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Relationship between depression, smartphone addiction, and sleep among Chinese engineering students during the COVID-19 pandemic

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Abstract

BACKGROUND

Existing research has demonstrated that depression is positively related to smartphone addiction, but the role of sleep has not been discussed thoroughly, especially among engineering undergraduates affected by the coronavirus disease 2019 pandemic.

AIM

To evaluate sleep as a mediator of the association between smartphone addiction and depression among engineering undergraduates.

METHODS

Using a multistage stratified random sampling method, a cross-sectional survey was conducted among 692 engineering undergraduates from a top engineering university in China, and data were collected by self-reported electronic questionnaires. The data included demographic characteristics, such as age, gender, the Smartphone Addiction Scale-Short Version (SAS-SV), the 9-item Patient Health Questionnaire, and the Pittsburgh Sleep Quality Index. Pearson correlation and multiple linear regression analyses were used to examine the association between smartphone addiction and depression, while structural equation models were established to evaluate the possible mediating role of sleep.

RESULTS

Based on the cutoffs of the SAS-SV, the rate of smartphone addiction was 63.58 percent, with 56.21 percent for women and 65.68 percent for men, among 692 engineering students. The prevalence of depression among students was 14.16 percent, with 17.65 percent for women, and 13.18 percent for men. Smartphone addiction was positively correlated with depression, and sleep played a significant mediating effect between the two, accounting for 42.22 percent of the total effect. In addition, sleep latency, sleep disturbances, and daytime dysfunction significantly mediated the relationship between depression and smartphone addiction. The mediating effect of sleep latency was 0.014 [$P < 0.01$; 95% confidence interval (95%CI) = 0.006, 0.027], the mediating effect of sleep disturbances was 0.022 ($P < 0.01$; 95%CI = 0.011, 0.040), and the mediating effect of daytime dysfunction was 0.040 ($P < 0.01$; 95%CI = 0.024, 0.059). The influence of sleep latency, sleep disturbances, and daytime dysfunction accounted for 18.42%, 28.95%, and 52.63% of the total mediating effect, respectively.

CONCLUSION

The results of the study suggest that reducing excessive smartphone use and improving sleep quality can help alleviate depression.

Key Words: Smartphone addiction; Depression; Pittsburgh Sleep Quality Index; Engineering students; COVID-19; Mediating effect

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Core Tip: This study described the prevalence of depression and smartphone addiction among engineering students during the coronavirus disease 2019 pandemic and analyzed the relationship between depression, smartphone addiction, and sleep. The results showed that there was an alarmingly high rate of smartphone addiction among

engineering students, and they suffered from mild depression on average. Smartphone addiction and poor sleep were significant factors affecting depression, and sleep mediated the relationship between smartphone addiction and depression, including sleep latency, sleep disturbances, and daytime dysfunction.

INTRODUCTION

The prevalence of depression among college students has aroused broad public concern. A review of studies demonstrated that the pooled prevalence of depressive symptoms was 34%[1]. A recent study of American college students showed that 48.14% experienced moderate to severe levels of depression[2], and the prevalence rate of depression among Chinese college students from 1997 to 2015 reached 23.8% on average[3]. Furthermore, 41.8% of Chinese college students struggled with depressive disorders during the coronavirus disease 2019 (COVID-19) pandemic[4], especially those in places at high risk of COVID-19 spread who showed more severe depressive symptoms[5].

In particular, engineering undergraduates reported higher levels of depression than students in other majors[6]. The heavy academic burden and long study time create tremendous psychological pressure[7]. Previous studies noted that engineering students were under higher pressure than students with nonengineering majors[8,9]. They also had a higher prevalence of depression[10] and suffered from more severe depressive symptoms[8]. Given the importance of engineering education to national development and the adverse mental health of engineering students, it is crucial to identify the influencing factors of engineering students' depression in the context of the COVID-19 pandemic to develop interventions to improve their mental health.

