

The Effect of Physical Activity on Sleep Quality Among Chinese College Students: The Chain Mediating Role of Stress and Smartphone Addiction During the COVID-19 Pandemic

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Purpose: During the period of COVID-19 pandemic, the social restrictions and isolation exerted a significant impact on the sleep quality of Chinese college students. This study aims to delve into the influence of physical activity on the sleep quality of college students as well as the mediating roles of stress and smartphone addiction.

Materials and Methods: A cohort of 274 eligible college students (146 males and 128 females) were selected for the investigation. The International Physical Activity Questionnaire Short Form, Stress Perception Scale, Smartphone Addiction Scale, and Pittsburgh Sleep Quality Index were employed to assess the levels of physical activity, stress, smartphone addiction, and sleep quality among college students. For data analysis, descriptive statistics, correlation analysis, and chained mediation effect tests were performed sequentially.

Results: The findings revealed: (1) a significant negative correlation between physical activity and stress, smartphone addiction, and sleep quality among college students ($r = -0.216, p < 0.001$; $r = -0.224, p < 0.001$; $r = -0.259, p < 0.001$); (2) independent mediating roles of stress and smartphone addiction in the relationship between physical activity and sleep quality; and (3) chained mediating effects of stress and smartphone addiction in the association between physical activity and sleep quality.

Conclusion: This study deepens our comprehension of how physical activity augments the quality of slumber, concurrently emphasizing that mitigating stress levels and alleviating smartphone addiction constitute effective strategies for preventing sleep issues among college students.

Keywords: sleep quality, physical activity, smartphone addiction, stress, chain mediating effect, college students

Introduction

The unprecedented global public health and sanitation crisis that COVID-19 caused in early 2020 has forced governments all over the world to impose a plethora of strict measures designed to slow down the virus's spread, such as maintaining physical distance, limiting physical activity, quarantining, and staying at home.¹⁻³ Although essential for mitigating interpersonal virus transmission, these limitations on outdoor activities and social distancing give rise to apprehension. Extended restrictions throughout the outbreak have been shown to exert detrimental effects on individual well-being, encompassing physiological stress,⁴ modifications in sleep patterns,^{5,6} and diminished physical activity.^{3,6} Recent research findings suggest that, as the pandemic advances, limitations linked to it might escalate the occurrence of subpar sleep quality among college students, thereby augmenting the risk to their physical and mental welfare. In this context, a study concentrating on Italians revealed that

57% of their participants experienced compromised sleep quality during the pandemic, a percentage markedly surpassing pre-pandemic statistics.⁷ Similarly, Huang et al identified that,⁸ amid the pandemic, collegiate individuals indicated diminished sleep quality scores in contrast to the pre-pandemic period.

Sleep quality is conceptualized as a subjective perception of an individual's sleep.⁹ Lack of access to adequate, quality sleep has been shown to be an independent contributor to a variety of health problems, including cardiovascular disease, diabetes, and cancer.¹⁰ Given the unequivocal bidirectional nature of the relationship between poor sleep quality and health problems, identifying the influencing factors of sleep quality and devising interventions for its amelioration assume heightened significance.¹¹ There exists compelling evidence positing that physical activity, characterized as a vigorous and salubrious intervention, can aid college students in mitigating specific sleep-related challenges.¹² Physical activity refers to any bodily movement driven by skeletal muscles that results in energy expenditure. It is also construed as an internal resource with strong subjectivity and directionality.¹³ Diniz et al discerned that augmenting daily physical activity levels constitutes an efficacious strategy for amplifying sleep quality.³ Feng et al showed that students participating in physical exercise manifested elevated sleep quality and a diminished risk of depression in comparison to their non-exercising counterparts.¹² A 19-day longitudinal study also demonstrated that less physical activity carries a higher risk of chronic insomnia.¹⁴

Nevertheless, prior research has predominantly concentrated on the nexus between physical activity and sleep quality, leaving the potential mediating mechanisms (ie, how physical activity exerts influence on sleep quality) considerably unexplored during the COVID-19 period. Furthermore, although the relationship between individual characteristics such as depression,¹⁵ anxiety,¹⁶ and loneliness¹⁷ and sleep quality has been extensively discussed in prior studies, the parallel psychological states of stress and smartphone addiction as factors affecting sleep quality have been relatively understudied. These variables have not received adequate research attention in the existing literature, possibly due to the complexity of their composite nature as psychological states and the intricacy of their interactions. In order to bridge these lacunae, this study formulates a chain mediation model to scrutinize the intermediary functions of stress and smartphone addiction in the nexus between physical activity and sleep quality among college students. These findings will propel the advancement of our comprehension regarding the mechanisms by which physical activity shapes the sleep quality of college students, thereby providing references for higher education professionals to optimize the sleep quality of college students.

