

# The Impact of Problematic Smartphone Use on Sleep Quality Among Chinese Young Adults: Investigating Anxiety and Depression as Mediators in a Three-Wave Longitudinal Study

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**Background:** Sleep disorders are a significant health issue that urgently needs to be addressed among undergraduate students, and one of the potential underlying problems could be problematic smartphone use (PSU). This study aimed to clarify the relationship between PSU and poor sleep quality by investigating the independent and serial mediating roles of anxiety and depressive symptoms in a population of university students in Tibet, China.

**Methods:** A total of 2993 Tibetan college students completed three waves of data surveys, with all participants completing questionnaires on PSU, anxiety, depressive symptoms, and sleep quality (Time 1 (T1) -Time 3 (T3)). Bootstrapped mediation analysis was used to explore the mediating role of anxiety and depressive symptoms in the longitudinal relationship between PSU and sleep quality.

**Results:** Both direct and indirect effects of PSU on poor sleep quality were found. PSU (T1) can had not only a direct negative influence on poor sleep quality (T3) among young adults (direct effect = 0.021, 95% CI = 0.010–0.033) but also an indirect negative impact via three pathways: the independent mediating effect of anxiety symptoms (T2) (indirect effect 1 = 0.003, 95% CI = 0.001–0.006), the independent mediating effect of depressive symptoms (T2) (indirect effect 2 = 0.004, 95% CI = 0.002–0.006), and the serial mediating effects of anxiety (T2) and depressive symptoms (T2) (indirect effect 3 = 0.008, 95% CI=0.005–0.011).

**Conclusion:** These findings highlight the role of anxiety and depression symptoms as joint mediating factors in the relationship between PSU and sleep disturbances. Interventions focused on improving sleep that incorporate behavioural measures could benefit from treatment approaches targeting mental disorders.

**Keywords:** sleep quality, problematic smartphone use, anxiety, depressive symptoms, longitudinal study

## Introduction

Sleep disorders have become a significant public health issue in society. According to a report by the World Health Organization, one-third of the global population is affected by sleep disturbances.<sup>1-3</sup> Sleep disorders can have short-term effects such as mood disturbances, decreased attention, and somatic symptoms. Long-term sleep issues may be associated with physiological and psychological problems, including cardiovascular diseases, metabolic disorders, and an increased risk of suicide.<sup>3,4</sup> University students are in a transitional stage from adolescence to adulthood, a phase known as “emerging

adulthood”, which is crucial for the development of various health behaviours that are important for their future adulthood and throughout their lifespan.<sup>5</sup> University students face numerous challenges such as interpersonal adaptation, academic pressure and financial stress, and may be at high risk for a variety of psychological issues and unhealthy behaviours.<sup>5</sup> Similarly, sleep problems are widespread among this group. A meta-analysis incorporating 57 studies showed that the average sleep duration for Chinese university students is 7.08 hours. The proportions of students sleeping less than 6 hours and 7 hours were 8.4% and 43.9%, respectively. The percentage of students who took more than 30 minutes to fall asleep is 25.5%. The average bedtime was at 00:51 AM, with approximately 23.8% of students going to bed after midnight.<sup>6</sup> Although sleep problems among university students are serious, effective measures for addressing these problems are lacking.

In recent years, while attention has been given to the effects of sleep on “downstream” health or disease outcomes, an increasing number of studies have focused on the determinants or “upstream” factors of sleep disorders.<sup>4</sup> Interventions targeting these modifiable behavioral lifestyle factors are highly important for maintaining sleep health. Among the factors influencing sleep disorders, the impact of excessive smartphone use on sleep has increasingly received scholarly attention.

