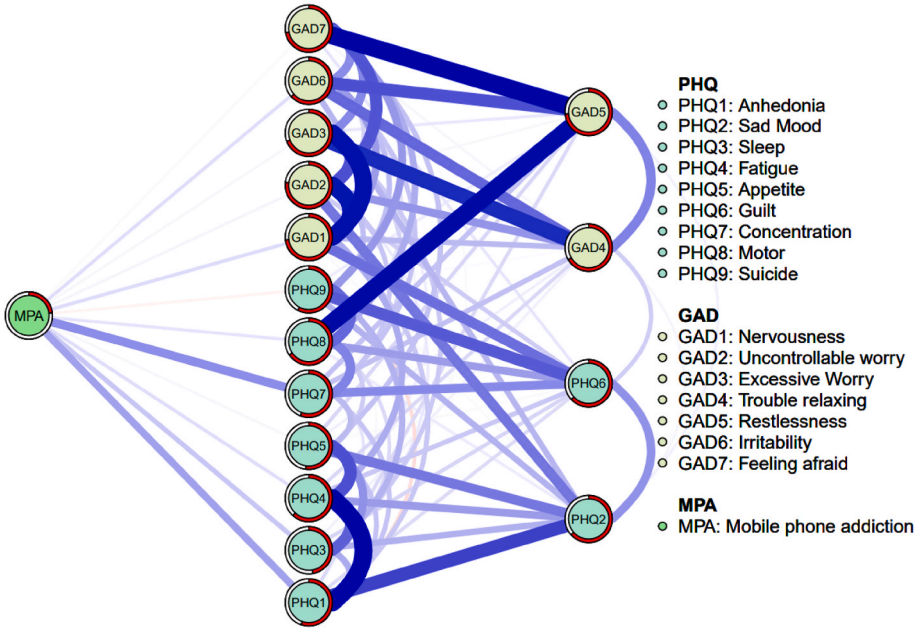

Fig. 3. Flow network of mobile phone addiction with depression and anxiety.

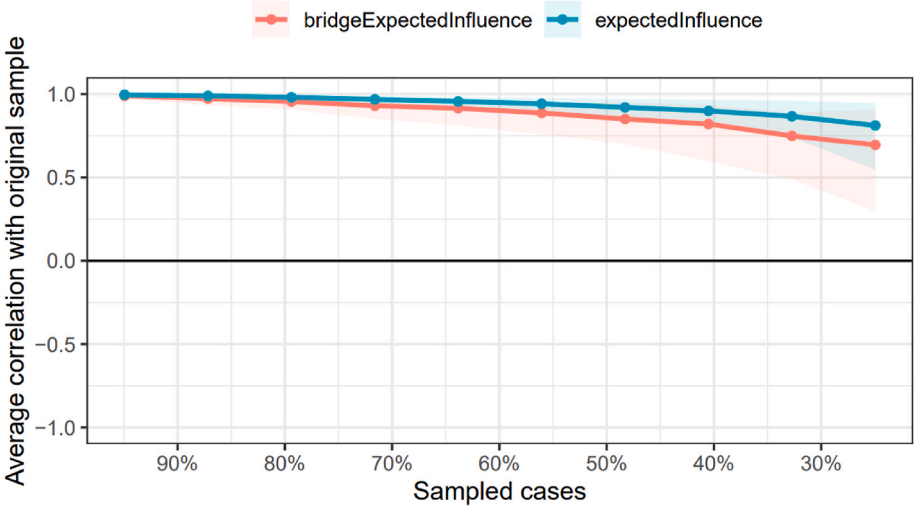

Fig. 4. The stability of centrality and bridge centrality indices according to a case-dropping bootstrap method.

medical students and their associations with MPA during the COVID-19 pandemic. In our network of depression and anxiety symptoms, the most central symptom was GAD-2 (uncontrollable worry), followed by GAD-5 (restlessness) and GAD-1 (nervousness); these symptoms were the most likely to maintain the rest of the depressive and anxiety symptoms. Furthermore, the bridge symptoms linking depression and anxiety communities were GAD-5 (restlessness), PHQ-8 (motor) and GAD-2 (uncontrollable worry). The strongest edges between MPA and depression and anxiety symptoms were between MPA and PHQ-7 (concentration), PHQ-1 (anhedonia) and PHQ-3 (sleep).

