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The chain mediating effect of psychological inflexibility and stress between physical exercise and adolescent insomnia

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Exploring the impact of physical exercise on adolescent insomnia and the chained mediating role of psychological inflexibility and stress between them. In September 2023, a questionnaire survey was conducted among 416 adolescents in Xiangxi Prefecture, collecting data on physical activity, insomnia, psychological inflexibility, stress, and related variables. Statistical analysis was performed, involving 215 boys and 201 girls with an average age of 15.37 ± 0.54 years. (1) Adolescent physical exercise showed significant negative correlations with stress ($r=-0.329$, $P<0.01$), Psychological inflexibility ($r=-0.251$, $P<0.01$), and insomnia ($r=-0.286$, $P<0.01$). Stress exhibited significant positive correlations with Psychological inflexibility ($r=0.746$, $P<0.01$) and insomnia ($r=0.601$, $P<0.01$). Psychological inflexibility also demonstrated a significant positive correlation with insomnia ($r=0.555$, $P<0.01$). (2) Psychological inflexibility and stress were found to mediate the relationship between physical exercise and adolescent insomnia. This study found that the relationship between physical exercise and adolescent insomnia can be mediated by psychological inflexibility and stress, thereby further enriching the understanding of the psychological mechanisms linking these variables. It is recommended that governments and schools implement corresponding measures to promote adolescent participation in physical exercise. These initiatives can help reduce adolescents' levels of Psychological Inflexibility, alleviate stress and insomnia issues, and simultaneously enhance their sleep quality, thereby promoting comprehensive development of their physical and mental health.

Keywords Psychological inflexibility, Stress, Physical Exercise, Insomnia, Adolescent

Insomnia refers to the inability to fall asleep or maintain sufficient sleep when desired, leading to daytime dysfunction, noticeable fatigue, and difficulties with concentration[1]. The quality of sleep is closely intertwined with both physiological and psychological health. In China, 36% of junior high school students experience sleep disorders[2], among which insomnia is one of the most prevalent, affecting approximately 4–5% of adolescents[3]. Similarly, studies abroad indicate a 36% prevalence of insomnia among adolescents[4]. Numerous studies have highlighted that insomnia in adolescents often co-occurs with other mental health disorders such as depression and anxiety[5–7]. Therefore, research into adolescent insomnia and interventions to improve their sleep quality are critically necessary.

Physical exercise encompasses activities aimed at enhancing physical fitness and mental health through leisure, recreational, or fitness routines. Regular participation in organized sports can improve physical fitness levels and enhance personal psychological resilience[8]. Engaging in high-quality group sports can alleviate psychological stress in adolescents, promote physical relaxation, reduce sleep onset latency, and thereby alleviate the severity of insomnia[9]. Moreover, research suggests that physical exercise helps expend excess energy, facilitating easier transition into sleep[10], and can also regulate the body's internal clock, thereby improving sleep quality and reducing sleep onset time[11]. Physical exercise is associated with lower levels of adolescent insomnia, showing a

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negative correlation between the two[12]. Hence, it is hypothesized that H1: Physical exercise significantly predicts adolescent insomnia.

Psychological inflexibility is defined as the inability to effectively pursue valuable life actions due to unwanted thoughts and emotions stemming from negative experiences[13]. Acceptance and Commitment Therapy (ACT) identifies experiential avoidance and cognitive fusion as two primary psychological processes contributing to increased psychological inflexibility[14]. Research indicates that heightened psychological inflexibility prevents effective emotional regulation, often leading to cycles of negativity that hinder sleep initiation or lead to frequent awakenings at night, exacerbating insomnia[15]. Furthermore, psychological inflexibility is identified as a high-risk factor for increased insomnia levels[16]. Studies in the field of sports indicate that regular, moderate physical exercise enhances social adaptability and cultivates perseverance, thereby reducing levels of psychological inflexibility[17]. Additionally, physical exercise has been shown to mitigate psychological inflexibility and enhance adaptability to external environments and problem-solving abilities[18]. Thus, it is proposed that H2: Psychological inflexibility mediates the relationship between physical exercise and adolescent insomnia.

