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The relationship between physical activity and sleep disorders in adolescents: a chain-mediated model of anxiety and mobile phone dependence

Ting Xiao¹, Mengting Pan², Xunjuan Xiao³ and Yang Liu^{1*}

Abstract

Background Adolescent sleep disorders have emerged as a significant global public health issue. This study aims to investigate the relationship between physical activity and sleep disorders in adolescents, and to further analyze the chain mediating effects of anxiety and mobile phone dependence, with the goal of providing empirical evidence for related clinical research.

Methods This cross-sectional study collected data through an offline questionnaire survey conducted in 2024. The survey assessed physical activity, sleep disorders, anxiety, and mobile phone dependence. Descriptive statistics and correlation analyses were utilized to construct a chain mediation model.

Results A total of 495 valid samples were obtained, with 227 girls (45.9%) and 268 boys (54.1%). The average age of the participants was 13.37 years (SD = 1.05). The results indicated significant negative correlations between physical activity and adolescent anxiety, mobile phone dependence, and sleep disorders. Anxiety and mobile phone dependence fully mediated the relationship between physical activity and sleep disorders.

Conclusion This study provides further insight into the underlying mechanisms linking physical activity and sleep disorders in adolescents. Physical activity not only has a direct negative effect on sleep disorders but also indirectly predicts sleep disorders through its impact on anxiety and mobile phone dependence. It is recommended that families and schools encourage increased physical activity among adolescents, as it can reduce anxiety and mobile phone dependence, thereby alleviating sleep disorders.

Keywords Adolescents, Physical activity, Sleep disorders, Anxiety, Mobile phone dependence

Introduction

Sleep disorders

With the accelerating pace of modern life, adolescents are increasingly exposed to stress, making sleep disorders a prevalent issue. Sleep disorder (SD), a general term, refers to a series of conditions that affect normal sleep patterns [1]. These are diseases that impact sleep quality, duration, or continuity and affect a person's ability to function normally while awake, including but not limited to insomnia, sleep-disordered breathing, and sleep-related movement

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disorders [2, 3]. The adolescent period, which spans ages 10 to 24 [2], is a critical phase for physical and psychological development. Research indicates that sleep disorders in adolescents not only compromise physical health but also contribute to a spectrum of psychological issues such as anxiety, depression, suicidal ideation, and substance abuse, thereby posing severe risks to their overall well-being [4]. Additionally, sleep disorders are significant contributors to various harmful conditions associated with psychological changes [5, 6], hypertension [7–9], diabetes [10], and weight gain [11]. A study by Liu et al. [12] revealed considerable variability in the prevalence of sleep disorders among Chinese adolescents, with the lowest incidence (7.5%) observed in elementary school students and the highest (41.9%) among high school students. A recent meta-analysis further indicates that the prevalence of sleep disorders is 20% among middle school students and 28% among high school students [13]. Consequently, adolescent sleep disorders have become a global public health issue, necessitating early prevention, identification, assessment, and intervention to effectively control and improve this condition.

Physical activity and sleep disorders

Extensive research has unequivocally demonstrated that physical activity has a significant positive effect in alleviating insomnia and improving sleep quality [14, 15]. Specifically, moderate aerobic activity, mind-body activity forms, and a combination of aerobic activity with light-intensity strength training have all shown important impacts on enhancing sleep quality in individuals with insomnia [16]. As a non-pharmacological intervention [17, 18], physical activity is increasingly recognized as an effective method for addressing sleep disorders. It not only contributes to improved mental health [19] and physical health [20], but also enhances sleep quality [14] and reduces mortality rates [21]. Recent review studies have explored the role of physical activity across the entire lifespan and in individuals with sleep disorders [22]. Numerous empirical studies have confirmed the effectiveness of different intensities and types of activity in improving sleep among healthy populations [23] including specific groups such as fibromyalgia patients [24] and children and adolescents [25]. However, given the extensive research on the relationship between physical activity and sleep, there exists some conflicting and ambiguous evidence [26–28]. Some studies suggest a positive correlation between physical activity and sleep quality [29]. In summary, this study aims to conduct a detailed analysis of the significant impact of physical activity on sleep disorders, with the goal of providing a reference for clinical research to effectively improve sleep

quality in adolescents with depressive sleep disorders [30].