GAD-2 (uncontrollable worry) was the most central symptom in our network of depression and anxiety symptoms; this is the first report to highlight its centrality. This may be caused by the impact of the COVID-19 pandemic on schoolwork and daily life, which worsened medical students' anxiety (Cao et al., 2020). Many students reported that the pandemic had seriously affected their capacity to prepare for residency and their ability to further their medical education (Harries et al., 2021). The changes from traditional teaching methods to online learning increased the stress levels of medical students and inevitably raised some concerns about their medical courses (Lyons et al., 2020). Furthermore, the uncertainty about when they could return to normal life and the effect of misleading media may have also increased their worry (Lyons et al., 2020; Saraswathi et al., 2020). Interestingly, although this is the first study to report that GAD-2 (uncontrollable worry) was the most central symptom, it was reported to be a central symptom in other studies conducted during the COVID-19 pandemic (Bai, Xi et al., 2021; Jin et al., 2022; Pu Peng et al., 2022; Wang et al., 2023). During the COVID-19 pandemic, a study of clinicians found that GAD-2 (uncontrollable worry) was the third most central symptom (Jin et al., 2022). Similarly, studies involving nurses, medical students, nursing students, and college students during the pandemic identified GAD-2 (controllable worry) as the second most central symptom (Bai, Xi et al., 2021; Ernst et al., 2021; P. Peng, Q. Chen et al., 2022; P. Peng, M. Liang et al., 2022; Wang et al., 2023). These findings suggest that GAD-2 (controllable worry) may have been a key central symptom during the COVID-19 pandemic.

GAD-5 (restlessness) and GAD-1 (nervousness) were another two central symptoms in our study, differing from some previous studies (Cai et al., 2022; Garabiles et al., 2019). Different study samples and periods may cause these inconsistent findings. The identification of GAD-5 (restlessness) and GAD-1 (nervousness) as influential symptoms may be partly explained by the following reasons: due to the pandemic, the increase in medical students' mobile phone use may have influenced excessive media consumption, which may have led them to feel restless and nervous (Daimer et al., 2022; Jiang, Luo, Guan, Jiang, & Tang, 2022). Studies have reported that COVID-19 media coverage was an emotional stressor during the pandemic (Bendau, Petzold, Pyrkosch, Mascarell Maricic, et al., 2021). COVID-19 information may have worried medical students more than nonmedical students (Xiong et al., 2021). Mobile phones provide a perfect tool for them to acquire such information, which may contribute to their restlessness and nervousness, although their broader knowledge of the disease could have alleviated this effect to a certain degree (Bendau, Petzold, Pyrkosch, Maricic, et al., 2021; Saddik et al., 2020).

The bridge symptoms, GAD-5 (restlessness) and PHQ-8 (motor), should be the focus of therapies to treat comorbid depression and anxiety. Our finding aligned with two previous studies among the general population and college student samples during the COVID-19 pandemic (Bai, Cai, et al., 2021; Wang, Hu, Feng, Wilson, & Chen, 2020). The lockdowns associated with the COVID-19 pandemic may have caused GAD-5 (restlessness) and PHQ-8 (motor) to become bridge symptoms (Wang et al., 2020). Limited or absent physical activity due to lockdowns could lead to symptoms of anxiety and depression (Hao et al., 2020; Lippi, Henry, Bovo, & Sanchis-Gomar, 2020). Previous studies have reported that GAD-5 (restlessness) plays a role in major depressive disorder (MDD). According to research, treating the early signs of restlessness was associated with remission of MDD (Sakurai et al., 2013). A longitudinal study also provided evidence that restlessness could predict the subsequent relapse of MDD (Sakurai, Suzuki, Yoshimura, Mimura, & Uchida, 2017). These results indicated that GAD-5 (restlessness) is an effective target for intervening in comorbid depression and anxiety.