As a notable type of technology, smartphones have become ubiquitous, providing convenience for people while also bringing about negative consequences that cannot be ignored. The excessive use of smartphones, inability to control the dependence on smartphones, and resulting impairment of daily functions can be termed problematic smartphone use (PSU).<sup>7,8</sup> Although PSU has not been classified as a clinical disorder, its manifestations are similar to the symptoms of internet gaming addiction and substance abuse as described in the Diagnostic and Statistical Manual of Mental Disorders (DSM-V).<sup>9</sup> The relationship between PSU and sleep disturbances has been extensively studied. The excessive use of smartphones, especially before bedtime, can delay sleep onset, disrupt sleep rhythms, and reduce total sleep duration. Studies have shown that the excessive use of smartphones increases exposure to blue light, which suppresses the secretion of melatonin, leading to disruptions in circadian rhythms and sleep problems, and may also be closely related to mental issues such as depression.<sup>10</sup> Multiple studies, including cross-sectional and longitudinal studies focusing on college students, have shown that PSU can significantly predict the risk of developing sleep disorders.<sup>11–14</sup> For instance, in a study involving 1181 college students, baseline smartphone addiction significantly predicted bedtime procrastination and poor sleep quality one year later.<sup>12</sup> This singular prediction of sleep quality by smartphone addition differs from the bidirectional predictive relationship found between the two variables in another study.<sup>15</sup> Given the current lack of consensus on the longitudinal predictive relationship between PSU and sleep quality, it is necessary to further explore the relationship between the two. Additionally, in addition to directly affecting sleep, PSU might serve as an aversive emotional avoidance strategy, indirectly impacting sleep health through negative psychological states such as anxiety and depressive symptoms.

Anxiety and depression disorders are very common mental health issues among college students, and both may independently mediate the relationship between PSU and sleep quality. Anxiety disorders refer to feelings of fear, distress, and panic caused by external objective factors or the subjective thoughts of an individual;<sup>16</sup> depression disorders are characterized by low spirits, loss of interest, self-deprecation, and despair.<sup>17</sup> A large number of cross-sectional studies have reported a positive correlation between PSU and anxiety/depression, and cohort studies have further shown that PSU can increase the risk of anxiety and depression.<sup>18,19</sup> Moreover, existing research evidence suggests that individuals with anxiety and depression are more prone to experiencing poor sleep quality, indicating that mental illnesses may serve as characteristic markers of a high-risk population for sleep issues.<sup>20</sup> Furthermore, since sleep problems are core symptoms of specific anxiety and depression disorders according to the fourth edition of the Diagnostic and Statistical Manual for Mental Disorders (DSM-IV), chronic sleep disorders accompanied by mental illness are commonly observed in both clinical and nonclinical populations.<sup>21</sup>

Previous cross-sectional studies have independently explored the mediating roles of anxiety or depression in the relationship between PSU and sleep quality.<sup>22,23</sup> A cross-lagged study based on two waves of panel data suggested that the individual mediating roles of anxiety or depression is only one aspect explaining the relationship between smartphone addiction and sleep quality.<sup>12</sup> Considering the common genetic susceptibility and comorbidity rates, anxiety and depression have a high rate of co-occurrence.<sup>24,25</sup> Anxiety can be considered a significant cause of depression.<sup>26</sup> Both cohort studies and meta-analyses have shown that anxiety can effectively predict future depressive symptoms, and vice versa.<sup>26,27</sup> Furthermore, compared to individual symptoms, the combination of these two emotional disorders leads to poorer social and psychological functioning, lower perceived quality of life, and a greater burden of illness.<sup>28</sup> The

individual and combined effects of both anxiety and depression play a significant role in explaining the relationships between other independent variables and outcomes.<sup>29–31</sup> The impact of excessive smartphone dependence on sleep quality may be influenced by symptoms of anxiety and/or depression. To some extent, sleep quality depends on people's lifestyles and the extent to which diseases affect various aspects of life. Whether the effect of PSU on sleep quality operates through symptoms of anxiety and/or depression deserves in-depth exploration.

In general, numerous studies have investigated the pathways through which PSU impacts sleep, including the independent mediating roles of depressive or anxiety symptoms.<sup>12,14,32–34</sup> However, to our knowledge, the majority of earlier investigations into the mechanisms by which smartphone use impacts sleep have employed cross-sectional designs or, at most, two-wave longitudinal studies. These studies have primarily focused on the individual mediating roles of anxiety or depression in this relationship. However, such approaches may not fully capture the dynamic and potentially cumulative effects these factors exert over time. In contrast, utilizing data from a three-wave survey is very necessary for a more nuanced and comprehensive understanding of how these variables interact across multiple points in time. Furthermore, our unique demographic and highland environmental background adds a degree of novelty. In highland areas characterized by high altitude, low oxygen, extreme cold, and low atmospheric pressure, the occurrence of anxiety and depression is significantly higher than in plains areas,<sup>35</sup> and it is only recently that this topic has begun to attract attention. This study used data from a three-wave survey of university students at two universities in Tibet, China, to explore the independent and joint mediating effects of anxiety and depressive symptoms. We hypothesize that anxiety symptoms at Time 2 (T2) would mediate the relationship between PSU at Time 1 (T1) and sleep quality at Time 3 (T3) (Hypothesis 1); depressive symptoms at Time 2 (T2) would mediate the relationship between PSU at Time 1 (T1) and sleep quality at Time 3 (T3) (Hypothesis 2); and anxiety and depressive symptoms at T2 would play a serial mediating role in the relationship between PSU at T1 and sleep quality at T3 (Hypothesis 3).