Smartphone addiction is considered a behavioral addiction and refers to an excessive use of smartphones that interferes with users' daily life and has harmful effects[11]. Evidence from China indicated that the prevalence of smartphone addiction among college students ranges from 20% to 50%[12-14]. Notably, smartphone addiction is associated with mental health problems[15]. Smartphone addicts may suffer from social

isolation and interpersonal relationship problems[16], musculoskeletal pain and neurological problems[17], emotion dysregulation[18], pressure, and anxiety[19], which may lead to depressive disorders. Previous empirical studies confirmed a positive correlation between depression and smartphone addiction[20,21], and smartphone addiction exerted a significant effect on depression in different countries and regions[22,23]. However, the mechanism of smartphone addiction's relationship to depression has not been thoroughly discussed, so analyzing the pathway between smartphone addiction and depression is still an important area of study.

Sleep serves as the basis of personal emotional and physical health[24], and empirical studies have verified that poor sleep quality is significantly correlated with depression[25-28]. Some longitudinal studies have indicated that sleep disturbance triggers depression[29]. Lack of sleep makes individuals more sensitive to emotional and stressful stimuli[30], further increasing their risk of depression. According to the gratification theory of the internet, individuals extend their smartphone use time to obtain a sense of satisfaction[31]. Rich smartphone applications also cause addiction in people and make them lose their sense of time[31]. Therefore, problems such as sleep delay, lack of sleep, and poor sleep quality are very likely to occur among college students. Empirical studies have proven that smartphone addiction correlates significantly with poor sleep quality[32,33] and is considered a risk factor for poor sleep quality[34]. The literature in the field also implies that sleep plays a mediating role in smartphone addiction and depression; however, this has not been thoroughly discussed.

There are several research gaps according to the review of relevant studies. First, most of these studies are based on the general population of college students or medical students. More pertinent research needs to be explicitly explored for students of different majors, such as engineering students. Second, college students' mental health status has considerably changed since the outbreak of COVID-19, with a large proportion of students suffering from severe depression and anxiety. Therefore, it is necessary to explore the changes in depression, mobile phone addiction, and sleep

status of college students under the influence of COVID-19 and investigate their relationship in this specific context. Third, the role of sleep in the relationship between mobile phone addiction and depression has been poorly analyzed. Although a few studies have confirmed that sleep mediates the relationship between smartphone addiction and depression[35], special attention has been given to engineering students, and the mediating role of sleep needs to be further discussed.

Therefore, this study carried out a cross-sectional survey among engineering students in the context of the COVID-19 pandemic. It adds to the literature mainly by analyzing the relationship between smartphone addiction, sleep, and depression among Chinese engineering students during COVID-19 and investigating the mediating role of sleep in the relationship between smartphone addiction and depression. Based on the extant empirical evidence, the present study hypothesized that there is a significant positive correlation between smartphone addiction and depressive symptoms (Hypothesis I) and that sleep significantly mediates the relationship between smartphone addiction and depression (Hypothesis II). Specifically, engineering students with higher levels of smartphone addiction in the context of the pandemic are more likely to struggle with sleep disorders, which further results in more severe depressive symptoms.

MATERIALS AND METHODS

Participants and procedure

The data were collected from an online survey of 692 engineering undergraduates at a top university in China in December 2021. This study adopted a multistage stratified random sampling method; first, five engineering schools were randomly selected from 25 engineering schools in the university, and then the respondents were randomly chosen according to the size of each school and the number of students in different years. Given the pandemic limiting the face-to-face investigation, the survey team sent electronic questionnaire links to the selected participants' mobile phone numbers or email accounts. All participants were notified of the purpose of the study and gave informed consent to participate. It took approximately 20 min on average to complete

the questionnaire, after which students received a cash reward ranging from 8 CYN to 15 CNY. To avoid duplications or fraud in the online survey, the links were exclusive to each student and automatically became invalid after students completed and submitted the questionnaire. Participants were required to complete all questions before submitting the questionnaire. The participants in the study were Chinese engineering undergraduates aged 18-24. The study was reviewed by the ethics committee of Tianjin University and used the STROBE cross-sectional reporting guidelines.