The Mediating Role of Stress

Stress refers to the internal response generated by an individual when encountering adverse or demanding situations.¹⁸ The General Adaptation Syndrome theory suggests that unresolved stress over time will progressively deplete an individual's adaptive resources, leading to a state of tension in the resistance phase, and may ultimately result in physical and psychological exhaustion.¹⁹ Studies have shown that stress is one of the risk factors that can explain depression and anxiety among college students.²⁰ Stress is also considered one of the causes of poor sleep quality.²¹ The stress response model of insomnia posits that under stress, the nervous system releases hormones that regulate sleep, stimulating adrenal activity, and consequently affecting sleep quality.²¹ Cross-sectional studies also indicate a positive correlation between stress and poor sleep quality in college students.²² An experimental study further demonstrates that long-term exposure to chronic stress can disrupt the regulatory mechanism of sleep homeostasis, leading to the loss of non-rapid eye movement sleep, and subsequently causing a decline in sleep quality.²³

Physical activity has a strong connection with stress. Individuals who engage in physical activity in a positive and conscious manner are less likely to exhibit high sensitivity to the impact and adverse consequences of stress. The antagonistic hypothesis of physical activity also suggests that physical activity can help individuals increase their resources for coping with stress, reduce the intensity of stress responses, and counteract the damage of stress to the body.²⁴ Cross-sectional and longitudinal studies indicate that physical activity serves as a protective factor in alleviating stress.^{25,26} Prospective research on the stress-reducing effects of physical activity also shows that stress significantly decreases with an increase in physical activity.²⁷ Given the negative correlation between physical activity and stress, and the positive correlation between stress and poor sleep quality, we hypothesize that stress will mediate the relationship between physical activity and sleep quality.

The Mediating Role of Smartphone Addiction

In addition to the psychological states of high stress discussed above, smartphone addiction, a behavioral pattern of excessive reliance on digital connectivity, is also considered a key factor in poor sleep quality,^{28,29} especially for young people who are in a critical developmental stage of establishing stable sleep cycles and seeking psychological well-being through healthy lifestyle habits. According to the replacement hypothesis,³⁰ the use of smartphones may occupy time that would otherwise be dedicated to sleep, leading to a reduction in sleep duration. Moreover, the blue light emitted by smartphones can delay an individual's circadian rhythm and suppress the secretion of melatonin, resulting in circadian rhythm disorders and prolonged sleep onset times.³¹ Cross-sectional studies also indicate that prolonged use of smartphones may cause physical discomfort, such as musculoskeletal pain and fever, which can negatively impact sleep quality.³²

On the other end of the spectrum, physical activity is considered a key factor in mitigating individual smartphone addiction. It has been demonstrated that physical activity can fulfill psychological needs, alleviate negative emotions such as depression and anxiety, and affect the frequency of smartphone use among addicts.³³ Furthermore, physical activity can increase the expression of tyrosine hydroxylase in the midbrain's ventral tegmental area, enhancing the transmission of dopamine signals, thereby helping to suppress psychological cravings and relapse behaviors associated with smartphones.³⁴ Based on these theories and research findings, we believe that physical activity can improve problematic smartphone use among college students and may, through this mechanism, enhance their sleep quality. Therefore, we hypothesize that smartphone addiction may play a mediating role between physical activity and sleep quality among college students.

Chain Mediation of Stress and Smartphone Addiction

This study aims to investigate the mediating role of stress and smartphone addiction between physical activity and sleep quality among Chinese college students, with the purpose of broadening and consolidating our understanding of the mechanisms linking physical activity and sleep quality. As we have previously discussed, stress and smartphone addiction may help to elucidate the nature of poor sleep quality among college students. We suspect that stress and smartphone addiction may jointly exert their effects through parallel mediation. However, the necessity of a sequential model to achieve the most comprehensive understanding remains to be verified. Exploration of this relationship may lead to a deeper understanding of the more complex interactive mechanisms between physical activity and sleep quality among college students. Existing theories provide insights into the connection between stress and smartphone addiction. For instance, the General Stress Theory posits that stress may lead individuals to experience negative emotions and engage in problematic behaviors.³⁵ The Stress Dissipation Theory suggests that individuals facing stress may resort to extreme measures (such as smartphone addiction) to alleviate their stress emotions.³⁶ Additionally, the Compensatory Internet Use Theory further posits that when individuals experience psychological stress, anxiety, or depression, leading to unfulfilled psychological needs related to social interaction, entertainment, and identity, they may engage in "psychological need compensation" through easily accessible activities such as smartphone use.³⁷ Based on these theories, we speculate that smartphone use may serve as an effective (yet counterproductive) means for individuals to alleviate stress. Therefore, we hypothesize that an individual's state of stress may increase the propensity for smartphone use; more specifically, high levels of stress may provoke excessive smartphone use. Based on this, the positive impact of physical activity on sleep quality may stem from its potential to reduce stress levels and decrease problematic smartphone use. In summary, we hypothesize that stress and smartphone addiction may serve a serial mediating role between physical activity and the sleep quality of college students.