Stress is a critical indicator of adolescent physical and mental health. Adolescence is a period of significant challenges and changes, with stressors arising from academic, familial, and social pressures. The Sleep Disturbance Theory suggests that significant internal stress can over-excite neurons in the brain, disturbing the sleep process and leading to insomnia[19]. Physiological analyses of insomnia stress response models indicate that prolonged stress can maintain brain excitability, further contributing to insomnia[20]. Studies also demonstrate that engaging in sports can provide enjoyment and serve as a stress reliever[21]. Accordingly, this study proposes H3: Stress mediates the relationship between physical exercise and insomnia.

Physical exercise, psychological inflexibility, and stress each impact the level of adolescent insomnia. Psychological inflexibility and stress serve as mediators in the relationship between physical exercise and adolescent insomnia. Individuals with high psychological inflexibility tend to rigidly adhere to certain thought patterns or emotional responses, which can impair their ability to adapt effectively to new situations or cope with changes, potentially leading to increased anxiety, depression, or emotional instability under stress, thereby affecting their problem-solving abilities and stress management outcomes[22]. The social adaptation and comprehensive adaptation development theory suggest that physical exercise enhances adolescents' social skills and adaptability, thereby promoting psychological flexibility and alleviating stress[23,24]. Adolescents with lower psychological inflexibility are better equipped to cope with or alleviate stress through physical exercise, enhancing their resilience against various difficulties[25]. Participation in sports can improve adolescents' resilience and social adaptation skills, enabling them to better face or resist various challenges and thus mitigate stress[26]. Consequently, this study proposes H4: psychological inflexibility and stress mediate the chain of effects of physical exercise on adolescent insomnia levels.

In conclusion, to enhance adolescent sleep quality, reduce insomnia levels, and promote their physical and mental well-being, this study constructs a chain mediation model (Fig. 1) to explore the relationships among physical exercise, psychological inflexibility, stress, and adolescent insomnia.

Methods

Participants

The study was conducted in September 2023 with approval from the Ethics Committee of the university where the authors are affiliated. The study was conducted in accordance with the provisions of the Declaration of Helsinki. Convenience sampling was employed to select 450 third-grade students from a secondary school in the Xiangxi Tujia and Miao Autonomous Prefecture, Hunan Province, China, as participants. All adolescents participated voluntarily without any financial compensation. To ensure data collection standardization, rigorous training was provided to all researchers to maintain consistency in survey administration. Additionally, participants were closely supervised during the on-site questionnaire completion, which took place before lunch

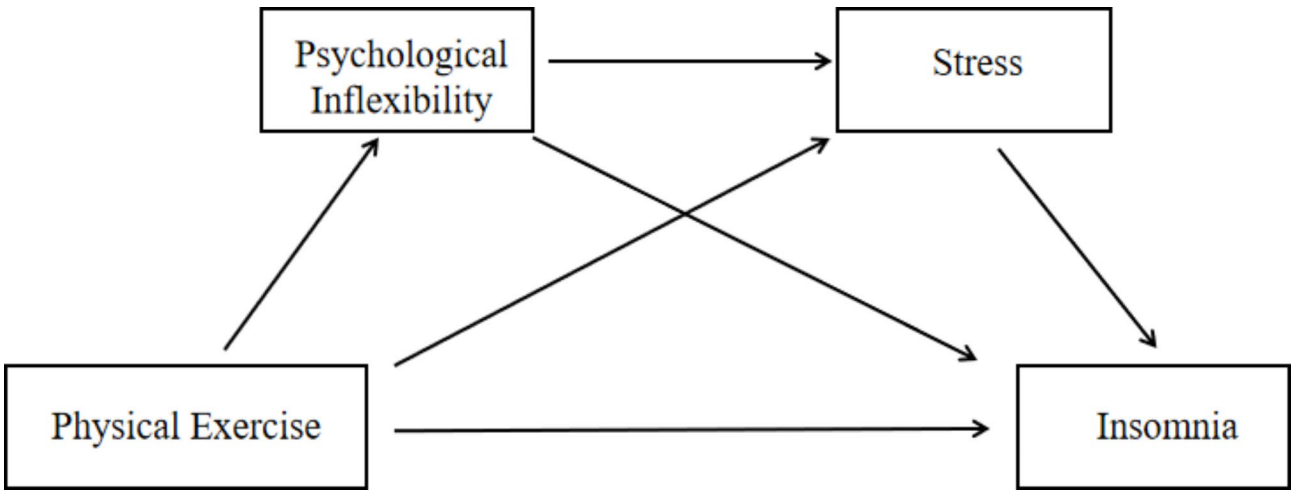

Figure 1. Chain mediation hypothesis model.

break to minimize disruption to their study schedules, with nearly all participants completing the questionnaire within 20 min or less.