The final sample comprised 153 females (22.11%) and 539 males (77.89%). The age of students ranged from 18 to 24 years old, and the mean age was 20.804 years old (SD = 1.109). Students were distributed evenly from freshmen to seniors, with 76 (11.03%), 240 (34.83%), 231 (33.53%), and 142 (20.61%), respectively. Among them, 608 (87.86%) were of Han nationality, and 84 (12.14%) were ethnic minorities. There were 439 (63.44%) only children and 253 (36.56%) with siblings. In terms of home location, 122 students (17.63%) were from rural areas, and 570 students (82.37%) were from towns. There were 343 (49.57%) students whose fathers completed tertiary education and 349 (50.43%) students whose fathers never received higher education. Regarding the types of high schools, 524 students (75.72%) attended the best local high schools, and 24.28% attended other high schools.

Measures

Depression: Students' depression was measured using the Patient Health Questionnaire-9 (PHQ-9), a part of the PHQ measuring depressive mood. The PHQ is a 3-page questionnaire self-assessed by patients[36], among which the 9-item depression module is used to measure depressive symptoms. Each item in the PHQ-9 ranges from 0 (no) to 3 (almost every day), and the total score ranges from 0 to 27, with higher scores representing more severe depression[37]. Most studies divide depression scores into five categories based on the severity of depression for practical applications, namely, minimal depressive symptoms (0-4), mild depression (5-9), moderate depression (10-

14), moderately severe depression (15-19), and severe depression (20-27), and use a total score of no less than 10 as a reasonable threshold for screening depression[38].

Smartphone addiction: This study used the Smartphone Addiction Scale-Short Version (SAS-SV) to measure participants' smartphone addiction levels. The SAS-SV was adapted by Kwon *et al*[39] based on the SAS. They invited at least 6 experts to select 10 questions from the 33 questions in the SAS and verified that the CVI was greater than 0.78, and the average I-CVI and S-CVI/UA were 0.943 and 0.60. Kwon *et al*[39] verified a Cronbach's alpha correlation coefficient of 0.91 for the SAS-SV in Korea; thus, it was regarded as a suitable tool for assessing smartphone addiction. In this study, experts were invited to translate English SAS-SV questions into Chinese, and appropriate adaptations were made according to the actual situation. For example, in the original item, "constantly checking my smartphone so as not to miss conversations between other people on Twitter or Facebook", "Twitter or Facebook" was changed to "QQ or WeChat" to adapt to the Chinese context. The answers were reported on a 7-point scale, with 1 meaning "strongly disagree" and 7 meaning "strongly agree". The total SAS-SV scale ranges from 10 to 70. Previous studies confirmed that the critical values of male and female smartphone addiction were 31 and 33, respectively[40]. Since the original SAS-SV is a six-point scale with a score range of 10-60, the critical values of male and female smartphone addiction in the study are 36.2 and 38.5, respectively. SAS-SV has been proven reliable and valid in mainland China and Hong Kong. Luk *et al*[40] used the Chinese version of the SAS-SV to measure the smartphone use addiction of adults in Hong Kong and found that the SAS-SV had good internal consistency, with an α coefficient of 0.844. Cheung *et al*[41] tested the SAS-SV scale among Hong Kong children and adolescents, and the α coefficient was 0.86, indicating that the scale had good reliability and validity when applied to Chinese students.

Sleep quality: Sleep quality in the study was measured by the Pittsburgh Sleep Quality Index (PSQI), a 19-item self-assessment questionnaire. It included seven components:

sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The seven components, each scoring 0-3 points, constituted the sleep index, with higher scores denoting worse sleep quality[42].