Mediating role of anxiety

Adolescents, as a distinct group, face significant challenges during this transformative phase of social development. Research indicates a high prevalence of mental disorders among university students worldwide, with anxiety disorders being particularly prominent [22, 31]. Adolescent anxiety disorders are frequently associated with neuroendocrine abnormalities, manifesting as unexplained anxiety and restlessness. These individuals often experience a heightened state of vigilance, which prevents mental relaxation and subsequently leads to difficulty falling asleep [32]. According to recent research data in China, the prevalence of anxiety disorders among adolescents is relatively high. A national survey indicates that the lifetime prevalence of anxiety disorders is 7.6%, while the prevalence in the past 12 months is 4.98% [33, 34]. The study found that approximately 31.9% of adolescents experience some form of anxiety disorder during their developmental process [35]. In recent studies, it has been found that adolescents with anxiety symptoms have a 2.06 times higher risk of developing insomnia symptoms than those without anxiety symptoms [36]. Evidence suggests that regular physical activity can mitigate anxiety and depressive symptoms by enhancing the function of serotonin receptors [37]. Furthermore, physical activity positively impacts mental health and sleep quality [38, 39]. Studies also highlight that sleep disorders are among the most common clinical manifestations of adolescent anxiety disorders, typically characterized by difficulties in maintaining sleep, excessive sleep, and mood problems upon waking. Insufficient sleep has been linked to mental health issues, decreased quality of life, and poor academic performance [40, 41], and there is a significant positive correlation between sleep disorders and anxiety [42, 43]. Therefore, improving sleep quality and preventing mental disorders are crucial and potentially beneficial for this group.

The mediating role of mobile phone dependence

Adolescents are among the primary users of mobile phones. Driven by the need for social interaction, young people, especially students, are increasingly reliant on mobile phones [44]. Moreover, they represent a high-risk group for mobile phone addiction [45, 46]. Mobile phone dependence, also known as mobile phone addiction or problematic mobile phone use, refers to the excessive use of mobile phones where individuals struggle to control their usage time [47–49]. The primary symptoms include irritability and anger when the network connection is lost, as well as persistent anxiety when the device's

battery is low [50]. Research indicates a significant rise in the prevalence of problematic mobile phone use among adolescents from 6.3% in 2011 to 16% in 2016 [51, 52]. Systematic reviews and meta-analyses provide a comprehensive understanding of the relationship between mobile phone dependence and sleep quality and disorders [53, 54]. According to the person-environment interaction theory, behavioral problems result from the interplay between individual and environmental factors [55]. This suggests that extensive use of digital devices before bedtime and irregular sleep patterns among students may lead to sleep disorders [56]. Physical activity, as a significant social behavior, can effectively reduce negative emotions and a sense of alienation [57, 58]. Additionally, physical activity not only reduces the incidence of negative emotions such as anxiety, but also alleviates the symptoms of psychological disorders [59, 60]. Furthermore, with cross-sectional studies finding that physical activity negatively impacts phone dependence [61]. The concept of reciprocal determinism in social cognitive theory [62] suggests that behavioral issues influence emotions. The cognitive-behavioral model [63] further indicates that behavioral problems may affect cognitive and emotional states. Empirical research also shows that adolescents addicted to mobile phones are more likely to experience psychological distress, particularly symptoms of anxiety [64].

The chain mediation effect of anxiety and mobile phone dependence

An increasing body of research indicates that mobile phone dependence is closely associated with a variety of psychological and behavioral issues, including anxiety, stress, and reduced sleep quality [65, 66]. Furthermore, social media use has been linked to various aspects of adolescent health, such as sleep quality and mental well-being [67–69]. According to previous research [70], cross-sectional data measured continuously for three years in a city in China indicate that the prevalence of anxiety among Chinese adolescents has increased significantly, especially among female adolescents. This