Prior to distributing the questionnaires, detailed explanations about the study's objectives were provided to the participants. It was emphasized that the survey was anonymous, and collected data would be used solely for scientific research purposes without public disclosure. Participants were also informed of their right to withdraw from the survey at any time without consequences. Following completion of the survey, responses were reviewed and incomplete, systematically answered, or unreasonably answered questionnaires were identified as invalid and excluded from analysis. Ultimately, 416 valid questionnaires were obtained, resulting in a response rate of 92.44%. Of these, 215 were male, 201 were female, 172 were left-behind children, and 244 were non-left-behind children, with an average age of 15.37 ± 0.54 years.

Research tools

Physical exercise

The physical exercise level of adolescents was assessed using the Physical Exercise Level Scale[27]. This scale consists of 3 items measuring exercise intensity, duration, and frequency, each rated on a 5-point scale. The total score for physical activity is calculated as intensity × (duration−1) × frequency, with scores ranging from 0 to 100. A higher score indicates a higher level of physical activity. In this study, the Cronbach's alpha for the scale was 0.610.

Insomnia

Insomnia severity was measured using the Athens Insomnia Scale[28]. This scale comprises 8 items rated on a 4-point Likert scale, with total scores ranging from 8 to 32. Higher scores indicate greater severity of insomnia. The Cronbach's alpha for the scale in this study was 0.827.

Psychological inflexibility

Psychological inflexibility in adolescents was assessed using the Avoidance and Fusion Questionnaire for Youth[29]. This scale consists of 8 items rated on a 5-point Likert scale, with total scores ranging from 8 to 40. Higher scores indicate higher levels of psychological inflexibility. The Cronbach's alpha for the scale in this study was 0.873.

Stress

Stress levels in adolescents were measured using the Stress subscale of the Depression Anxiety Stress Scales (DASS−21)[30]. This subscale consists of 7 items rated on a 4-point Likert scale, with total scores ranging from 7 to 28. Higher scores indicate more severe stress levels. The Cronbach's alpha for the scale in this study was 0.863.

Statistical data processing

The initial data were exported and analyzed using SPSS 26.0 software. After organizing the data, internal consistency reliability analysis was first conducted using Cronbach's alpha to assess reliability. Subsequently, normality of the data was tested and confirmed to follow a normal distribution[31]. Therefore, Pearson correlation analysis was employed. Additionally, a serial mediation model was constructed.Bootstrap resampling was performed 5,000 times to obtain standard errors of parameter estimates and Bootstrap confidence intervals. A relationship was considered significant if the 95% confidence interval (95% CI) did not include zero. Gender and age were included as covariates in the analysis to control for their effects. Statistical significance was set at $p < 0.05$.

Results

Common method bias

The results indicate that three factors had eigenvalues greater than 1, with the first common factor explaining 32.82% of the total variance, which did not reach the critical threshold of 40%. Therefore, there is no significant common method bias present in this study.

Correlations among physical exercise, insomnia, psychological inflexibility, and stress

Table 1 presents the correlation coefficients and significance levels for the variables under study. The findings reveal significant negative correlations between physical exercise among adolescents and stress (r = -0.329, P < 0.01), psychological inflexibility (r = -0.251, P < 0.01), and insomnia (r = -0.286, P< 0.01). Additionally, positive correlations were observed between stress and psychological inflexibility ($r = 0.746$, $P < 0.01$), stress and insomnia ($r = 0.601$, $P < 0.01$), as well as psychological inflexibility and insomnia ($r = 0.555$, $P < 0.01$).