## Methods

### Participants and Procedure

This study was conducted in June, September, and December 2021 first-year and second-year students were selected from two universities in the Tibet Autonomous Region to complete questionnaire surveys and follow-up research. The students participated on a voluntary basis and provided informed consent, and they could withdraw from the study at any time during the follow-up. Before the survey, the research team members communicated with the relevant leaders of each participating college and the instructors responsible for student affairs. The instructors then preformed the student representatives and their respective classes about the purpose and significance of the survey, emphasizing the principle of voluntariness. Members of the research team and graduate students who had undergone on-site questionnaire training coordinated the survey timing with the instructors and student representatives. The students were then gathered in classrooms, where a paperless questionnaire (wenjuanxing) was administered. QR codes for the questionnaire were distributed to the students, who completed the questionnaire anonymously. During the implementation of the survey, if students had any questions, they were addressed on the spot by the survey team members or trained surveyors. The questionnaire took approximately 18 minutes to complete. For students who did not come to the classroom, trained student representatives from their respective colleges introduced the survey method and content, guiding the students through the questionnaire completion and submission process. A total of 2993 students participated in the three surveys.

## Measures

### Sleep Quality

The widely-used Chinese version of the Pittsburgh Sleep Quality Index (PSQI) self-rating scale was adopted to measure students' sleep quality and disturbances over the past month. The PSQI comprises 19 items, divided into seven component scores: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The score for each component ranges from 0 to 3 points. The total PSQI score ranges from 0 to 21, with a higher score indicating poorer sleep quality.<sup>36,37</sup> The PSQI has been extensively used in the Chinese population and has good validity and reliability, with an overall reliability coefficient of 0.82–0.83. In the

Chinese population, a PSQI total score exceeding 7 points indicates poor sleep quality or sleep disturbances.<sup>37</sup> This self-rating scale was utilized at T1-T3.

### Problematic Smartphone Use

Smartphone use behaviours comprises smartphone dependence and usage duration. This was assessed using the short version of the Smartphone Addiction Scale<sup>38</sup> (Smartphone Addiction Scale-short Version, SAS-SV). The scale was originally constructed by Kwon and others, mainly to evaluate smartphone use problems.<sup>39</sup> Researchers created a simplified version of the scale with 10 items based on the original 33 items. The SAS-SV has been widely applied in different cultural contexts and includes aspects such as daily life impact, withdrawal, and tolerance.<sup>40</sup> Examples include “I constantly check my smartphone so as not to miss new messages from social apps such as WeChat, Weibo, and QQ” and “I feel impatient and restless when my smartphone is not within reach”. A six-point Likert scale is used for each item, with scores ranging from 1 to 6: “strongly disagree”, “disagree”, “somewhat disagree”, “somewhat agree”, “agree”, and “strongly agree”. The total score for the scale ranges from 10 to 60 points, with a higher score indicating a greater degree of smartphone dependence. According to previous literature, cut-off scores of  $\geq 31$  (for males) and  $\geq 33$  (for females) are used to determine smartphone use dependence, reflecting the smartphone dependence situation among university students.<sup>39,40</sup> The Chinese short version of the Smartphone Addiction Scale has good reliability and validity.<sup>38</sup> The Cronbach’s alpha in this scale was 0.912 at T1.<sup>31</sup>

### Anxiety Symptoms

Anxiety symptoms were assessed using the Generalized Anxiety Disorder-7 (GAD-7) scale. In this scale, Cronbach’s alpha coefficient of the GAD-7 at T1-T3 was 0.935–0.937. This scale was originally developed by Spitzer et al and is widely used due to its simplicity, ease of administration, and scoring ability.<sup>41</sup> The frequency of seven core symptoms over the past two weeks is assessed through seven items scored on a 4-point Likert scale, ranging from “not at all = 0” to “nearly every day = 3”. The total score for the GAD-7 ranges from 0 to 21. A score exceeding 10 points is considered indicative of anxiety symptoms.<sup>41</sup> The higher the score, the greater the severity of anxiety.