has interfered with their sleep, relaxation, and quality of life [71]. The cognitive-behavioral model suggests that cognitive factors are a primary cause of behavioral addiction, positing that situational cues do not directly trigger addictive behaviors but rather influence individuals' maladaptive cognitions [63]. This implies that individuals addicted to mobile phones often exhibit higher levels of anxiety and stress [72]. The compensatory internet use theory proposes that individuals may increase their internet use in response to negative life situations, seeking relief from adverse emotions. Specifically, when internet use compensates for unmet needs in real life and effectively alleviates these issues, individuals may become more inclined to spend additional time online, potentially leading to negative outcomes [73, 74]. There is a bidirectional relationship between mobile phone dependence and anxiety symptoms [75, 76]. Individuals with anxiety, due to a lack of social skills, often rely more on online media for communication, a correlation that has been confirmed in research [77, 78]. Higher levels of dependence on mobile phones among anxious individuals are associated with a greater likelihood of addiction, and a significant positive correlation exists between the intensity of mobile phone use and anxiety levels [79–81].

Overview

Building on the preceding analysis, this study aims to investigate the impact of physical activity on sleep disorders, as well as the roles of anxiety and mobile phone dependence in mediating this relationship. To this end, a chain mediation hypothesis model is proposed (see Fig. 1), which examines the relationships between adolescent physical activity and sleep disorders while considering the mediating effects of anxiety and mobile phone dependence. The following hypotheses are therefore posited:

H1: Adolescent physical activity levels are significantly related to sleep disorders.

H2: Anxiety mediates the relationship between adolescent physical activity and sleep disorders.

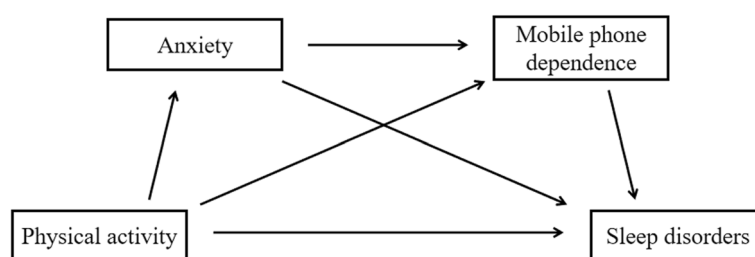


Fig. 1 Diagram of the chain mediation hypothesis model

H3: Mobile phone dependence mediates the relationship between adolescent physical activity and sleep disorders.

H4: Anxiety and mobile phone dependence have a chain mediation effect on the relationship between adolescent physical activity and sleep disorders.

Methods

Participants

This study utilized a convenience sampling approach to conduct a questionnaire survey among 574 adolescents in four rural middle schools in Hunan Province, China. Based on this sampling method, we initially contacted middle schools with which we had established a solid foundation of cooperation in advance. After explaining the content and purpose of this survey, we obtained permission from the schools. Subsequently, our experienced investigators entered these schools and classes to carry out the subsequent survey work. Prior to distributing the questionnaires, the investigators provided detailed information to the class teachers and participants regarding the purpose of the study, the anonymity of the data, the confidentiality measures, and the intended use of the data. Written informed consent was obtained from all participants and their guardians. The completion time for the questionnaire was approximately 20 min. After data screening, a total of 79 samples with abnormally short completion time and obvious answer patterns were excluded. Ethical approval was obtained from the institutional medical ethics committee before the commencement of the study. The study was conducted in accordance with the Declaration of Helsinki. In total, the final effective sample consisted of 495 participants, with an average age of 13.37 years (SD=1.05). Specific information is presented in Table 1.

Measures

Physical activity

Physical activity levels were assessed using the “Physical Activity Level Scale,” revised by Liang Deqing et al. [82]. This scale includes three dimensions: intensity, duration, and frequency of activity. The scoring formula is “Intensity × (Duration – 1) × Frequency = Total Physical Activity Score,” The score range is from 0 to 100 points, where a higher score indicates greater physical activity. This type of research has been explored within the context of China [83]. The Cronbach’s α for this scale in the current sample was 0.672.

Anxiety

Anxiety was measured using the anxiety subscale from the revised “Depression-Anxiety-Stress Scale - Short Form” by Gong Xu et al. [84]. This subscale consists of 7

Table 1 Demographic characteristics

Demographic variables	Number (proportion)
Gender	
Male	268
Female	227
Grade	
Grade 7	209
Grade 8	148
Grade 9	138
Father’s educational level	
Primary school education or below	80
Junior high school education	226
Senior high school education	35
University education	9
Postgraduate education or above	6
Unknown	139
Mother’s educational level	
Primary school education or below	98
Junior high school education	174
Senior high school education	34
University education	16
Postgraduate education or above	8
Unknown	165

items, rated on a 4-point Likert scale from 1 (not at all) to 4 (very much). The score range is from 7 to 28 points. Higher scores indicate greater levels of anxiety. This type of research has been explored in the Chinese context [85]. The Cronbach’s α for this subscale in the current sample was 0.745.