Chain mediation of psychological inflexibility and stress in the relationship between physical exercise and insomnia

The results, as presented in Table 2; Fig. 2, indicate that physical exercise significantly negatively predicts adolescents' insomnia directly (β=−0.038, P<0.001). Even when Psychological inflexibility and stress are included as mediating variables, the predictive effect of physical exercise on adolescents' insomnia remains significant (β=−0.014, P<0.001). Furthermore, physical exercise significantly negatively predicts both Psychological inflexibility (β=−0.050, P<0.001) and stress (β=−0.024, P<0.001).Psychological Inflexibility demonstrates a significant positive prediction for adolescents' stress (β= 0.479, P<0.001) and insomnia (β= 0.144, P<0.001). Similarly, stress significantly positively predicts adolescents' insomnia (β= 0.349, P<0.001).

The mediation analysis results (Table 3) indicate that physical exercise has a significant direct effect on insomnia, with an effect size of−0.014. Psychological inflexibility and stress mediate the relationship between physical exercise and insomnia through three distinct pathways: (1) Psychological inflexibility as a sole mediator

Variables	M ± SD	1	2	3	4	5	6
1 Gender	-	-					
2 Age	15.37 ± 0.536	-0.089	-				
3 Physical exercise	25.90 ± 26.653	-0.324**	0.009	-			
4 Stress	14.25 ± 4.653	0.258**	0.015	-0.329**	-		
5 Psychological inflexibility	28.62 ± 6.798	-0.224**	-0.052	-0.251**	0.746**	-	
6 Insomnia	15.99 ± 4.179	0.207**	0.052	-0.286**	0.601**	0.555**	-

Table 1. Correlation coefficients of study variables (n=416) *P<0.05,**P<0.01,***P<0.001 (The same applies hereinafter)

Outcome variables	Predictor Variable	β	SE	t	R^2	F
Insomnia	Gender	1.123	0.412	2.711*	0.101	15.406
	Age	0.516	0.366	1.410		
	Physical exercise	-0.038	0.008	-4.923***		
Psychological inflexibility	Gender	-2.251	0.678	-3.322**	0.090	13.610
	Age	-0.872	0.599	-1.457		
	Physical exercise	-0.050	0.013	3.998***		
Stress	Gender	0.525	0.320	1.644	0.581	142.169
	Age	-0.131	0.279	-0.470		
	Physical exercise	-0.024	0.006	-3.915***		
	Psychological inflexibility	0.479	0.023	20.897***		
Insomnia	Gender	0.238	0.345	0.689	0.398	54.204
	Age	0.290	0.301	0.964		
	Physical exercise	-0.014	0.007	-2.155*		
	Psychological inflexibility	0.144	0.036	-4.063***		
	Stress	0.349	0.053	6.575***		

Table 2. The chained mediation effect of psychological inflexibility and stress.