### Depressive Symptoms

The assessment of depressive symptoms was conducted using the Patient Health Questionnaire-9 (PHQ-9), a scale composed of 9 items, reflecting the occurrence of symptoms over the past 14 days. The response options for each item include “Not at all (scored 0)”, “Several days (1 point)”, “More than half the days (2 points)”, and “Nearly every day (3 points)”. The total score of the scale ranges from 0 to 27, with higher scores indicating more severe depressive symptoms. A score exceeding 10 points is considered indicative of depressive symptoms.<sup>42</sup> The scale has good reliability and validity.<sup>42</sup> In T1-T3, the Cronbach’s alpha coefficient in our scale was 0.920–0.921.<sup>31</sup>

### Covariates

This study collected data on multiple baseline demographic characteristics, interpersonal relationships, academic stress, and behavioral factors. Sex (male/female), age (years), place of origin (urban/rural), family economic status (better/average/poor), ethnicity (Han/Tibetan and others), and parents’ marital status (harmonious/sometimes, frequent quarrels/separated, divorced/other) were all considered. The respondents’ relationships with their families, classmates, and teachers (all rated as better/average/poor) were evaluated. Previous studies have shown that sleep quality is strongly associated with students’ academic performance.<sup>43</sup> Considering the relationship between academic stress and sleep quality, drawing on previous methods of measuring academic stress,<sup>44,45</sup> we collected students’ academic stress levels by their self-assessed levels (1 = Minor, 2 = Moderate, and 3 = Major). A respondent who smoked at least once in the past month was considered a current smoker; a respondent who drank alcohol at least once in the past month was considered a current drinker.

### Statistical Analyses

Data analysis was conducted using SPSS V23.0. The basic demographic characteristics of the study participants at baseline are described. Qualitative data are presented as rates or percentages, while quantitative data are expressed as the mean  $\pm$  standard deviation. In the mediation analysis study, a sub dataset was established based on the original dataset. This sub dataset was created by excluding individuals with poor sleep quality at baseline (T1) and follow-up (T2) (PSQI score  $\geq 7$ ) and individuals with

anxiety (GAD-7 score  $\geq 10$ ) and depressive symptoms at baseline T1 (PHQ-9 score  $\geq 10$ ). Pearson correlation analysis was used for pairwise correlation analysis of the variables. SPSS PROCESS V3.3 Model 6 was used for the chain mediation analysis to explore the mediating role of anxiety and depressive symptoms in the relationship between PSU at T1 and sleep quality at T3. The significance of the mediation effect was tested using the bias-corrected bootstrap method, with 5000 bootstrap samples. A 95% bootstrap confidence interval that did not include 0, it was considered to indicate statistical significance.<sup>46</sup>

## Results

### Descriptive Analyses

Among the 2993 subjects included in the study, the average age at T1 was  $19.7 \pm 1.25$  years. There were 1007 (34.3%) male participants and 1926 (65.7%) female participants. Among the participants, 1267 (43.2%) were of Han ethnicity, 1583 (54.0%) were of Tibetan ethnicity, and 83 (2.8%) belonged to other minority ethnic groups. Regarding academic status, 1610 (54.9%) participants were first-year students, and 1383 (45.1%) were second-year students. In terms of self-assessed family economic status, 478 (16.3%) considered it good, 1540 (52.5%) considered it average, and 915 (31.2%) considered it poor. Among the participants, 304 (10.2%) were smokers, and 391 (13.1%) consumed alcohol. The basic demographic characteristics of the study subjects are summarized in Table 1.

Bivariate correlation analysis revealed that at T1, PSU was positively correlated with anxiety symptoms at T2 ( $r=0.20$ ,  $P<0.001$ ), depressive symptoms at T2 ( $r=0.23$ ,  $P<0.001$ ), and poor sleep quality at T3 ( $r=0.16$ ,  $P<0.001$ ). Furthermore, anxiety at T2 and depressive symptoms at T2 were positively correlated ( $r=0.76$ ,  $P<0.001$ ), as was poor sleep quality at T3 ( $r=0.34$ ,  $P<0.001$ ). Depressive symptoms at T2 and sleep quality at T3 were also positively correlated ( $r=0.39$ ,  $P<0.001$ ). Please refer to Table 2 for the detailed results.