Mobile phone dependence

Mobile phone dependence was assessed using the “Self-Report Questionnaire on Adolescent Mobile Phone Use Dependence,” developed by Tao Shuman et al. [86]. This scale contains 13 items, rated on a 5-point Likert scale from 1 (never) to 5 (always). The score range is from 13 to 65 points. Higher scores indicate a higher degree of dependence on mobile phones. The Cronbach’s α for this scale in the current sample was 0.912.

Sleep disorders

Sleep disorders was evaluated using the sleep disorders subscale from the “Pittsburgh Sleep Quality Index” developed by Buysse et al. [87]. According to the theme of this study and the constructed model, this research adjusted the scoring method of this scale. There are nine items in this dimension, ranging from 0 (none) to 3 (three or more times/week). The score range is from 0 to 27 points. The higher the score, the higher the degree of sleep disorder.

This type of research has been explored within the context of China [88]. The Cronbach's α for this subscale in the current sample was 0.762.

Covariates

Demographic variables, including gender and age, were considered in the analysis and were controlled for as covariates.

Statistical analysis

Data were analyzed using SPSS 26.0, encompassing differential analysis, correlation analysis, and chain mediation model testing. Initial assessment involved testing for method bias; a threshold of 40% was used to determine if significant common method bias was present [89]. With no substantial bias detected, we proceeded to perform descriptive statistics and correlation analysis on participants' demographic characteristics and key variables. Prior to further analysis, the data for the primary variables were standardized. To test our hypotheses, we employed the PROCESS macro (Model 6) in SPSS to examine the relationship between physical activity and adolescent sleep disorders, focusing on the chain mediation effects of anxiety and mobile phone dependence. We conducted 5000 bootstrap resampling iterations to assess model fit and estimate 95% confidence intervals (95% CI) to ensure the robustness of our data analysis. The significance level was set at $\alpha=0.05$. Regression analysis for the chain mediation model was conducted using SPSS's PROCESS macro [90] with 5000 bias-corrected bootstrap samples for Model 6. Statistical significance was determined with a p-value threshold of 0.05. Indirect effects were assessed at the 0.05 significance level. A significant effect was indicated if the bootstrap 95% confidence interval (95% CI) did not include 0.

Results

Common method bias check

The common method bias analysis revealed two factors with eigenvalues greater than 1. The first factor accounted for 33.817% of the total variance, which is below the 40%

threshold. This indicates that there is no substantial risk of common method bias in this study.

Descriptive analysis

As shown in Table 2, there are significant gender differences in physical activity ($t=7.85$, $p<0.001$), anxiety ($t=-3.84$, $p<0.001$), and sleep disorders ($t=-2.34$, $p<0.05$). Specifically, boys engage in more physical activity than girls, while girls exhibit higher levels of anxiety and sleep disorders compared to boys.

Correlation analysis

Table 3 presents the results of the correlation analysis, which indicate that physical activity is significantly negatively correlated with adolescent anxiety ($r=-0.217$, $p<0.001$), mobile phone dependence ($r=-0.193$, $p<0.001$), and sleep disorders ($r=-0.169$, $p<0.001$). Anxiety is significantly positively correlated with both mobile phone dependence ($r=0.361$, $p<0.001$) and sleep disorders ($r=0.516$, $p<0.001$). Furthermore, mobile phone dependence shows a significant positive correlation with adolescent sleep disorders ($r=0.315$, $p<0.001$).