MPA has been widely reported to have a positive relationship with depression and anxiety (Li et al., 2020). Compared to other symptoms in this study, PHQ-7 (concentration), PHQ-1 (anhedonia) and PHQ-3 (sleep) had the strongest positive associations with MPA in medical students, indicating that these major symptoms of depression and anxiety were connected with MPA. PHQ-7 (concentration) had the strongest association with MPA. This result is similar to a recent study in which the PHQ-7 (concentration) was an influential bridge between MPA symptoms and depressive symptoms (Wei et al., 2023). PHQ-7 (concentration) is an essential diagnostic symptom for major depressive disorder and is considered a mediator of the effect of depression on MPA (Mordeno, Carpio, Mendoza, & Hall, 2018; Wei et al., 2023). PHQ-1 (anhedonia) had the second strongest association with MPA; in previous studies, anhedonia (a negative emotion) led to an escape motivation that could develop into MPA (Kardefelt-Winther, 2014; Wei et al., 2023). PHQ-3 (sleep) had the third strongest association with MPA, suggesting that smartphone overuse could impair sleep quality and cause negative emotions (Guang-hui & Xin, 2019). Sleep disruption brought on by MPA may result in depressive symptoms (Billieux, 2012). In this flow network, we found that the symptoms of depression were more closely associated with MPA than anxiety symptoms; thus, we propose that depressive symptoms may be better intervention targets for MPA than anxiety symptoms. Further research is needed to determine the connection between MPA and specific depressive and anxiety symptoms.

Through network analysis, this study examined the central and bridge symptoms of depression and anxiety among Chinese medical students during the COVID-19 pandemic, providing a more explicit structure for understanding the relationship between these symptoms. These findings provided some clues to improve interventions addressing medical students' mental health when facing similar pandemics in the future. This study also examined the relationship between depression and anxiety symptoms and MPA in medical students during the pandemic using flow networks, giving us another perspective.

Several limitations apply to our investigation. First, because our study was cross-sectional, we could not identify causal relationships. Second, self-report bias may have been present since all symptoms were measured using self-reported methods. Third, the COVID-19 pandemic especially affected our sample medical students, so the findings may not apply to other populations or time periods. However, network analysis methods have advantages in discovering the different patterns of mood disorders. Our study described their network structure in a special period, and these findings can be compared with other studies in the future to understand the common or unique characteristics of depression and anxiety in different groups or periods. Additionally, this study identified the target symptoms to inform the development of specific stress management strategies for medical students to cope with depression and anxiety in future pandemics (Bughrara et al., 2023).

In conclusion, GAD-2 (uncontrollable worry), GAD-5 (restlessness) and GAD-1 (nervousness) were central symptoms, and GAD-5 (restlessness) and PHQ-8 (motor) were the bridge symptoms in the network of depression and anxiety symptoms. These symptoms may be the targets of intervention among medical students. Furthermore, targeting the symptoms PHQ-7 (concentration), PHQ-1 (anhedonia) and PHQ-3 (sleep) may be important in reducing MPA.

Ethical statement

The Human Experiment Committee of China Medical University authorized this study, and all research procedures followed ethical guidelines. Prior to the survey, each participant signed an online informed consent form.

CRediT authorship contribution statement

Zhihan Chen: Conceptualization, Formal analysis, Writing – original draft. **Jiexi Xiong:** Writing – original draft. **Hongfei Ma:** Methodology, Visualization. **Yunan Hu:** Data curation, Investigation. **Junni Bai:** Data curation, Investigation. **Hui Wu:** Resources, Supervision, Writing – review & editing. **Yang Wang:** Investigation, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

None.

Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2023.101567.

References

Al-Jbouri, N. A.-A.-H. D., Mashkury, Z. J. K., & Al-Ameri, R. J. K. (2022). Mental health during COVID-19 pandemic/Baghdad Al-Karkh [Article]. *International Journal of Social Psychiatry, 68*(4), 738–744. https://doi.org/10.1177/00207640211004987. Article 00207640211004987.

Alsoufi, A., Alsuyihili, A., Msherghi, A., Elhadi, A., Atiyah, H., Ashini, A., et al. (2020). Impact of the COVID-19 pandemic on medical education: Medical students' knowledge, attitudes, and practices regarding electronic learning [Article]. *PLoS One, 15*(11), Article e0242905. https://doi.org/10.1371/journal.pone.0242905

Bai, W., Cai, H., Liu, S., Chen, X., Sha, S., Cheung, T., et al. (2021). Anxiety and depressive symptoms in college students during the late stage of the COVID-19 outbreak: A network approach [article]. *Translational Psychiatry, 11*(1). https://doi.org/10.1038/s41398-021-01738-4. Article 638.