Statistical analysis

First, descriptive statistical analysis was conducted to demonstrate the general situation of smartphone addiction, overall sleep quality, and depression among engineering students and to compare differences in gender subgroups with the t test. Second, the correlation between smartphone addiction, sleep, and depression was explored with Pearson's correlation analysis. Third, the influence of smartphone addiction on depression among engineering students was examined with multiple linear regression. Depression level was the outcome variable in the regression models, while smartphone addiction level and sleep quality was the core independent variables. It controlled for confounding variables such as students' age, gender, ethnicity, political status, only child status and family socioeconomic status. To identify the effects of different variables, we successively included control variables, smartphone addiction, and sleep in the multiple regression model. Specifically, Model 1, $Y = \beta_0 + \beta_1 x' + \varepsilon$, was developed first to include control variables on engineering students' depression. Mobile phone addiction was further included in Model 2, $Y = \beta_0 + \beta_1 x' + \beta_2 SA + \varepsilon$. The seven sleep index components were then incorporated into Model 3, $Y = \beta_0 + \beta_1 x' + \beta_2 SA + \beta_3 SleepQuality + \beta_4 SleepLatency + \beta_5 SleepDuration + \beta_6 HabitualSleepEfficiency + \beta_7 SleepDisturbances + \beta_8 SleepMedication + \beta_9 DaytimeDysfunction + \varepsilon$. Y denotes the level of depression of engineering students at college. SA represents the degree of smartphone addiction. "x'" represents the control variables, including students' age, gender, ethnicity, political status, only child status, family socioeconomic status, and whether their father received higher education. "ε" defines the error. Finally, a structural equation model was built to examine the mediating role of sleep in the relationship

between smartphone addiction and depression. Data analysis was performed by Stata SE 15.

RESULTS

Descriptive statistics and correlations of variables

Table 1 shows the mean and SD of depression, smartphone addiction, and overall sleep quality. The mean score of depression among engineering students was 5.082 (± 4.971); the average score of females was 5.425 (± 4.656), and the average score of males was 4.985 (± 5.056). In general, engineering students experienced mild depression at college, and there was no statistically significant difference in the mean level of depression between female and male students. Regarding the prevalence of depression (Figure 1), 54.91%, 30.92%, 8.82%, 3.61%, and 1.73% of the students exhibited minimal, mild, moderate, moderately severe, and severe depression, respectively. For female students, 82.36% had minimal or mild depression, while 3.92% had moderate or severe depression. For males, 86.83% had minimal or mild depression, whereas 5.76% struggled with moderately severe or severe depression. Given that the extant literature usually uses a PHQ-9 total score of no less than 10 to distinguish whether the participants suffer from depression, 14.16% of students experienced depression disorders (depression ≥ 10), and female and male students who suffered from depressive disorders accounted for 17.65% and 13.18%, respectively (Table 1, Figure 1).

The mean value of mobile phone addiction was 39.126 (± 11.252); the score for females was 39.000 (± 10.668), and the score of males was 39.161 (± 11.422). There was also no significant gender difference in the average mobile phone addiction level. It should be noted that 63.58% of engineering students were addicted to mobile phones, with 56.21% of females and 65.68% of males being addicted to mobile phones. The mean sleep quality score was 5.496 (± 2.827), with female students scoring 5.856 (± 3.023) and males scoring 5.393 (± 2.763). The sleep quality of females was significantly worse than that of males (P = 0.074). Specifically, among the seven components of the sleep quality

index, day dysfunction showed a significant gender difference, with girls having higher perceived day dysfunction than boys ($P < 0.010$).

In sum, smartphone addiction among engineering students was alarming, with more than 60% exhibiting smartphone addiction, which is higher than that reported by most studies in other countries[43-46]. In addition, engineering students suffered from mild depression on average, and female students had more serious sleep problems than males.

The correlation analysis shown in Table 2 demonstrated that depression was positively correlated with mobile phone addiction, with a coefficient of 0.330 ($P < 0.01$). There was also a positive correlation between depression and PSQI, with a coefficient of 0.503 ($P < 0.01$). Mobile phone addiction and PSQI were significantly positively correlated with a coefficient of 0.250 ($P < 0.01$). In addition, depression was positively correlated with the seven components of the sleep index, among which daytime dysfunction had the strongest correlation with a coefficient of 0.414. Mobile phone addiction had a statistically significant positive correlation with sleep quality, sleep latency, sleep disturbances, and daytime dysfunction, among which the strongest correlation was also with daytime dysfunction, with a coefficient of 0.246. The results revealed that depression, smartphone addiction, and sleep index were closely related. The increased risk of smartphone addiction might not only predict the deterioration of sleep quality but also lead to an increase in depressive mood (Table 2).