The Current Study

In summary, we have conducted an initial exploration of the interconnections involving physical activity, stress, smartphone addiction, and sleep quality. We note that previous studies mainly focused on the pairwise associations among these elements, creating a knowledge gap regarding how stress and smartphone addiction influence the correlation between physical activity and individual sleep quality and the interconnected pathways. Thus, based on the insomnia stress response model, replacement hypothesis, general stress theory, stress dissipation theory, and compensatory internet use theory, this study aims to investigate the impact of physical activity on the sleep quality of college students amid the COVID-19 pandemic. Additionally, it aims to investigate the mediating roles of stress and smartphone addiction, seeking to consolidate and broaden our understanding of the mechanisms underlying the relationship between physical activity and sleep quality. Building upon the aforementioned theories and discussions, we propose the following hypotheses and hypothesis model (Figure 1):

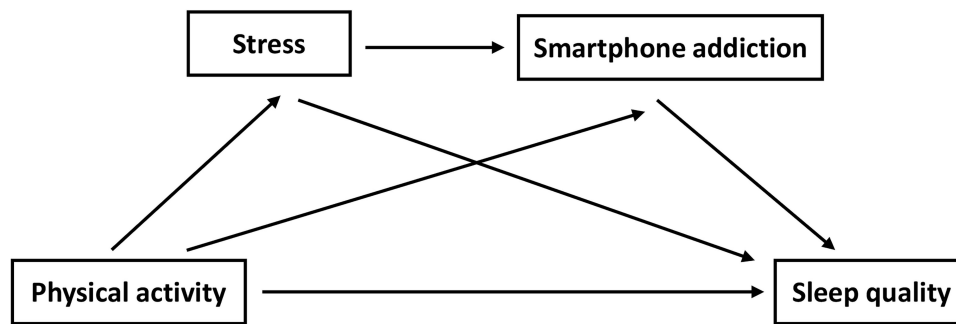


Figure 1 Hypothesized chain inter-mediation model.

Hypothesis 1: Physical activity exerts a positive influence on the sleep quality of college students.

Hypothesis 2: Stress acts as a mediating factor in the connection between physical activity and sleep quality among college students.

Hypothesis 3: Smartphone addiction functions as a mediating factor in the relationship between physical activity and sleep quality among college students.

Hypothesis 4: Stress and play a chain mediating role in the relationship between physical activity and sleep quality among college students.

Materials and Methods

Procedures and Participants

Given the constraints of maintaining social distancing measures at the time, this cross-sectional study was conducted in May 2022 at Shandong University in Jinan, Shandong Province, China, employing convenient sampling and online data collection methods. To facilitate online data collection, we selected the Questionnaire Star platform (<https://www.wjx.cn/>) to conduct the survey. Through the internet, researchers widely disseminated the Quick Response code of the questionnaire, allowing participants to scan and complete the survey via their mobile devices. In the process of screening participants, we established clear inclusion and exclusion criteria to ensure the accuracy and generalizability of the study. The inclusion criteria were: having Chinese nationality, being a full-time university student (undergraduate and postgraduate), having no physical disabilities, being capable of engaging in physical activity, and not having participated in similar studies before. The exclusion criteria included not meeting the inclusion criteria, answering anomalies (such as repeatedly selecting the same option), or failing to complete the questionnaire. Before participants began the questionnaire, researchers provided them with detailed instructions, including navigation of the questionnaire, the estimated time to complete it, and a commitment to anonymity. The entire research process strictly adhered to the principles of voluntary participation and informed consent. To ensure the accuracy, internal logic, and reliability of the data, we implemented a series of data verification measures, such as verifying cases that reported zero minutes of physical activity on specific days and excluding incomplete or obviously erroneous questionnaires. Additionally, we used G*Power 3.1 for a priori sample size estimation for this study,³⁸ with an effect size $f = 0.25$, a significance level $\alpha = 0.05$, and statistical power $(1-\beta) = 0.95$, resulting in a minimum required sample size of 210. Therefore, the sample size of this study is sufficiently powered statistically. A total of 297 questionnaires were collected, of which 7 were excluded due to overly rapid completion (less than half of the estimated completion time) and 16 due to incomplete information, resulting in an effective response rate of 92.25%. Ultimately, 274 eligible college students successfully completed the online questionnaire survey. Their average age was 20.31 years ($SD = 1.29$), with 146 males (53.28%) and 128 females (46.72%). The distribution across academic years was as follows: 61 freshmen (22.26%), 70 sophomores (25.55%), 88 juniors (32.12%), and 55 seniors (20.07%). Prior to survey participation, professional researchers communicated ethical principles, ensuring participants were informed about the

survey's anonymity, confidentiality, and purpose, emphasizing voluntary engagement. Rigorous data verification procedures were implemented to guarantee the accuracy, internal logic, and consistency of the completed questionnaires.