Bai, W., Xi, H.-T., Zhu, Q., Ji, M., Zhang, H., Yang, B.-X., et al. (2021). Network analysis of anxiety and depressive symptoms among nursing students during the COVID-19 pandemic* [Article]. *Journal of Affective Disorders, 294*, 753–760. https://doi.org/10.1016/j.jad.2021.07.072

Beard, C., Millner, A. J., Forgeard, M. J. C., Fried, E. I., Hsu, K. J., Treadway, M. T., et al. (2016). Network analysis of depression and anxiety symptom relationships in a psychiatric sample [Article]. *Psychological Medicine, 46*(16), 3359–3369. https://doi.org/10.1017/s0033291716002300

Bendau, A., Petzold, M. B., Pyrkosch, L., Maricic, L. M., Betzler, F., Rogoll, J., et al. (2021). Associations between COVID-19 related media consumption and symptoms of anxiety, depression and COVID-19 related fear in the general population in Germany [Article]. *European Archives of Psychiatry and Clinical Neuroscience, 271*(2), 283–291. https://doi.org/10.1007/s00406-020-01171-6

Bendau, A., Petzold, M. B., Pyrkosch, L., Mascarell Maricic, L., Betzler, F., Rogoll, J., et al. (2021). Associations between COVID-19 related media consumption and symptoms of anxiety, depression and COVID-19 related fear in the general population in Germany (vol 271, pg 283, 2021) [Correction]. *European Archives of Psychiatry and Clinical Neuroscience, 271*(7), 1409. https://doi.org/10.1007/s00406-021-01290-8, 1409.

Billieux, J. (2012). Problematic use of the mobile phone: A literature review and a pathways model. *Current Psychiatry Reviews, 8*, 299–307.

Borsboom, D. (2017). A network theory of mental disorders [Article]. *World Psychiatry, 16*(1), 5–13. https://doi.org/10.1002/wps.20375

Borsboom, D., & Cramer, A. O. J. (2013). Network analysis: An integrative approach to the structure of psychopathology. In S. NolenHoeksema (Ed.), *Annual review of clinical psychology* (Vol. 9, pp. 91–121). https://doi.org/10.1146/annurev-clinpsy-050212-185608

Bringmann, L. F., Lemmens, L. H. J. M., Huibers, M. J. H., Borsboom, D., & Tuerlinckx, F. (2015). Revealing the dynamic network structure of the beck depression inventory-II [article]. *Psychological Medicine, 45*(4), 747–757. https://doi.org/10.1017/s0033291714001809

Bughrara, M. S., Swanberg, S. M., Lucia, V. C., Schmitz, K., Jung, D., & Wunderlich-Barillas, T. (2023). Beyond COVID-19: The impact of recent pandemics on medical students and their education: A scoping review. *Medical Education Online, 28*(1), Article 2139657. https://doi.org/10.1080/10872981.2022.2139657

Cai, H., Bai, W., Liu, H., Chen, X., Qi, H., Liu, R., et al. (2022). Network analysis of depressive and anxiety symptoms in adolescents during the later stage of the COVID-19 pandemic [Article]. *Translational Psychiatry, 12*(1). https://doi.org/10.1038/s41398-022-01838-9. Article 98.

Cao, W., Fang, Z., Hou, G., Han, M., Xu, X., Dong, J., et al. (2020). The psychological impact of the COVID-19 epidemic on college students in China [Article]. *Psychiatry Research, 287*. https://doi.org/10.1016/j.psychres.2020.112934. Article 112934.

Chen, L., Yan, Z., Tang, W., Yang, F., Xie, X., & He, J. (2016). Mobile phone addiction levels and negative emotions among Chinese young adults: The mediating role of interpersonal problems [Article]. *Computers in Human Behavior, 55*, 856–866. https://doi.org/10.1016/j.chb.2015.10.030

Chen, Y., Zhang, X., Chen, S., Zhang, Y., Wang, Y., Lu, Q., et al. (2021). Bibliometric analysis of mental health during the COVID-19 pandemic. *Asian Journal of Psychiatry, 65*. https://doi.org/10.1016/j.ajp.2021.102846. Article 102846.

Cucinotta, D., & Vanelli, M. (2020). WHO declares COVID-19 a pandemic. *Acta BioMedica : Atenei Parmensis, 91*(1), 157–160. https://doi.org/10.23750/abm.v91i1.9397

Daimer, S., Mihatsch, L. L., Neufeld, S. A. S., Murray, G. K., & Knolle, F. (2022). Investigating the relationship of COVID-19 related stress and media consumption with schizotypy, depression, and anxiety in cross-sectional surveys repeated throughout the pandemic in Germany and the UK [Article]. *Elife, 11*. https://doi.org/10.7554/eLife.75893. Article e75893.