Multivariate regression of depression on smartphone addiction and sleep

The regression model sequentially included the control variables, mobile phone addiction, and sleep index (Table 3). Model 1 shows the influence of engineering students' age, gender, nationality, political status, household registration, and other factors on depression ($R^2 = 0.011$). Model 2 further displays the impact of smartphone addiction and control variables on depression ($R^2 = 0.116$). For every one-point increase in the mobile phone addiction score, the average depression score increased significantly by 0.141 among engineering students. Model 3 depicts the influence of the

seven components of the sleep index, mobile phone addiction, and control variables (R^2 = 0.352). Sleep latency, sleep duration, sleep disturbance, sleep medication, daytime dysfunction, and smartphone addiction significantly affected the depressive mood of students, among which sleep disturbances had the most considerable effect. For every additional point scored by the sleep disturbances, the average depression score of students increased significantly by 1.817. The regression coefficient of smartphone addiction on depression in Model 3 was lower than that in Model 2, indicating that smartphone addiction may indirectly affect depressive mood by affecting sleep quality (Table 3).

Path analysis

This study further established a structural equation model of mobile phone addiction, sleep index, and depression based on correlation and regression analyses to explore possible mediating effects (Figure 2). According to the results in Table 4, the total effect of smartphone addiction on depression was 0.180 (P < 0.01; 95%CI= 0.134, 0.233), with the direct effect of smartphone addiction on depression being 0.104 (P < 0.01; 95%CI = 0.063, 0.149), accounting for 57.78% of the total effect. The mediating effect of sleep on the relationship between mobile phone addiction and depression was 0.076 (P < 0.01; 95%CI = 0.053, 0.102), accounting for 42.22% of the total. Specifically, the mediating effect of sleep latency was 0.014 (P < 0.01; 95%CI = 0.006, 0.027), the mediating effect of sleep disturbances was 0.022 (P < 0.01; 95%CI = 0.011, 0.040), and the mediating effect of daytime dysfunction was 0.040 (P < 0.01; 95%CI = 0.024, 0.059). The influence of sleep latency, sleep disturbances, and daytime dysfunction accounted for 18.42%, 28.95%, and 52.63% of the total mediating effect, respectively (Figure 2, Table 4).

DISCUSSION

This study analyzed the relationship between smartphone addiction and depression among engineering students, which has been extensively discussed in the extant literature, yet the underlying mechanisms need to be further explored and verified in

diverse contexts and among different populations. The results generally support the hypotheses that smartphone addiction is a significant predictor of depression and that sleep mediates the effect of smartphone addiction on depression. Therefore, alleviating smartphone addiction and improving sleep quality could be an effective strategy to reduce the incidence of depression among engineering students.

The study found a high prevalence rate of smartphone addiction of 63.58% among engineering students in China, with that of male students at 65.68% and female students at 56.21%. The addiction rate appeared to be much higher than in other regions or populations, such as 11.8% in Taiwan[47], 36.8% in Nepal[48], and 41.93% of medical students in Asian countries[49]. There are two reasons for our study's high prevalence of smartphone addiction apart from different cultural backgrounds or various measurement tools. First, given that engineering students usually confront heavy learning tasks and relatively poor face-to-face communication, smartphones might be essential for them to release pressure and maintain social networking. Second, the survey was conducted amid the coronavirus pandemic, which may have exacerbated smartphone addiction among college students. Indeed, the risk of smartphone addiction increased due to the fear of contracting the disease, reduced social interactions due to lockdowns, and long hours of online education. Previous empirical studies confirmed that the smartphone addiction rate of college students in the beginning and fading periods of the pandemic was significantly lower than that in the severe period[50]. It should also be noted that the gender difference in mobile phone addiction in this study was insignificant, inconsistent with existing research findings[24]. This may be due to the small percentage of female engineering students and the widespread influence of online teaching on engineering students.

The prevalence of depression among engineering students in the study was 14.16%, and most students (85.83%) experienced minimal or mild depression during COVID-19. Relevant research found that the prevalence rate of depression among college students was 9.0% in China one month after the outbreak of COVID-19[51] and 34.19% in Spain in March 2020[52]. Forty-four percent of students experienced some depressive thoughts

during the COVID-19 pandemic in the United States[53]. The prevalence of depression among engineering students in this study was within the rate range of previous studies, which may be related to the time of the survey. The study was conducted in December 2021, when the pandemic spread was effectively contained, and college students returned to school. The general situation had improved at this stage, and relevant fear and worries had been alleviated, although their study life was still partially affected by the pandemic.