**Table 1** The Basic Demographic Characteristics of the Study Subjects (n=2993)

Characteristics	n(%)	Characteristics	n(%)
<b>Sex</b>		<b>Relationships with families</b>	
Male	1007 (34.3)	Better	2634 (89.8)
Female	1926 (65.7)	Average	244 (8.3)
		Poor	55 (1.9)
<b>Age(years), M<math>\pm</math>SD</b>	2993 (19.7 $\pm$ 1.2)		
<b>Ethnicity</b>		<b>Relationships with classmates</b>	
Han	1267 (43.2)	Better	2467 (84.1)
Tibetan	1583 (54.0)	Average	437 (14.9)
Others	83 (2.8)	Poor	29 (1.0)
<b>Place of origin</b>		<b>Relationships with teachers</b>	
Urban	852 (29.0)	Better	2046 (69.8)
Rural	2081 (71.0)	Average	864 (29.5)
		Poor	23 (0.8)
<b>Family economic status</b>		<b>Smoked</b>	
Better	478 (16.3)	Yes	304 (10.2)
Average	1540 (52.5)	No	2629 (87.8)
Poor	915 (31.2)		

(Continued)

**Table 1** (Continued).

Characteristics	n(%)	Characteristics	n(%)
<b>Academic stress</b>		<b>Drank alcohol</b>	
Minor	454 (15.5)	Yes	391 (13.1)
Moderate	1160 (39.5)	No	2542 (86.9)
Major	1319 (45.0)		
<b>Parents' marital status</b>			
Harmonious	1686 (57.5)		
Sometimes, frequent quarrels	929 (31.7)		
Separated, divorced	184 (6.3)		
Other	134 (4.6)		

**Abbreviation:** M±SD, Mean ± Standard Deviation.

**Table 2** Variable Correlation Analysis

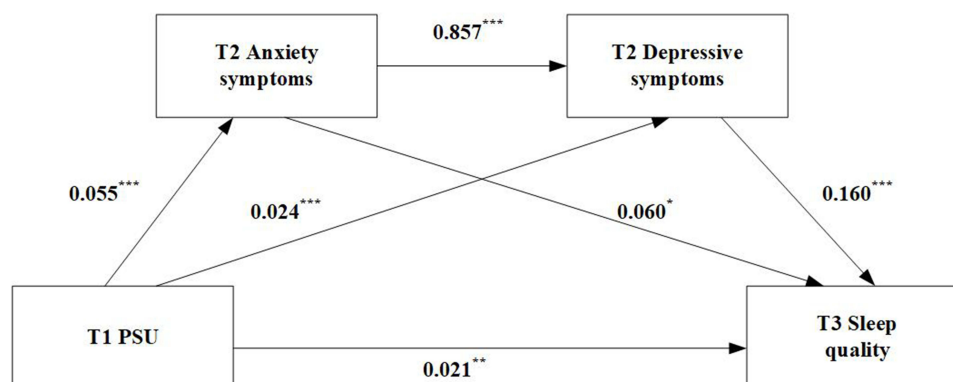
Variable	1	2	3	4
1.T1 PSU	1			
2.T2 Anxiety symptoms	0.20***	1		
3.T2 Depressive symptoms	0.23***	0.76***	1	
4.T3 Sleep quality	0.16***	0.34***	0.39***	1

**Note:** \*\*\* $p < 0.001$ .

**Abbreviation:** PSU, problematic smartphone use.

## Serial Mediation Model

From the original dataset, students with poor sleep quality at T1 and T2, as well as those with symptoms of anxiety and depression at T1, were excluded from the new dataset. This new dataset was used to investigate the serial mediating roles of anxiety and depressive symptoms in the relationship between PSU and sleep quality. The details are shown in Figure 1.



**Figure 1** The chain mediating pathway of T2 anxiety and depressive symptoms on T1 PSU and T3 sleep quality; The model corrected for baseline factors like sex, age, place of origin, family economic status, ethnicity, academic pressure, parents' marital status, the respondents' relationships with their families, classmates, and teachers, smoked and drank alcohol consumption; \*\*\* $P < 0.001$ , \*\* $P < 0.01$ , \* $P < 0.05$ .