De-Sola Gutiérrez, J., Rodríguez de Fonseca, F., & Rubio, G. (2016). Cell-phone addiction: A review. *Frontiers in Psychiatry, 7*, 175. https://doi.org/10.3389/fpsyt.2016.00175

Epskamp, S., Borsboom, D., & Fried, E. I. (2018). Estimating psychological networks and their accuracy: A tutorial paper [article]. *Behavior Research Methods, 50*(1), 195–212. https://doi.org/10.3758/s13428-017-0862-1

Epskamp, S., Cramer, A. O. J., Waldorp, L. J., Schmittmann, V. D., & Borsboom, D. (2012). qgraph: Network visualizations of relationships in psychometric data [article]. *Journal of Statistical Software, 48*(4), 1–18. https://doi.org/10.18637/jss.v048.i04

Ernst, J., Jordan, K. D., Weilenmann, S., Sazpinar, O., Gehrke, S., Paolercio, F., et al. (2021). Burnout, depression and anxiety among Swiss medical students - a network analysis. *Journal of Psychiatric Research, 143*, 196–201. https://doi.org/10.1016/j.jpsychires.2021.09.017

Feng, Z., Diao, Y., Ma, H., Liu, M., Long, M., Zhao, S., et al. (2022). Mobile phone addiction and depression among Chinese medical students: The mediating role of sleep quality and the moderating role of peer relationships. *BMC Psychiatry, 22*(1), 567. https://doi.org/10.1186/s12888-022-04183-9

Fried, E. I., & Nesse, R. M. (2015). Depression sum-scores don't add up: Why analyzing specific depression symptoms is essential. *BMC Medicine, 13*. https://doi.org/10.1186/s12916-015-0325-4. Article 72.

Garabiles, M. R., Lao, C. K., Xiong, Y., & Hall, B. J. (2019). Exploring comorbidity between anxiety and depression among migrant Filipino domestic workers: A network approach. *Journal of Affective Disorders, 250*, 85–93. https://doi.org/10.1016/j.jad.2019.02.062

Gorman, J. M. (1996). Comorbid depression and anxiety spectrum disorders. *Depression and Anxiety, 4*(4), 160–168. https://doi.org/10.1002/(sici)1520-6394 (1996)4:4<160::Aid-da2>3.0.Co;2-j.

Guang-hui, N., & Xin, Y. (2019). Relationship between mobile phone addiction and sleep quality,depression among students in a medical college in Guangxi. *Modern Preventive Medicine, 46*(14), 2591–2593+2611.

Hai, H., Lu-ying, N., Chun-yan, Z., & He-ming, W. (2014). Reliability and validity of mobile phone addiction Index for Chinese college students. *Chinese Journal of Clinical Psychology, 22*(5), 835–838. https://doi.org/10.16128/j.cnki.1005-3611.2014.05.062

Hao, F., Tan, W., Jiang, L., Zhang, L., Zhao, X., Zou, Y., et al. (2020). Do psychiatric patients experience more psychiatric symptoms during COVID-19 pandemic and lockdown? A case-control study with service and research implications for immunopsychiatry [article]. *Brain, Behavior, and Immunity, 87*, 100–106. https://doi.org/10.1016/j.bbi.2020.04.069

Harries, A. J., Lee, C., Jones, L., Rodriguez, R. M., Davis, J. A., Boysen-Osborn, M., et al. (2021). Effects of the COVID-19 pandemic on medical students: A multicenter quantitative study [article]. *BMC Medical Education, 21*(1). https://doi.org/10.1186/s12909-020-02462-1. Article 14.

Haslbeck, J. M. B., & Waldorp, L. J. (2018). How well do network models predict observations? On the importance of predictability in network models [article]. *Behavior Research Methods, 50*(2), 853–861. https://doi.org/10.3758/s13428-017-0910-x

Hettema, J. M. (2008). What is the genetic relationship between anxiety and depression? *Am J Med Genet C Semin Med Genet, 148c*(2), 140–146. https://doi.org/10.1002/ajmg.c.30171

Hevey, D. (2018). Network analysis: A brief overview and tutorial [; review]. *Health psychology and behavioral medicine, 6*(1), 301–328. https://doi.org/10.1080/21642850.2018.1521283

Hofmann, S. G., Curtiss, J., & McNally, R. J. (2016). A complex network perspective on clinical science [article]. *Perspectives on Psychological Science, 11*(5), 597–605. https://doi.org/10.1177/1745691616639283

Hou, F., Bi, F., Jiao, R., Luo, D., & Song, K. (2020). Gender differences of depression and anxiety among social media users during the COVID-19 outbreak in China:a cross-sectional study [Article]. *BMC Public Health, 20*(1). https://doi.org/10.1186/s12889-020-09738-7. Article 1648.