The study strictly adhered to the ethical principles outlined in the 1964 Helsinki Declaration and its subsequent amendments, receiving approval from the South China University of Technology Research Ethics Committee. All participants provided online informed consent before formally engaging in the survey.

Measures

Physical Activity

Employing the International Physical Activity Questionnaire Short Form to evaluate the physical activity levels of college students.³⁹ This questionnaire comprises seven items, encompassing the frequency and duration of walking, moderate-intensity, and high-intensity physical activities. Specifically, the metabolic equivalent (MET) values corresponding to walking and sedentary behavior, moderate-intensity, and high-intensity physical activities are 3.3 METs, 4.0 METs, and 8.0 METs, respectively. The calculation method for an individual's physical activity MET values (METs-min/week) is as follows: MET value \times duration of physical activity (minutes) \times frequency of activity per week.⁴⁰ The IPAQ-SF and its Chinese version have demonstrated good psychometric properties and are widely recognized as reliable tools for assessing levels of physical activity.^{41,42} For instance, the content validity coefficient of the Chinese version of the IPAQ-SF is as high as 0.99,⁴² indicating that the questionnaire comprehensively captures various aspects of physical activity. In this study, the Cronbach's alpha coefficient for the questionnaire was 0.688.

Sleep Quality

College student sleep quality was assessed using the Pittsburgh Sleep Quality Index scale developed by Buysse et al.⁴³ This scale comprises 7 components with a total of 18 participant-scored self-assessment items; each component was scored on a scale of 0 to 3. The cumulative score of the components forms the overall sleep quality score, with higher scores indicating poorer sleep quality. This scale has been widely applied among Chinese college students and has demonstrated strong reliability and validity.⁴⁴ In this study, the total Cronbach's α coefficient for the PSQI was 0.797, and the split-half reliability was 0.751, indicating good overall internal consistency of the scale. Additionally, a confirmatory factor analysis conducted on the scale showed that the model fit indices were satisfactory, with $\chi^2/df=1.488$, RMSEA=0.042, NFI=0.933, CFI=0.976, IFI=0.977, and RMR=0.033, indicating that the scale has good construct validity.

Stress

Utilizing the Perceived Stress Scale-10 to evaluate the stress levels of college students in their living conditions over the past month.⁴⁵ The scale includes 10 items, with 6 items evaluating negative experiences and 4 items evaluating positive experiences; each item employs a Likert 5-point rating scale (ranging from Never = 0, Occasionally = 1, Sometimes = 2, Often = 3, and Always = 4). The total score, obtained by summing the scores for each item, reflects an individual's stress level, with higher scores indicating heightened stress. The scale has been widely used among Chinese college students and has demonstrated good reliability and validity.⁴⁶ In this study, the total Cronbach's α coefficient for the PSS-10 was 0.791, with the Cronbach's α coefficients for the two subscales being 0.908 and 0.80, respectively, and the split-half reliability was 0.871, indicating good overall internal consistency. Additionally, a confirmatory factor analysis conducted on the scale showed that the model fit indices were satisfactory, with $\chi^2/df = 2.589$, RMSEA = 0.076, NFI = 0.949, CFI = 0.968, IFI = 0.968, and AGFI = 0.904, indicating that the scale has good construct validity.

Smartphone Addiction

Employing the Internet Addiction Scale adapted by Kwon et al and crafting a Smartphone Addiction Scale tailored to the characteristics of smartphones to assess the degree of smartphone addiction among college students.⁴⁷ This scale comprises 33 items, encompassing six dimensions: daily life interference, positive expectations, withdrawal, internet-oriented relationships, excessive use, and tolerance. The scale employs a Likert 6-point scoring system, ranging from 1 (strongly disagree) to 6 (strongly agree), with no reverse-scored items. Higher scores indicate a higher degree of smartphone addiction. This measurement method has been widely used among Chinese college students and has shown good reliability and validity.⁴⁸ In this study, the total Cronbach's α coefficient for the scale was 0.949, with the Cronbach's α coefficients for the six subscales ranging from 0.716 to

0.856, and the split-half reliability was 0.908, indicating good overall internal consistency. Additionally, a confirmatory factor analysis conducted on the scale showed that the model fit indices were acceptable, with $\chi^2/df = 2.461$, RMSEA = 0.073, NFI = 0.800, CFI = 0.869, IFI = 0.871, and AGFI = 0.736, indicating that the scale has decent construct validity.