Mediation model testing

After controlling for demographic variables, the results in Table 4 and Fig. 2 indicate that physical activity significantly and negatively predicts adolescent sleep disorders ($\beta=-0.150$, $p<0.01$). However, when the mediator variables are included, the direct effect of

Table 3 Correlation analysis

Variables	1	2	3	4
1 Age	-			
2 Physical activity	0.044	-		
3 Anxiety	-0.046	-0.217***	-	
4 Mobile phone dependence	-0.019	-0.193***	0.361***	-
5 Sleep disorders	-0.068	-0.169***	0.516***	0.315***

*** $p<0.001$

Table 2 Describes the analysis

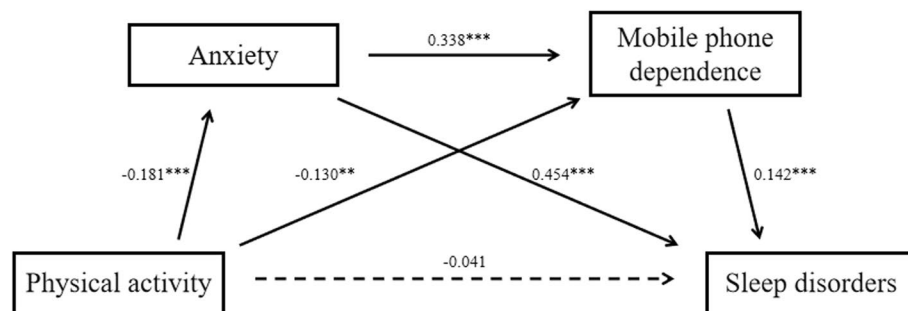
Variables	Physical activity		Anxiety		Mobile phone dependence		Sleep disorders	
	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
Boys	27.22	23.92	12.07	4.34	26.52	11.91	5.64	5.09
Girls	13.53	14.31	13.54	4.12	28.08	11.35	6.67	4.63
t	7.85***		-3.84***		-1.48		-2.34*	

* $p<0.05$

*** $p<0.001$

Table 4 Tests the mediation model

Outcome variables	Predictor variables	β	SE	t	R^2	F
Sleep disorders	Gender	0.050	0.047	1.066	0.035	5.845***
	Age	-0.056	0.045	-1.249		
	Physical activity	-0.150	0.047	-3.211**		
Anxiety	Gender	0.109	0.047	2.333*	0.059	10.260***
	Age	-0.026	0.044	-0.585		
	Physical activity	-0.181	0.046	-3.920***		
Mobile phone dependence	Gender	-0.033	0.045	-0.736	0.145	20.738***
	Age	-0.001	0.042	-0.025		
	Physical activity	-0.130	0.045	-2.907**		
Sleep disorders	Anxiety	0.338	0.043	7.843***	0.289	39.780***
	Gender	0.001	0.041	0.011		
	Age	-0.043	0.038	-1.111		
	Physical activity	-0.041	0.041	-0.989		
	Anxiety	0.454	0.042	10.890***		
	Mobile phone dependence	0.142	0.041	3.453***		

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$ **Fig. 2** Diagram of the chain mediation model

physical activity on adolescent sleep disorders becomes non-significant ($\beta = -0.041$, $p > 0.05$). Additionally, the mediation model testing reveals that physical activity significantly and negatively predicts adolescent anxiety ($\beta = -0.181$, $p < 0.001$), and anxiety significantly and positively predicts adolescent sleep disorders ($\beta = 0.454$, $p < 0.001$). Physical activity also significantly and negatively predicts mobile phone dependence ($\beta = -0.130$, $p < 0.01$), and mobile phone dependence significantly and positively predicts adolescent sleep disorders ($\beta = 0.142$, $p < 0.001$). Finally, anxiety and mobile phone dependence fully mediate the relationship between physical activity and adolescent sleep disorders ($\beta = 0.338$, $p < 0.001$). The proportion of variance explained by the mediation paths is detailed in Table 5.