Huang, H., Wan, X., Lu, G., Ding, Y., & Chen, C. (2022). The relationship between alexithymia and mobile phone addiction among mainland Chinese students: A meta-analysis. *Frontiers in Psychiatry, 13*, Article 754542. https://doi.org/10.3389/fpsyt.2022.754542

Jacobson, N. C., & Newman, M. G. (2017). Anxiety and depression as bidirectional risk factors for one another: A meta-analysis of longitudinal studies. *Psychological Bulletin, 143*(11), 1155–1200. https://doi.org/10.1037/bul0000111

Jiang, W., Luo, J., Guan, H., Jiang, F., & Tang, Y.-L. (2022). Problematic mobile phone use and life satisfaction among university students during the COVID-19 pandemic in Shanghai, China [article]. *Frontiers in Public Health, 9*. https://doi.org/10.3389/fpubh.2021.805529. Article 805529.

Jin, Y., Sha, S., Tian, T., Wang, Q., Liang, S., Wang, Z., et al. (2022). Network analysis of comorbid depression and anxiety and their associations with quality of life among clinicians in public hospitals during the late stage of the COVID-19 pandemic in China [Article]. *Journal of Affective Disorders, 314*, 193–200. https://doi.org/10.1016/j.jad.2022.06.051

Jones, P. J., Ma, R., & McNally, R. J. (2021). Bridge centrality: A network approach to understanding comorbidity [article]. *Multivariate Behavioral Research, 56*(2), 353–367. https://doi.org/10.1080/00273171.2019.1614898

Kaiser, T., Herzog, P., Voderholzer, U., & Brakemeier, E.-L. (2021). Unraveling the comorbidity of depression and anxiety in a large inpatient sample: Network analysis to examine bridge symptoms [Article]. *Depression and Anxiety, 38*(3), 307–317. https://doi.org/10.1002/da.23136

Kardefelt-Winther, D. (2014). A conceptual and methodological critique of internet addiction research: Towards a model of compensatory internet use [Article]. *Computers in Human Behavior, 31*, 351–354. https://doi.org/10.1016/j.chb.2013.10.059

Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2001). The PHQ-9 - validity of a brief depression severity measure [Article]. *Journal of General Internal Medicine, 16*(9), 606–613. https://doi.org/10.1046/j.1525-1497.2001.016009606.x

Leow, M. Q. H., Chiang, J., Chua, T. J. X., Wang, S., & Tan, N. C. (2023). The relationship between smartphone addiction and sleep among medical students: A systematic review and meta-analysis. *PLoS One, 18*(9), Article e0290724. https://doi.org/10.1371/journal.pone.0290724

Leung, L. (2008). Linking psychological attributes to addiction and improper use of the mobile phone among adolescents in Hong Kong. *Journal of Children and Media, 2*, 93–113. https://doi.org/10.1080/17482790802078565

Li, Y., Li, G., Liu, L., & Wu, H. (2020). Correlations between mobile phone addiction and anxiety, depression, impulsivity, and poor sleep quality among college students: A systematic review and meta-analysis. *Journal of Behavioral Addictions, 9*(3), 551–571. https://doi.org/10.1556/2006.2020.00057

Lippi, G., Henry, B. M., Bovo, C., & Sanchis-Gomar, F. (2020). Health risks and potential remedies during prolonged lockdowns for coronavirus disease 2019 (COVID-19). *Diagnosis (Berlin, Germany), 7*(2), 85–90. https://doi.org/10.1515/dx-2020-0041

Liu, S., Zhou, W., Wang, J., Chen, B., He, G., & Jia, Y. (2021). Association between mobile phone addiction Index and sugar-sweetened food intake in medical college students stratified by sex from Shanghai, China. *Nutrients, 13*(7). https://doi.org/10.3390/nu13072256

Li, Y., Wang, A. W., Wu, Y. L., Han, N. N., & Huang, H. M. (2021). Impact of the COVID-19 pandemic on the mental health of college students: A systematic review and meta-analysis. *Frontiers in Psychology, 12*. https://doi.org/10.3389/fpsyg.2021.669119. Article 669119.