Data Analysis

Utilizing SPSS 23.0 software for data processing, we subjected all continuous variable data to a test for normality, expressing normally distributed continuous variables as ($M \pm SD$). If continuous variables deviated from the normal distribution, we applied the square root transformation for normality conversion. In this research endeavor, we initially employed Harman's single-factor factor analysis method to examine the common method bias in the data. Subsequently, descriptive statistical analysis and Pearson correlation analysis were conducted to explore potential correlations among physical activity, stress, smartphone addiction, and sleep quality. Following this, in alignment with our hypotheses, we conducted tests for mediating effects using the SPSS macro program PROCESS, specifically designed for testing complex models.⁴⁹ Within PROCESS, Model 6 software was employed for models involving two mediators. Significance testing for the mediation effects was performed using the bias-corrected percentile Bootstrap method (with 5000 resamplings), where a 95% confidence interval excluding 0 indicates statistical significance. Previous research has indicated that gender and academic year are significant factors affecting variables such as sleep quality, perceived stress, smartphone addiction, and physical activity. Therefore, when testing the mediating effects, we controlled for these variables to ensure the accuracy and reliability of the results.⁵⁰⁻⁵² The significance level for this study was set at $\alpha=0.05$.

Results

Common Method Bias Analysis

Owing to the fact that all data in this study originate from participants' self-reports, there may be concerns regarding the presence of common method bias. Prior to the data analysis, we employed Harman's single-factor test to scrutinize the presence of common method bias. The outcomes demonstrate the existence of 10 factors with eigenvalues surpassing 1, and the initial factor expounds 28.75% of the variance, which is below the critical threshold of 40%. This signifies the absence of common method bias within this study.

Descriptive Statistics and Correlation Analysis

The descriptive statistics and correlation analysis of smartphone addiction, physical activity, stress, and sleep quality are delineated in Table 1. Due to the fact that the distribution of physical activity variables does not follow a normal distribution, the corresponding normal transformation was first performed. The results revealed that physical activity shares a negative correlation with stress, smartphone addiction, and sleep quality ($r = -0.216, p < 0.001$; $r = -0.224, p < 0.001$; $r = -0.259, p < 0.001$). Moreover, a significant positive correlation graces the interplay between stress and smartphone addiction ($r = 0.359, p < 0.001$). Sleep quality had a significant positive correlation with stress and smartphone addiction ($r = 0.422, p < 0.001$; $r = 0.419, p < 0.001$). These relationships among variables lend their support to our subsequent hypothesis-testing endeavors.

Table 1 Means, Standard Deviations, and Correlations of the Main Variable (N=274)

Variables	M	SD	1	2	3	4
1. Smartphone addiction	124.4	29.6	I			
2. Physical activity	33.51	22.9	-0.224***	I		
3. Sleep quality	6.91	3.29	0.419***	-0.259***	I	
4. Stress	17.64	6.64	0.359***	-0.216***	0.422***	I

Notes: *** $p < 0.001$.

Table 2 Testing the Interconnections Among Variables

Variables	Stress			Smartphone Addiction			Sleep Quality		
	β	SE	t	β	SE	t	β	SE	t
Constant	22.54***	1.652	13.63	105.8**	9.218	11.48	0.220	1.153	0.191
Gender	-0.006	0.794	-0.098	-0.008	3.411	-0.151	0.062	0.349	1.176
Grade	-0.174*	0.371	-2.976	0.005	1.621	0.087	0.017	0.166	0.315
Physical activity	-0.209***	0.017	-3.491	-0.156**	0.076	-2.656	-0.119*	0.008	-2.172
Stress				0.326***	0.261	5.577	0.296***	0.028	5.188
Smartphone addiction							0.285***	0.006	5.075
R	0.278			0.389			0.530		
R ²	0.077			0.152			0.281		
F	7.549***			11.99***			20.90***		

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Abbreviations: β , Standardized coefficient; SE, standard error.

Chain Mediation Effect Test

Utilizing Model 6 in the SPSS macro program, we examined the chained mediation effect of stress and smartphone addiction. The results, as illustrated in Table 2 and Figure 2, demonstrate that after controlling for gender and grade, physical activity significantly negatively predicts sleep quality, stress, and smartphone addiction ($\beta = -0.245$, $p < 0.001$; $\beta = -0.209$, $p < 0.001$; $\beta = -0.156$, $p = 0.008$). Stress significantly positively predicts smartphone addiction ($\beta = 0.326$, $p < 0.001$). When simultaneously considering stress, smartphone addiction, and sleep quality, physical activity significantly negatively predicts sleep quality ($\beta = -0.119$, $p = 0.031$), while stress and smartphone addiction significantly positively predict sleep quality ($\beta = 0.296$, $p < 0.001$; $\beta = 0.285$, $p < 0.001$).