**Abbreviation:** PSU, problematic smartphone use.



**Table 3** The Effect of T1 PSU on T3 Sleep Quality: Serial Mediating Effects of T2 Anxiety and Depressive Symptoms (n=1807)<sup>a</sup>

	T2: Anxiety Symptoms			T2: Depressive Symptoms			T3: Sleep Quality		
	$\beta$	SE	95% CI	$\beta$	SE	95% CI	$\beta$	SE	95% CI
T1: PSU	0.055	0.008	0.039–0.070	0.024	0.006	0.012–0.035	0.021	0.006	0.010–0.033
T2: Anxiety symptoms				0.857	0.017	0.824–0.889	0.060	0.026	0.008–0.112
T2: Depressive symptoms							0.160	0.024	0.113–0.206
	$R^2=0.047$			$R^2=0.619$			$R^2=0.132$		
	$F=9.760^{***}$			$F=291.153^{***}$			$F=9.002^{***}$		
						Effect size	SE	95% CI	Relative mediation (%)
Total effect						0.036	0.006	0.024–0.048	100.0
Direct effect						0.021	0.006	0.010–0.033	58.3
Indirect effect						0.015	0.002	0.011–0.019	41.7
T1 PSU -T2 Anxiety symptoms -T3 Sleep quality (ind1)						0.003	0.002	0.000–0.006	20.0
T1 PSU -T2 Depressive symptoms -T3 Sleep quality (ind2)						0.004	0.001	0.002–0.006	26.7
T1 PSU -T2 Anxiety symptoms -T2 Depressive symptoms -T3 Sleep quality (ind3)						0.008	0.002	0.005–0.011	53.3
Comparison one (ind1-ind2)						–0.002	0.008	–0.018–0.014	–
Comparison two (ind1-ind3)						–0.163	0.010	–0.038–0.002	–
Comparison three (ind2-ind3)						–0.143	0.007	–0.028–0.003	–

**Notes:** <sup>a</sup>The model excluded students with poor sleep quality in T1 and T2 and students with anxiety and depression symptoms in T1 from the original data; The model corrected for baseline factors like sex, age, place of origin, family economic status, ethnicity, academic pressure, parents' marital status, the respondents' relationships with their families, classmates, and teachers, smoked and drank alcohol consumption; \*\*\* $P<0.001$ .

**Abbreviations:** PSU, problematic smartphone use; ind, indirect.

Table 3 presents the results of the serial mediation analysis, taking anxiety and depressive symptoms at T2 as the mediator variables, PSU at T1 as the independent variable, and sleep quality at T3 as the dependent variable. This analysis controlled for baseline factors such as age, sex, ethnicity, family economic status, family relationships, parental marital status, academic pressure, peer relationships, and teacher relationships. The relationship between baseline PSU and sleep quality at T3 was significant (total effect=0.036, 95% CI=0.024–0.048). The direct effect between the two variables was also significant (direct effect=0.021, 95% CI=0.010–0.033), with a significant total indirect effect (total indirect effect=0.015, 95% CI=0.011–0.019), accounting for 41.7% of the total effect. Specifically, the mediating effect of anxiety at T2 on the relationship between PSU at T1 and poor sleep quality at T3 was significant (indirect effect 1=0.003, 95% CI=0.001–0.006), accounting for 20.0% of the total indirect effect. The mediating effect of depressive symptoms at T2 was significant (indirect effect 2=0.004, 95% CI=0.002–0.006), accounting for 26.7% of the total indirect effect. Moreover, the chain mediating effect of anxiety and depressive symptoms at T2 was significant (indirect effect 3=0.008, 95% CI=0.005–0.011), representing 53.3% of the total indirect effect. Upon further comparison of the mediating effects, a significant difference between the chain mediating effect (indirect effect 3) and indirect effect 2 was found, suggesting that the impact of PSU on poor sleep quality is considerably enhanced when mediated by both anxiety and depressive symptoms.

## Discussion

Based on the findings of previous studies, this research further explored the possible mechanisms linking PSU and poor sleep quality. Using a sample of 2993 Tibetan college students, the study employed a longitudinal multiple mediation model to investigate the independent and combined mediating roles of anxiety and depression symptoms in the relationship between poor and poor sleep quality.