Li, W., Zhao, Z., Chen, D., Peng, Y., & Lu, Z. (2022). Prevalence and associated factors of depression and anxiety symptoms among college students: A systematic review and meta-analysis. *Journal of Child Psychology and Psychiatry, 63*(11), 1222–1230. https://doi.org/10.1111/jcpp.13606

Lopez-Fernandez, O. (2017). Short version of the Smartphone Addiction Scale adapted to Spanish and French: Towards a cross-cultural research in problematic mobile phone use. *Addictive Behaviors, 64*, 275–280. https://doi.org/10.1016/j.addbeh.2015.11.013

Lyons, Z., Wilcox, H., Leung, L., & Dearsley, O. (2020). COVID-19 and the mental well-being of Australian medical students: Impact, concerns and coping strategies used [article]. *Australasian Psychiatry, 28*(6), 649–652. https://doi.org/10.1177/1039856220947945. Article 1039856220947945.

Mordeno, I. G., Carpio, J. G. E., Mendoza, N. B., & Hall, B. J. (2018). The latent structure of major depressive symptoms and its relationship with somatic disorder symptoms among Filipino female domestic workers in China [Article]. *Psychiatry Research, 270*, 587–594. https://doi.org/10.1016/j.psychres.2018.10.029

Paz, D. C., Bains, M. S., Zueger, M. L., Bandi, V. R., Kuo, V. Y., Cook, K., et al. (2022). COVID-19 and mental health: A systematic review of international medical student surveys. *Frontiers in Psychology, 13*, Article 1028559. https://doi.org/10.3389/fpsyg.2022.1028559

Peng, P., Chen, Q., Liang, M., Liu, Y., Chen, S., Wang, Y., et al. (2022). A network analysis of anxiety and depression symptoms among Chinese nurses in the late stage of the COVID-19 pandemic [Article]. *Frontiers in Public Health, 10*. https://doi.org/10.3389/fpubh.2022.996386. Article 996386.

Peng, P., Chen, Q., Liang, M., Liu, Y., Chen, S., Wang, Y., et al. (2022). A network analysis of anxiety and depression symptoms among Chinese nurses in the late stage of the COVID-19 pandemic. *Frontiers in Public Health, 10*, Article 996386. https://doi.org/10.3389/fpubh.2022.996386

Peng, P., Hao, Y., Liu, Y., Chen, S., Wang, Y., Yang, Q., et al. (2023). The prevalence and risk factors of mental problems in medical students during COVID-19 pandemic: A systematic review and meta-analysis. *Journal of Affective Disorders, 321*, 167–181. https://doi.org/10.1016/j.jad.2022.10.040

Peng, P., Liang, M., Wang, Q., Lu, L., Wu, Q., & Chen, Q. (2022). Night shifts, insomnia, anxiety, and depression among Chinese nurses during the COVID-19 pandemic remission period: A network approach. *Frontiers in Public Health, 10*, Article 1040298. https://doi.org/10.3389/fpubh.2022.1040298

Saddik, B., Hussein, A., Sharif-Askari, F. S., Kheder, W., Temsah, M. H., Koutaich, R. A., et al. (2020). Increased levels of anxiety among medical and non-medical university students during the COVID-19 pandemic in the United Arab Emirates. *Risk Management and Healthcare Policy, 13*, 2395–2406. https://doi.org/10.2147/rmhp.S273333

Sakurai, H., Suzuki, T., Yoshimura, K., Mimura, M., & Uchida, H. (2017). Predicting relapse with individual residual symptoms in major depressive disorder: A reanalysis of the STAR*D data [article]. *Psychopharmacology, 234*(16), 2453–2461. https://doi.org/10.1007/s00213-017-4634-5

Sakurai, H., Uchida, H., Abe, T., Nakajima, S., Suzuki, T., Pollock, B. G., et al. (2013). Trajectories of individual symptoms in remitters versus non-remitters with depression [Article]. *Journal of Affective Disorders, 151*(2), 506–513. https://doi.org/10.1016/j.jad.2013.06.035