Further, we utilized the bias-corrected non-parametric percentile Bootstrap method (with 5000 resamplings) to test the mediating effect of stress and smartphone addiction in the relationship between physical activity and sleep quality. The standardized estimates of each indirect path and the 95% confidence intervals for the mediating effects are presented in Table 3. The results reveal that the 95% confidence interval for the total mediating effect of stress and smartphone addiction in the relationship between physical activity and sleep quality does not include 0, indicating a significant overall mediating effect. Physical activity primarily impacts the sleep quality of college students through three mediated pathways: (1) Physical activity \rightarrow stress \rightarrow sleep quality, where the confidence interval for the mediating effect does not include 0, indicating a significant mediating effect (mediation effect value is 0.009, accounting for 25.71% of the total effect), supporting Hypothesis 2. (2) Physical activity \rightarrow Smartphone addiction \rightarrow Sleep quality, where the confidence interval for the mediating effect does not include 0, indicating a significant mediating effect (mediation effect value is 0.006, accounting for 17.14% of the total effect), supporting Hypothesis 3. (3) Physical activity \rightarrow stress \rightarrow smartphone addiction \rightarrow sleep quality, where the confidence interval for the mediating effect does not include 0, indicating a significant mediating effect (mediation effect value is 0.003,

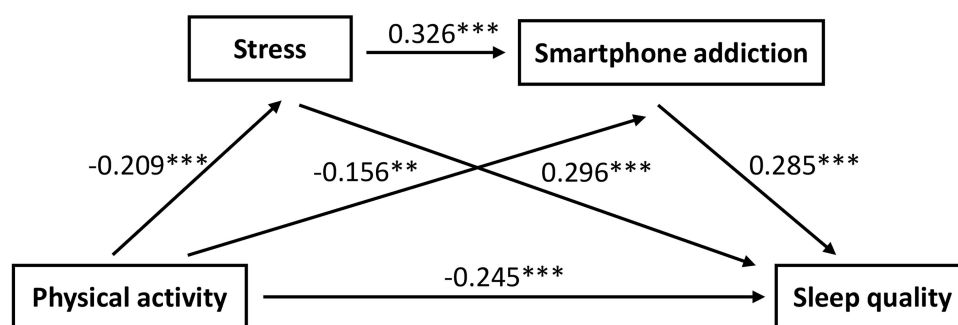


Figure 2 The final model of this study. ** $p < 0.01$; *** $p < 0.001$.

Table 3 Testing for Chain Mediation Effects

Paths	Effect	Boot SE	Bootstrap 95% CI	Effect Size Ratio
Physical activity → Stress → Sleep quality	-0.009	0.003	[-0.015, -0.004]	25.71%
Physical activity → Smartphone addiction → Sleep quality	-0.006	0.004	[-0.014, -0.001]	17.14%
Physical activity → Stress → Smartphone addiction → Sleep quality	-0.003	0.001	[-0.006, -0.001]	8.60%
Total indirect effect between physical activity and sleep quality	-0.018	0.005	[-0.028, -0.009]	51.43%
Direct effect	-0.017	0.008	[-0.033, -0.002]	48.57%
Total effect	-0.035	0.009	[-0.052, -0.018]	100%

accounting for 8.57% of the total effect), supporting Hypothesis 4. Therefore, stress and smartphone addiction in college students serve as chained mediators between physical activity and sleep quality.

Discussion

The present study explores the association between physical activity and sleep quality in Chinese college students and examines the mediating roles of stress and smartphone addiction. Our results indicate that stress and smartphone addiction not only independently mediate the link between physical activity and sleep quality, but their chain pathways are also important. These findings substantiate our hypotheses and offer profound insights into the association between physical activity and the sleep quality of college students.

Physical Activity and Sleep Quality

In consonance with antecedent research, our present study found a significant negative relationship between physical activity and the sleep quality of college students. Specifically, the higher the physical activity, the less likely it is that poor sleep quality occurs among college students. Indeed, the benefits of physical activity in fostering health and ameliorating sleep quality are indisputable in most of the literature. For instance, Zhang et al posited that routine physical exercise serves as a protective factor against the occurrence of chronic insomnia.¹⁴ Hurdiel et al revealed that college students engaging in regular physical activity exhibit a notably lower incidence of sleep disturbances compared to their counterparts without such routines.⁵³ The facilitation of enhanced sleep quality through physical activity can be elucidated from several perspectives. On one hand, research substantiated the affirmative impact of physical activity on self-control, thereby assisting in mitigating dependence on smartphones, a factor that potentially contributes to enhanced sleep quality.⁵⁴ On the other hand, a cross-sectional study revealed that individuals engaging in periodic physical activity tend to adopt a spectrum of health-related behaviors, including wholesome dietary habits and reduced alcohol consumption,^{10,12} correlated with elevated sleep quality. Moreover, studies also indicated that the positive effects of physical activity on sleep quality are mediated through mental well-being, such as the reduction of depressive symptoms or the augmentation of self-esteem.¹² Consequently, we posit that enhancing the level of physical activity among college students stands as a profoundly pivotal factor in ameliorating their sleep quality.