Pearson correlation and multiple regression analysis verified Hypothesis I that smartphone addiction was a significant influencing factor of depression and that high levels of smartphone addiction caused more serious depressive symptoms among engineering students. The result was consistent with most previous studies that there was a positive correlation between mobile phone addiction and depression[21,22,54,55]. The influence of smartphone addiction on depression can be explained by the effect on physiological health and social relations. First, smartphone addiction may result in individuals' unhealthy states, including physical pain, sleep disorders, and inattention, leading to mental health problems such as depression[56]. Second, the overuse of smartphones may increase social isolation and aggravate social anxiety due to the reduction of face-to-face communication and the narrowing of social circles, thus increasing the risk of depression, according to displacement theory and Sullivan's interpersonal theory[57]. The longitudinal study by Herrero *et al*[58] strongly confirmed that smartphone addiction negatively affected college students' social support over time and generated high levels of depression.

For smartphone addiction as a predictor of poor sleep outcomes, the findings agree with most relevant research[59,60]. The overuse of smartphones may expose individuals to blue light from screens for a long time, affecting melatonin levels and thus normal circadian rhythm[61]. Furthermore, when users browse social networking sites through smartphones, the intensity of emotional synchronization may be amplified, resulting in emotional contagion[62]. Smartphone addiction affects the emotions of mobile phone users[35] and increases their psychological pressure[63], thus affecting their normal sleep

procedure. In particular, the continuous use of smartphones may lead to bedtime procrastination[31]. The study also found that smartphone addiction was related to sleep quality but not sleep duration, which is consistent with the findings of relevant studies in this field[21,64,65].

Poor sleep positively predicted depressive symptoms in engineering students, especially the components of sleep latency, sleep duration, sleep disturbances, sleep medication, and daytime dysfunction. This finding partially coincides with prior studies[66,67]. Hypothesis II confirms that sleep plays a mediating role in the effect of smartphone addiction on depression, especially sleep latency, sleep disturbances and daytime dysfunction. In fact, poor sleep may affect the emotional regulation ability of the individual through a physiological mechanism[68], and a lack of sleep increases the threat across multiple domains of dysfunction[69]. Sleep is associated with depression at the molecular and neurophysiological levels, and abnormalities in these neurotransmitter systems associated with sleep disorders may contribute to the exacerbation of depression[70]. In addition, sleep disorders affect students' daytime function, resulting in daytime sleepiness, drowsiness, and inattention. This interferes with students' daily tasks and reduces their interest in activities, exposing them to stress and irritability and worsening depressive symptoms[67].

The role of daytime dysfunction was noticeable in both the direct and indirect effects of depression. The influence of daytime dysfunction on depression has been partially confirmed by studies[71,72]. Daytime dysfunction can be regarded as the primary link between night sleep and depression[73]. In fact, daytime dysfunction is closely related to fatigue and burnout[74]. People with high levels of daytime dysfunction tend to be more tired and therefore more vulnerable to depressive moods.

This study suggests that colleges and universities can alleviate depression among students by intervening in smartphone addiction and improving sleep. Studies have discussed effective interventions to reduce smartphone addiction, such as self-awareness and self-control, involuntary restriction, and peer support[75]. College students in adulthood should be soberly aware of the harm of smartphone addiction

and seek scientific interventions when necessary. For instance, cognitive behavioral therapy (CBT) was proven effective in a meta-analysis of treatment interventions for adolescents with internet addiction[76]. The group mindfulness-based cognitive-behavioral intervention[77] and mind-body exercise (ME)[78] have been shown to be helpful in the intervention of smartphone addiction among Chinese college students. Thus, cognitive behavioral interventions and MEs (*e.g.*, QigongBaduanjin) should be encouraged. For involuntary restraint, using technology against it, a new mode of intervention for treating smartphone addiction, focuses on monitoring and limiting the use of smartphones with functionalities built into the smartphone and third-party apps. Empirical studies have found that ways to limit notifications and reduce screen time are becoming more widely accepted[79,80]. Social support, such as favorable peer relationships and harmonious family relationships, is also a protective factor against smartphone addiction[81]. In addition, colleges and universities should also make efforts to expand the accessibility of mental health services to alleviate smartphone addiction.