Santander-Hernandez, F. M., Peralta, C. I., Guevara-Morales, M. A., Diaz-Velez, C., & Valladares-Garrido, M. J. (2022). Smartphone overuse, depression & anxiety in medical students during the COVID-19 pandemic. *PLoS One, 17*(8), Article e0273575. https://doi.org/10.1371/journal.pone.0273575

Saraswathi, I., Saikarthik, J., Kumar, K. S., Srinivasan, K. M., Ardhanaari, M., & Gunapriya, R. (2020). Impact of COVID-19 outbreak on the mental health status of undergraduate medical students in a COVID-19 treating medical college: A prospective longitudinal study [article]. *PeerJ, 8*. https://doi.org/10.7717/peerj.10164. Article e10164.

Shi, M., Zhai, X., Li, S., Shi, Y., & Fan, X. (2021). The relationship between physical activity, mobile phone addiction, and irrational procrastination in Chinese college students. *International Journal of Environmental Research and Public Health, 18*(10). https://doi.org/10.3390/ijerph18105325

Spitzer, R. L., Kroenke, K., Williams, J. B. W., & Löwe, B.,A brief measure for assessing generalized anxiety disorder: the GAD-7. Archives of Internal Medicine, 166(10), 1092-1097. https://doi.org/10.1001/archinte.166.10.1092..

Tiller, J. W. G. (2013). Depression and anxiety [article]. *Medical Journal of Australia, 199*(6), 28–31. https://doi.org/10.5694/mjao12.10628

Van Borkulo, C. D., Van Bork, R., Boschloo, L., Kossakowski, J. J., Tio, P., Schoevers, R. A., Borsboom, D., & Waldorp, L. J.,Comparing Network Structures on Three Aspects: A Permutation Test. Psychological Methods. https://doi.org/10.1037/met0000476..

Wang, Y., Hu, Z., Feng, Y., Wilson, A., & Chen, R. (2020). Changes in network centrality of psychopathology symptoms between the COVID-19 outbreak and after peak [Article]. *Molecular Psychiatry, 25*(12), 3140–3149. https://doi.org/10.1038/s41380-020-00881-6

Wang, W., Wang, J., Zhang, X., Pei, Y., Tang, J., Zhu, Y., et al. (2023). Network connectivity between anxiety, depressive symptoms and psychological capital in Chinese university students during the COVID-19 campus closure. *Journal of Affective Disorders, 329*, 11–18. https://doi.org/10.1016/j.jad.2023.02.087

Wei, X., An, F., Liu, C., Li, K., Wu, L., Ren, L., et al. (2023). Escaping negative moods and concentration problems play bridge roles in the symptom network of problematic smartphone use and depression [Article]. *Frontiers in Public Health, 10*. https://doi.org/10.3389/fpubh.2022.981136. Article 981136.

Xiong, P., Ming, W.-k., Zhang, C., Bai, J., Luo, C., Cao, W., et al. (2021). Factors influencing mental health among Chinese medical and non-medical students in the early stage of the COVID-19 pandemic [article]. *Frontiers in Public Health, 9*. https://doi.org/10.3389/fpubh.2021.603331. Article 603331.

Zhang, K., Peng, Y., Zhang, X., & Li, L. (2021). Psychological burden and experiences following exposure to COVID-19: A qualitative and quantitative study of Chinese medical student volunteers [article]. *International Journal of Environmental Research and Public Health, 18*(8). https://doi.org/10.3390/ijerph18084089. Article 4089.

Zhang, J., Zhang, X., Zhang, K., Lu, X., Yuan, G., Yang, H., et al. (2022). An updated of meta-analysis on the relationship between mobile phone addiction and sleep disorder. *Journal of Affective Disorders, 305*, 94–101. https://doi.org/10.1016/j.jad.2022.02.008

Zhong, Y., Ma, H., Liang, Y. F., Liao, C. J., Zhang, C. C., & Jiang, W. J. (2022). Prevalence of smartphone addiction among asian medical students: A meta-analysis of multinational observational studies. *International Journal of Social Psychiatry, 68*(6), 1171–1183. https://doi.org/10.1177/00207640221089535

Zou, Z., Wang, H., d'Oleire Uquillas, F., Wang, X., Ding, J., & Chen, H. (2017). Definition of substance and non-substance addiction. *Advances in Experimental Medicine and Biology, 1010*, 21–41. https://doi.org/10.1007/978-981-10-5562-1_2