Discussion

The relationship between physical activity and sleep disorders

This study identified a significant negative correlation between physical activity and sleep disorders in adolescents, thereby confirming hypothesis H1. However, this direct predictive effect was no longer significant when considering mediating variables. Existing research indicates that physical activity is a key factor in enhancing sleep quality among adolescents [91]. Moderate physical activity can increase cerebral blood flow [92, 93], reduce nocturnal arousal [94], and improve overall sleep quality [95], thus contributing to a beneficial sleep cycle. Further studies suggest that extensive physical activity has a more pronounced effect on improving sleep quality in students [15]. The impact of physical

Table 5 Path analysis of mediation model

Intermediate path	effect size	SE	Bootstarp 95% CI	Proportion of mediating effect
Total effect	-0.150	0.047	-0.242,-0.058	
Direct effect	-0.041	0.041	-0.122, 0.040	
Physical activity→Anxiety→Sleep disorders	-0.082	0.023	-0.132,-0.041	54.667%
Physical activity→Mobile phone dependence→Sleep disorders	-0.019	0.010	-0.044,-0.003	12.667%
Physical activity→Anxiety→Mobile phone dependence→Sleep disorders	-0.009	0.004	-0.019,-0.002	6.000%
Total indirect effect	-0.110	0.029	-0.173,-0.060	73.333%

activity on sleep disorders in adolescents underscores the importance of strategically planning activity time, frequency, and intensity to improve sleep quality. Notably, as a non-pharmacological intervention, activity has a positive effect on sleep structure [96], normalizing the duration and proportion of different sleep stages and benefiting endocrine, metabolic, immune, autonomic nervous system, and cardiovascular functions during sleep [97]. In summary, physical activity is an effective method for improving sleep disorders in adolescents. Through careful planning of activity routines, sleep quality can be significantly improved, promoting both physical and mental health in young individuals.

The mediating role of anxiety

This study confirms the mediating role of anxiety in the relationship between adolescent physical activity and sleep disorders, thus validating Hypothesis H3. Existing literature indicates that physical activity is an effective means of alleviating anxiety [98]. For instance, research conducted on university students has revealed a significant negative correlation between physical activity and anxiety levels, suggesting that activity may indirectly improve sleep quality by reducing anxiety [99]. Previous studies have demonstrated that [100] Anxiety can affect sleep through various mechanisms, including the increase of muscle tension and heightened activity of the autonomic nervous system. These physiological responses can interfere with the sleep process, as the heightened state of arousal may prevent the body from entering deep sleep stages, thereby negatively impacting sleep quality [101]. Furthermore, individuals with higher anxiety levels are more prone to experiencing sleep disorders [102]. In states of anxiety, the balance of neurotransmitters in the brain, particularly serotonin and melatonin, can be disrupted, which may lead to instability in sleep cycles and subsequently result in sleep issues [103]. Studies have shown a positive correlation between

the prevalence of anxiety symptoms and the incidence of sleep disorders; that is, higher anxiety levels are associated with an increased risk of sleep problems [104]. Physical activity not only directly improves an individual's emotional state but may also positively impact mood indirectly by enhancing sleep quality [104]. These findings suggest that physical activity plays a beneficial role in mitigating sleep disorders by reducing anxiety, and anxiety itself may be a significant factor affecting sleep quality. According to self-esteem theory, engaging in physical activity and achieving activity goals can enhance self-worth and provide psychological buffering, thereby fostering positive emotional experiences [105]. Additionally, physical activity effectively regulates students' emotions, reduces anxiety levels, and mitigates sleep disorders, which is crucial for improving the sleep quality of adolescents.

The mediating role of mobile phone dependence

This study confirms the mediating role of mobile phone dependence in the relationship between physical activity and sleep disorders in adolescents, thus validating Hypothesis H3. Research shows a negative association between physical activity and mobile phone dependence [106, 107], while mobile phone dependence is significantly positively correlated with sleep quality [108, 109]. Specifically, higher levels of mobile phone dependence are associated with poorer sleep quality. Consequently, increasing physical activity may improve sleep quality by reducing mobile phone dependence [110, 111]. Physical activity is able to predict sleep quality by decreasing smartphone usage [112, 113]. Increased physical activity may help reduce the frequency of mobile phone use [114], thereby improving sleep conditions. According to psychological dependence theory, mobile phone dependence frequently originates from emotional attachment to the device. Physical activity can serve as a positive alternative behavior to help adolescents reduce their

dependence on mobile phones [115]. This social support and interaction can effectively reduce dependence on virtual social networks [116], thus decreasing the frequency of mobile phone use as an entertainment or escape tool and reducing the risk of mobile phone dependence. Moreover, the blue light emitted by mobile phone screens can suppress melatonin secretion [117], making it difficult for adolescents to fall asleep and leading to a reduction in overall sleep time and the onset of sleep disorders [118]. These findings suggest that mobile phone dependence may act as a mediating factor between physical activity and sleep disorders, indicating that physical activity could positively impact sleep quality by reducing mobile phone dependence.