This study's findings reveal that anxiety symptoms significantly mediate the link between problematic smartphone use (PSU) and diminished sleep quality. In essence, higher PSU levels correlate with intensified anxiety symptoms and deteriorating sleep quality, aligning with past research.<sup>34,47,48</sup> Yet, Yingnan Zhang's work introduces a nuanced perspective, identifying anxiety symptoms as a complete mediator in the PSU-sleep quality association, highlighting anxiety's detrimental role on sleep.<sup>49</sup> This distinction underscores the seductive lure of smartphones for college students, offering a virtual escape that, while momentarily soothing, potentially exacerbates stress-handling incapacity, heightening anxiety and subsequently impairing sleep quality.<sup>48</sup> Moreover, excessive smartphone engagement may erode the fabric of real-life social interactions, fueling interpersonal strains and anxiety,<sup>50</sup> which directly precipitate sleep disturbances like insomnia, superficial sleep, and sensitivity to disruptions.<sup>51</sup>

Biologically, anxiety magnifies the emotional fragility wrought by sleep loss. Experiments show that sleep-deprived individuals exhibit amplified amygdala and anterior insula responses to stressors, with heightened anxiety amplifying these reactions. This suggests that even minor anxiety levels can worsen emotional susceptibility under sleep deprivation.<sup>52</sup> Comparative studies on anxious versus non-anxious adolescents reveal that sleep deprivation in anxious individuals dampens activity in emotion-regulation centers (dorsal anterior cingulate cortex and hippocampus) while enhancing specific neural connections, indicating a unique vulnerability to sleep loss.<sup>53</sup> These insights pivot us toward reevaluating the multifaceted impacts of PSU, especially as it pertains to mental health and sleep hygiene. Understanding the intricate dynamics between PSU, anxiety, and sleep quality not only sheds light on the underlying mechanisms but also urges the development of nuanced intervention strategies.

This study illuminates the critical mediating role of depression symptoms in the nexus between problematic smartphone use (PSU) and sleep quality deterioration. It prompts us to question: How does the escalation of PSU exacerbate depression symptoms and concurrently impair sleep quality, paralleling earlier discoveries?<sup>54,55</sup> The journey into excessive smartphone engagement leads to a solitary lifestyle shift, from tangible to digital social exchanges, potentially deepening the chasm of loneliness. This introspection raises another inquiry: Could the loneliness and diminished self-esteem faced by college students, amplified by life's pressures and academic demands, heighten their vulnerability to depression and sleep disturbances?<sup>56</sup>

Joel et al's "Inappropriate Use of Mobile Phones Path Model" posits PSU as a quest for solace, marred by impulse control failure and extraversion.<sup>57</sup> This model challenges us to consider: Is emotional dysregulation the root, fueling the inability to curb unnecessary impulses, thereby diminishing emotional self-efficacy and exacerbating depression symptoms?<sup>58,59</sup>

Furthermore, the discourse on biological mechanisms offers a provocative angle—could PSU-induced depressive symptoms be intricately linked to the brain's reward system? This exploration unveils the reward circuitry, including the ventral striatum and medial prefrontal cortex, as potential culprits in the reduced sensation of pleasure, a hallmark of depression. Intriguingly, does severe PSU correlate with structural brain changes, such as reduced grey matter volume in the anterior cingulate cortex, implicating the reward circuit in this maladaptive pattern?<sup>60</sup> Research has shown that the more severe the PSU is, the smaller the volume of grey matter in the anterior cingulate cortex, and the poorer the integrity of white matter in the brain. PSU is associated with the function of the reward circuit. Moreover, in the PSU group, the functional connectivity (FC) between the left inferior frontal gyrus and the left parahippocampal gyrus and specific brain regions was enhanced. This suggests that brain structure and the reward circuit are related to PSU.<sup>61</sup>

In this investigation, we find that PSU impairs sleep quality via a sequential mediation of anxiety and depressive symptoms, accumulating negative emotional burdens. This pattern aligns with prior research, revealing the intricate dance between PSU, social anxiety, and depression among university students. A curious question emerges: How does PSU, through its intricate web of social anxiety and depressive symptoms, erode the foundation of good sleep? Research underscores social anxiety's full mediation role between PSU and depression,<sup>62</sup> spotlighting its pivotal position in the



depression narrative. Could this highlight a deeper, more complex interaction at play, where social anxiety not only bridges but amplifies the relationship between PSU and depressive symptoms?

As students' reliance on smartphones grows, so does the time and energy devoted to these devices, inversely affecting physical activity. A striking finding from Su et al's study<sup>29</sup> among adults in Guangdong points to a noteworthy conclusion: the more physically inactive one becomes, the poorer the sleep quality, mediated by anxiety and depression. This cascading effect—physical activity reduction leading to anxiety, which in turn leads to depression and subsequently poor sleep—accounts for a significant portion of the impact on sleep quality. Could this suggest a deeper, systemic issue where lifestyle choices intertwined with digital habits are fundamentally altering our well-being?