Mediation of Stress

As anticipated, the confirmed mediating role of stress has been substantiated through regression analysis. Consequently, Hypothesis 2 has also been affirmed. This discovery extends the existing research findings on the interplay between physical activity, stress, and sleep quality. Elevated levels of physical activity serve as one of the contributing factors to mitigate individual stress responses, enhancing their adaptive capabilities,^{55,56} which in turn reduces the incidence of their sleep-related issues.⁵⁷ Furthermore, this result is novel and can provide some evidence for the extension and integration of the Sleep Disturbance Process Theory and Flow Theory. Specifically, the Sleep Disturbance Process Theory posits that stress,⁵⁸ as a negative emotion, significantly and adversely predicts sleep quality. When individuals encounter stressful life events or engage in psychological processes such as depression and anxiety, they experience heightened activation in physiological, cognitive, or emotional realms, thereby disrupting typical sleep patterns. The Flow Theory suggests that the state of “flow” induced by physical activity plays a role in fostering intrinsic motivation for the activity, heightening personal well-being, and mitigating adverse emotions like stress and anxiety.⁵⁹ Hence, by actively participating in physical activity, college students

might encounter diminished stress levels, subsequently reducing the occurrence of subsequent sleep problems. Our findings also align with the Diathesis-Stress Model,⁶⁰ indicating that potential protective factors, such as physical activity, as the model's input component, capable of positively influencing sleep by mitigating stress directly or indirectly.

Mediation of Smartphone Addiction

Moreover, our study found that smartphone addiction mediates between physical activity and sleep quality, confirming Hypothesis 3. In recent years, smartphone addiction among college students has received increasing attention from scholars. Some studies suggest an inverse correlation between physical activity and individual smartphone usage frequency, which may positively impact the prevention of smartphone addiction.^{54,61} Individuals with higher levels of physical activity can, through enhancing the structure and function of specific regions in the central nervous system, bidirectionally regulate dopamine and its receptors, thereby correcting addictive behaviors, including smartphone addiction.⁶² Nevertheless, the identification of smartphone addiction as a consequential risk element contributes markedly to the degradation of sleep quality.⁶³ Individuals exhibiting heightened smartphone addiction commonly report more instances of insufficient sleep and heightened fatigue during wakefulness.³² This may be attributed to the immersive experience that smartphone addicts undergo during usage, leading to physiological arousal and psychological activation.⁶⁴ The excitement and anxiety encountered before bedtime may exacerbate challenges in initiating sleep and impede the attainment of the profound sleep phase.⁶⁵ In other words, physical activity can reduce the occurrence of sleep-related issues by diminishing the development of individual smartphone addictions. This research result can additionally be elucidated through immersion theory⁶⁴ and self-regulation theory.⁶⁶ Generally, those ensnared by smartphone addiction manifest deficiencies in self-discipline, and they involuntarily immerse themselves in the gratifying psychological encounters engendered by smartphone utilization.⁶⁷ During this period, the content presented on the smartphone screen possesses the capacity to captivate their focus, dominate their self-awareness, and diminish their perception of time, thereby affecting overall sleep duration and quality.¹⁸ Serving as a positive self-regulatory mechanism,⁶⁸ physical activity may potentially alleviate the impact on sleep quality by regulating individual smartphone addiction behaviors, such as curtailing time spent on smartphones.

Chain Mediating of Stress and Smartphone Addiction

Finally, our study divulges that physical activity can indirectly prognosticate sleep quality through the chain mediation of stress and smartphone addiction, thereby substantiating Hypothesis 4. Our findings align with previous research, indicating that physical activity significantly negatively predicts individual stress levels.²⁵ To delve more deeply, participation in physical activity induces both physiological and psychological relaxation responses, releasing substances such as BDNF and serotonin that contribute to alleviating tension and anxiety, consequently mitigating negative emotions associated with stress.⁶⁹ However, as a pivotal perilous factor influencing individuals, especially the holistic well-being of college students, stress can precipitate an array of adverse emotions, behaviors, and social maladaptation issues.⁷⁰ The theory of stress dissipation posited that when faced with substantial pressure, individuals are prone to seeking solace through immersion in the realm of smartphones.⁷¹ Recent studies also demonstrate that individuals with higher stress levels are more inclined to retreat into the virtual realm of smartphones as a means of escaping real-life pressures and negative emotions.⁷² It has also been shown that the higher the level of smartphone addiction, the more pronounced the sleep disorder is.⁶³ Hence, physical activity contributes to the mitigation of stress. A lower level of stress acts on smartphone addiction, which can alleviate the occurrence of smartphone addiction behavior and consequently avoid adverse effects on sleep quality. In summary, this study not only broadens our understanding of the intrinsic mechanisms connecting physical activity to sleep quality through the examination of the chained mediation of stress and smartphone addiction but also deepens and extends the investigation into the factors influencing sleep quality.