Chain mediating effect of anxiety and mobile phone dependence

This study reveals that physical activity directly predicts sleep disorders in adolescents; however, this direct effect becomes non-significant when mediators are introduced. The research results indicate that the influence of physical activity on sleep disorders in adolescents is mainly through regulating the emotions and behaviors of adolescents, thereby indirectly alleviating sleep disorders [15]. Specifically, physical activity effectively reduces negative emotions in adolescents [102]. Physical activity not only fosters social interaction [119], emotional support, and exchange of perspectives but may also influence hormone secretion related to anxiety by modulating the hypothalamic-pituitary-adrenal (HPA) axis, thereby reducing anxiety levels [120, 121]. When anxiety is alleviated, adolescents are less likely to rely on mobile phones as a tool for emotional regulation. Studies show that individuals with high anxiety levels are more prone to mobile phone dependence [122], and the proliferation of mobile networks in modern society makes it easier for individuals to become engrossed in social media and mobile games. However, when individuals' real-life social needs are met and emotional issues are supported and mitigated, their dependence on mobile phones significantly decreases [123]. Therefore, the chain mediating effect of physical activity—reducing anxiety—decreasing mobile phone dependence—improving sleep disorders is validated in this study. In summary, anxiety and mobile phone dependence indeed mediate the relationship between physical activity and adolescent sleep disorders. Physical activity indirectly improves sleep disorders by reducing anxiety and mobile phone dependence, contributing to the promotion of adolescents' physical and mental health.

Strengths and limitations

This study further investigates the underlying psychological and behavioral mechanisms between physical activity

and sleep disorders in adolescents. It demonstrates that physical activity can improve sleep disorders in adolescents by reducing negative emotions (such as anxiety) and alleviating maladaptive behaviors (such as mobile phone dependence), thereby contributing to the theoretical foundation linking physical activity and sleep disturbances in this population. However, there are several limitations to this study. First, convenience sampling, as an efficient and cost-effective research method, allows for the rapid collection of data within limited time and resources. Its flexibility facilitated the smooth progress of the study and provided preliminary data to support larger-scale future research. However, the sample selection was based on the researchers' convenience, which may introduce bias in certain key characteristics, limiting the generalizability and external validity of the findings. Additionally, all data in this study were self-reported by participants. Although the questionnaires were completed under the guidance of teachers and collected on-site, the accuracy and validity of the data may still be compromised. Future studies should incorporate interviews and other more objective assessment methods to ensure greater reliability. Second, as a cross-sectional study, the ability to draw causal conclusions, direct interpretations, and overall generalizations is limited. Longitudinal studies are necessary to clarify the direction of effects. Third, the research did not fully consider a range of socio-economic factors, such as family income and parental employment status, which may have had significant effects on both physical activity levels and sleep quality in adolescents. The inclusion of such variables could provide a deeper understanding of the results. Finally, the study was conducted within a limited cultural and geographic context, which may constrain the generalizability of the findings to different cultural and geographical settings. Future research should address this by examining these relationships in diverse cultural and geographic contexts to enhance the applicability and generalizability of the results.

Conclusion

This study further elaborates on the potential mechanisms underlying the association between physical activity and sleep disorders in adolescents. Physical activity can directly negatively predict adolescent sleep disorders. Additionally, it can indirectly predict these disorders via anxiety and mobile phone dependence. Furthermore, it can negatively predict adolescent sleep disorders through both of these pathways simultaneously.

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Authors' contributions

Ting Xiao123456, Mengting Pan156, Xunjuan Xiao356, Yang Liu1234561
Conceptualization; 2 Methodology; 3 Data curation; 4 Writing - Original Draft;
5 Writing - Review & Editing; 6 Funding acquisition.

Funding

Not applicable.

Data availability

The datasets generated and/or analysed during the current study are not publicly available due [our experimental team's policy] but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the Biomedicine Ethics Committee of Jishou University before the initiation of the project (Grant number: JSDX-2024-0086). And informed consent was obtained from participants and their guardians before the start of the program.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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