In addition, physical exercise is the most common way to enhance sleep quality, and sleep therapy training is also practical in improving the sleep situation of college students[82]. For example, sleep training programs for university students with sleep problems proved feasible to significantly enhance students' sleep quality[83]. Psychological interventions such as cognitive behavior therapy for insomnia (CBT-I) have also been recommended to improve sleep[84]. Other interventions, such as improving sleep hygiene, relaxation, mindfulness and hypnotherapy, also play a role in improving sleep quality[85]. Therefore, college students should be encouraged to strengthen their physical exercise, improve their sleeping conditions and restrict mobile phone use to ensure sleep time and quality. For students with serious sleep problems, necessary psychological intervention and medical treatment should be carried out in time to avoid deterioration of the problem and more severe sleep disorders and psychological problems.

The study has several limitations. First, the self-reported data by students may have measurement errors. For example, students may underestimate their smartphone

addiction tendency, sleep disorders, and depressive symptoms. Second, other possible influencing factors of depression, such as stress and self-esteem, were not included in this study's analysis framework for assessment. Third, there may exist sample selection bias in the analysis results since written informed consent was obtained before students entered the questionnaire, and those who refused to consent were not included in the sample of this study. Fourth, the cross-sectional data used in this study make it difficult to identify the causal relationship between smartphone addiction and depression. Future studies may investigate the causal relationship between smartphone addiction and depression based on longitudinal data and incorporate more factors into the theoretical mechanisms to discover more effective measures.

CONCLUSION

This cross-sectional study investigated the relationship between smartphone addiction and depression and examined the mediating role of sleep among engineering students in China. First, there was an alarmingly high rate of smartphone addiction among engineering students with no significant gender difference, which has become an urgent issue requiring attention from all parties. In addition, engineering students suffered from mild depression on average, and female students had more severe sleep problems than males. Second, smartphone addiction and sleep deterioration were significant factors affecting depression among engineering students, which might increase the risk of their depressive disorders. Third, sleep latency, sleep disturbances, and daytime dysfunction mediated the relationship between smartphone addiction and depression, among which daytime dysfunction had the most pronounced mediating effect.

The effects of smartphone addiction and sleep on depression may be complicated. Existing literature has confirmed that smartphone addiction could increase the risk of individual depression not only through social reasons (such as social difficulties and task conflicts) but also by affecting physiological functions (such as insomnia and physical pain). In addition, the mediating role of sleep should be considered

thoroughly. Sleep disorders can increase the risk of depression by influencing students' emotional control and regulation function or affecting their learning behaviors. Therefore, depression can be alleviated by reducing the use of smartphones and improving sleep quality. Colleges and universities can take measures to relieve depressive problems and improve engineering students' mental health, such as enhancing their self-control ability, restricting mobile phone use, creating a soothing sleep environment, developing a daily routine, and improving physical fitness.

Figure Legends

Figure 1 Prevalence of depression among engineering students. n = 692.

Figure 2 Structural equation model of depression. n = 692.

Table 1 Descriptive statistics of depression, smartphone addiction and sleep (n = 692)

Variables	All		Female		Male		Test statistic	*P* value
	Mean	SD	Mean	SD	Mean	SD		
Depression	5.082	4.971	5.425	4.656	4.985	5.056	-0.966	0.335
Smartphone Addiction	39.126	11.252	39	10.668	39.161	11.422	0.157	0.876
Pittsburgh Sleep Quality Index	5.496	2.827	5.856	3.023	5.393	2.763	-1.790	**0.074**
Sleep quality	0.990	0.731	1.059	0.771	0.970	0.718	-1.323	0.186
Sleep latency	0.906	0.858	0.928	0.897	0.900	0.848	-0.360	0.719
Sleep duration	1.009	0.766	1.052	0.768	0.996	0.766	-0.797	0.426
Habitual sleep efficiency	0.201	0.542	0.190	0.483	0.204	0.558	0.293	0.770
Sleep disturbances	0.883	0.574	0.915	0.584	0.874	0.571	-0.784	0.434
Sleep medication	0.104	0.441	0.111	0.467	0.102	0.434	-0.224	0.823
Day dysfunction	1.403	1.007	1.601	1.009	1.347	1.000	-2.771	**0.006**

Bold represents statistically significant.