Limitations and Practical Implications

Several limitations of this work and directions for future research should be noted. Firstly, given the reliance on subjective reports from participants in this study, potential errors may arise due to memory biases and social desirability. Future research endeavors should contemplate diverse data sources (eg, individuals, peers, parents, and teachers) for an objective measurement of pertinent variables.⁷³ Secondly, utilizing a cross-sectional design and questionnaire-based methodology, our analysis and discussion, while grounded in existing research, are inadequate to deduce causal relationships among variables and

ascertain their long-term effects. Future research could consider longitudinal or experimental designs to robustly validate causal relationships among these variables.⁷⁴ Thirdly, while our sample includes students of different genders, ages, and grades, which helps us to obtain a diverse perspective, we acknowledge that due to the use of convenience sampling and online data collection methods, there may be selection bias in our sample, and it may not fully represent all college student populations. Therefore, to bolster methodological rigor, subsequent research should contemplate employing random sampling methods and larger sample sizes to enhance the ecological validity of outcomes. Fourthly, amidst the COVID-19 period, given our exclusive focus on the Chinese college student population, the applicability of this relationship model to other populations or standard periods may be limited. Subsequent research should evaluate the applicability of our study outcomes to alternative groups, cultures, and temporal contexts. Last but not least, stress and smartphone addiction cannot fully explain why physical activity affects sleep quality, indicating that there may be other mediating variables to explore, such as loneliness.⁷⁵ Future research should explore analogous potential variables to facilitate a more comprehensive understanding of the underlying mechanisms influencing the sleep quality of college students. Despite that, our choice of stress and smartphone addiction as mediator variables is based on their significant role in the existing literature and the known association with sleep quality.

Despite these limitations, the current study has made some original contributions and holds significant theoretical and practical implications. To our knowledge, this study is the first to explore the mediating role of stress and cell phone addiction in the relationship between physical activity and sleep quality, which largely deepens previous research. Through the analysis of the chained mediation model, the internal mechanism of how physical activity affects the sleep quality of college students has been perfectly elucidated. It distinctly informs us about how physical activity enhances sleep quality and underscores that attenuating stress levels and mitigating smartphone addiction may constitute pivotal focus points in safeguarding the sleep quality of college students. More importantly, based on the results of this study, several important practical implications can naturally be derived. Firstly, given the correlation between physical activity and better sleep quality, parents and higher education professionals should enhance the development of physical activities among college students and help them cultivate the habit of consciously engaging in physical activities. Secondly, considering smartphone addiction as a crucial mechanism linking physical activity and sleep quality, curtailing unnecessary smartphone usage may imply an improvement in sleep quality. Consequently, schools and parents should promptly implement relevant intervention measures, assisting students in mastering effective strategies to manage smartphone usage in their daily lives. It has been shown that,⁷⁶ in addition to physical activity, diminished levels of peer harm and positive teacher-student relationships can help to engender a sense of security among college students, consequently mitigating addictive behaviors, including smartphone addiction. Finally, predicated on the chained mediation effect of stress and smartphone addiction within the correlation involving physical activity and sleep quality in college students, parents and school educators should strive to improve the mental health problems of college students and prevent excessive use of smartphones by college students due to increased stress levels in order to achieve prevention and intervention of sleep problems in college students.

Conclusion

The present study delves into the correlation between physical activity and sleep quality among Chinese college students, unraveling its inherent mechanisms. By crafting a chained mediation model, we discern that physical activity not only directly foretells sleep quality but also indirectly predicts sleep quality through the independent mediating roles of stress and smartphone addiction. Furthermore, it can also anticipate sleep quality through the chained mediation effects of stress and smartphone addiction.

Data Sharing Statement

The data supporting this article is available within the article. For additional inquiries and access to the data, please contact Guan Yang at yangmp6@scut.edu.cn

Ethics Approval and Informed Consent

The studies involving human participants were reviewed and approved by the Ethics Committee of the School of Physical Education and Sport of South China University of Technology, and adhered rigorously to the ethical tenets of the Helsinki Declaration. All participants provided online informed consent before formally engaging in the survey.

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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.

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Disclosure

The authors report no conflicts of interest in this work.

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