The Social Replacement Hypothesis offers another layer of insight, proposing that excessive smartphone use diminishes the quality and frequency of real-world social interactions, a crucial component of mental health.<sup>63</sup> Meanwhile, Harvey's cognitive model of insomnia<sup>64</sup> introduces a psychological perspective, suggesting that negative emotions, primarily anxiety, and depressive symptoms, catalyze cognitive biases towards stressful life scenarios, such as the interpersonal issues stemming from smartphone dependency. This cognitive spiraling, fixating on stressors, incrementally degrades sleep quality, potentially leading to insomnia. Could these models collectively offer a framework to understand the nuanced ways in which our digital habits are reshaping our psychological landscape, sleep patterns, and overall health? This prompts a broader contemplation on the mechanisms through which PSU influences our lives and the potential pathways for mitigating its effects, inviting further exploration into the complex interplay between digital engagement, emotional health, and sleep hygiene.

## Limitations and Future Directions

This study has the following limitations. First, although self reports are easily accepted by respondents, recall bias is inevitable. In the future, a variety of methods, such as face-to-face interviews, sleep diaries and more objective measurements (such as polysomnography), should be used. Second, our study only included university students as subjects; future studies should be conducted in a broader population. Third, given that we did not investigate the usage tendencies for different apps or other issues, we were unable to explore the specific relationships between the collected data on usage content and anxiety, depressive symptoms, and sleep quality;<sup>65</sup> moreover, we did not consider information on the usage of other electronic devices such as tablets, computers, or televisions.<sup>66,67</sup> Fourth, this study did not have an experimental design, so causal relationships among the four variables cannot be determined. Interventional study designs are needed in the future. Fifth, the relationship between PSU and sleep quality may be mediated by complex psychological and behavioral mechanisms. Previous studies have shown that factors such as bedtime procrastination, self-regulation, and psychological inflexibility can mediate the relationship between PSU and sleep quality.<sup>12,33,68</sup> These factors were not included in this study, which may limit the interpretability of the results. Future studies should comprehensively explore the mediating role of the above factors in this relationship.

Despite the aforementioned limitations, this study still has several advantages, including the three-wave longitudinal design, the relatively large sample size, and better control for covariates. This research will have theoretical and practical significance for reducing PSU, sleep issues, and psychological distress among college students. Theoretically, this study preliminarily clarifies the longitudinal mediating role of anxiety and depressive symptoms in the relationship between college students' PSU and sleep quality, filling the gap in previous studies that used only cross-sectional or two-wave data. Moreover, as this study is based on the comprehensive relationships of multiple variables, it can provide a foundation for further research into related mechanisms. Practically speaking, when addressing sleep disorders, more attention should be given to students' behavioural issues. Student counsellors should adopt appropriate methods to strengthen interventions for excessive smartphone use among students. Mental health professionals can mitigate the impact of PSU on sleep quality by reducing students' psychological distress, including symptoms of anxiety and depression.

## Conclusion

This study explored the potential pathways connecting PSU and sleep quality among university students in Tibet, China, thereby expanding upon the findings of previous research. Anxiety and depressive symptoms were found to play

independent and serial mediating roles in the longitudinal relationship between PSU and sleep quality. Specifically, the mediating role of depressive symptoms was more significant than that of anxiety. Consequently, effective interventions aimed at addressing university students' PSU and psychological distress, including anxiety and depression, could be beneficial for improving their sleep quality.

## Ethics Statement

This study received approval from the Ethics Committee of Xizang Minzu University [No. 202329] and complied with the Declaration of Helsinki. The subjects were fully informed of the content and purpose of the survey before participation. All participants provided informed consent before the participation in the present study.

## Acknowledgment

The authors would like to express their special thanks for the support and assistance of the participating schools and student administrators, as well as the study participants.

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

## Funding

This work was supported by the Scientific Research Plan Projects of Shaanxi Province Education Department (Grant No. 22JK0205), National Natural Science Foundation of China (International Cooperation and Exchange Programme) (Grant No. 81761128030), Natural Science Foundation of Tibet Autonomous Region (Grant No. XZ202201ZR0055G), Tibet Autonomous Region Higher Education Teaching Reform Project (Grant No. JG2023-53), Research Projects of Xizang Minzu University (Grant No. 23MDY08), the Scientific Research Project of Xizang Minzu University (No. 23MDQ03).

## Disclosure

The authors declare that they have no competing interests.

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