Table 2 Correlation analyses among depression, smartphone addiction, and sleep (*n* = 692)

No.	Variable	1	2	3	4	5	6	7	8	9	10
1	Depression	1.000									
2	Smartphone addiction	0.330[a]	1.000								
3	Pittsburgh Sleep Quality Index	0.503[a]	0.250[a]	1.000							
4	Sleep quality	0.315[a]	0.153[a]	0.738[a]	1.000						
5	Sleep latency	0.334[a]	0.203[a]	0.676[a]	0.483[a]	1.000					
6	Sleep duration	0.164[a]	0.027	0.470[a]	0.204[a]	0.072[c]	1.000				
7	Habitual sleep efficiency	0.090[b]	0.060	0.378[a]	0.151[a]	0.156[a]	0.226[a]	1.000			
8	Sleep disturbances	0.369[a]	0.182[a]	0.539[a]	0.311[a]	0.351[a]	0.091[b]	0.104[a]	1.000		
9	Sleep medication	0.232[a]	0.036	0.373[a]	0.219[a]	0.194[a]	-0.007	0.076[b]	0.191[a]	1.000	
10	Daytime dysfunction	0.414[a]	0.246[a]	0.664[a]	0.425[a]	0.272[a]	0.179[a]	0.016	0.210[a]	0.140[a]	1.000

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[a]$P < 0.01$;

[b]$P < 0.05$;

[c]$P < 0.10$.

Table 3 Multiple linear regression of depression (*n* = 685)

Variables	Model 1	Model 2	Model 3
Sleep quality	-	-	0.158
Sleep latency	-	-	**0.587[a]**

Sleep duration	-	-	**0.471**[b]
Habitual sleep efficiency	-	-	0.185
Sleep disturbances	-	-	**1.817**[a]
Sleep medication	-	-	**1.436**[a]
Daytime dysfunction	-	-	**1.304**[a]
Smartphone addiction	-	**0.141**[a]	**0.082**[a]
Age	-0.130	-0.113	-0.066
Gender	0.526	0.602	0.112
Nationality	-0.524	-0.570	-0.292
Political status	0.435	-0.035	-0.102
Only child	-0.279	-0.047	0.092
Home location	-0.557	-0.668	-0.392
Family socioeconomic status	-0.170	-0.153	-0.181
Father' education	-0.115	-0.152	0.228
Observations	685	685	685
Adjusted R^2	0.011	0.116	0.352

[a]$P < 0.01$;

[b]$P < 0.05$;

[c]$P < 0.10$.

Bold represents statistically significant. Gender: 0 = male, 1 = female. Nationality: 0 = minority nationality, 1 = Han nationality. Political status: 0 = nonparty member, 1 = Communist Party member; only child: 0 = siblings; 1 = only child. Home location: 0 = rural, 1 = town. Family socioeconomic status: 1 = lower, 2 = lower middle, 3 = middle, 4 = upper middle, 5 = upper. Father's educational level: 0 = never receiving higher education, 1 = completing higher education.

Table 4 Bootstrapping indirect effect and 95% confidence interval for mediation model (*n* = 692)

Effect path	Estimated effect	*P* value	Standard Errors	95%CI
Total effects	0.180	**0.001**	0.025	0.134, 0.233

Smartphone addiction-depression	0.104	**0.001**	0.022	0.063, 0.149
Smartphone addiction-sleep latency/sleep; disturbances/daytime dysfunction-depression	0.076	**0.001**	0.012	0.053, 0.102
Smartphone addiction-sleep latency-depression	0.014	**0.001**	0.005	0.006, 0.027
Smartphone addiction-sleep disturbances-depression	0.022	**0.000**	0.007	0.011, 0.040
Smartphone addiction-daytime dysfunction-depression	0.040	**0.001**	0.009	0.024, 0.059

Bold represents statistically significant. 95%CI: 95% confidence interval.

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