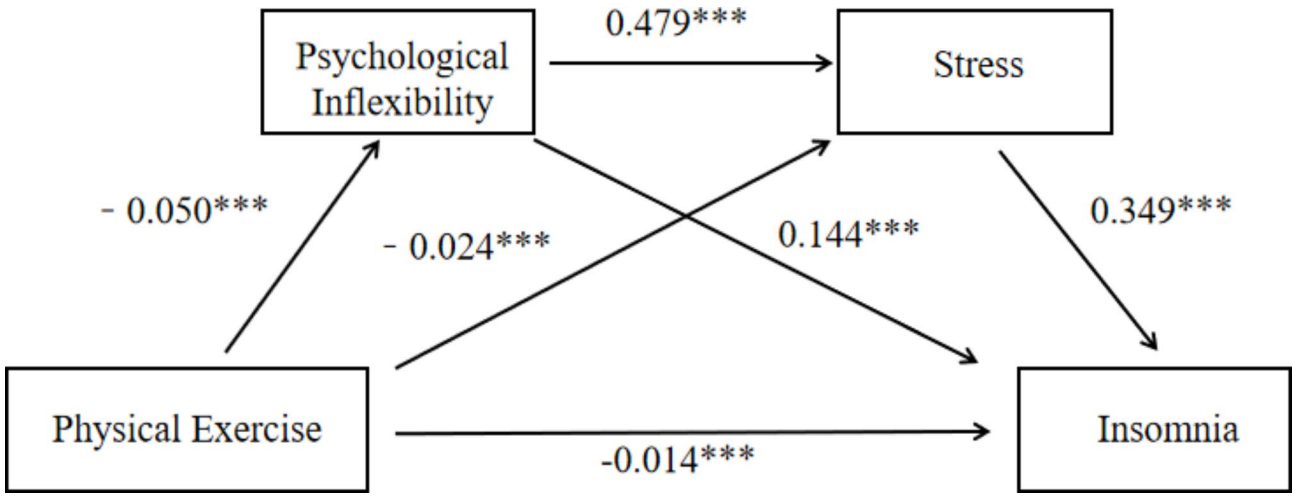

Figure 2. The chained mediation model.

with an effect size of−0.007, accounting for 18.42% of the variance; (2) stress as a sole mediator with an effect size of−0.008, explaining 21.05% of the variance; and (3) the sequential mediation of Psychological inflexibility and stress with an effect size of−0.008, also explaining 21.05% of the variance. Importantly, the 95% CI for all three pathways do not include zero, indicating their significant effects.

Type of Effect	Mediation Pathway	95% CI	SE	Effect size	Ratio of effect
Direct Effect	Physical exercise→Insomnia	[−0.027,−0.001]	0.007	−0.014	36.84%
Mediation Effect	Physical exercise→Psychological inflexibility→Insomnia	[−0.013,−0.028]	0.003	−0.007	18.42%
	Physical exercise→Stress→Insomnia	[−0.013,−0.004]	0.002	−0.008	21.05%
	Physical exercise→Psychological inflexibility→Stress→Insomnia	[−0.014,−0.004]	0.003	−0.008	21.05%
Total Mediation Effect		[−0.033,−0.015]	0.005	−0.024	63.16%
Total Effect		[−0.053,0.022]	0.006	−0.038	

Table 3. Mediation analysis of psychological inflexibility and stress.

Discussion

This study investigates the impact of physical exercise on adolescent insomnia, with a focus on the mediating roles of psychological inflexibility and stress. The results indicate that physical exercise significantly predicts adolescent insomnia, confirming Hypothesis (1) Research supports that moderate physical exercise enhances adolescents' mental health, alleviates insomnia symptoms, and improves sleep quality[32]. Intervention studies targeting adolescents with insomnia symptoms due to difficulty falling asleep have shown a significant reduction in detection rates and noticeable improvement in sleep quality post-intervention, thus affirming that physical exercise can mitigate adolescent insomnia and enhance sleep quality to a certain extent[33].

Psychological inflexibility mediates the relationship between physical exercise and adolescent insomnia, validating Hypothesis (2) Physical exercise negatively predicts psychological inflexibility in adolescents. It affects the nervous system by promoting neurotransmitter release such as dopamine and endorphins, thereby enhancing emotional regulation. Moreover, exercise helps in shifting attention away from negative thoughts and emotions, thereby reducing psychological inflexibility[34]. Higher psychological inflexibility positively predicts adolescent insomnia; individuals with higher psychological inflexibility may struggle more with excessive worry and difficulty in relaxation, particularly noticeable at night, leading to difficulties in falling asleep or sleep interruptions. Consistent with prior research findings, the severity of insomnia correlates positively with higher levels of psychological inflexibility[15]. Individuals with lower psychological inflexibility tend to manage daily stressors more effectively, reducing anxiety and worry, which aids in relaxation and improves sleep onset and maintenance.

Stress also mediates the relationship between physical exercise and insomnia in adolescents, validating Hypothesis (3) Physical exercise negatively predicts adolescent stress, consistent with previous research[21]. Exercise promotes the release of neurotransmitters like endorphins and endocannabinoids, contributing to mood enhancement and emotional stability. By reducing anxiety and depression, physical exercise indirectly improves sleep quality, as these emotional issues are often root causes of insomnia, aligning with previous studies[35]. Conversely, stress positively predicts adolescent insomnia; heightened stress levels induce physical and psychological tension, resulting in difficulty falling asleep or obtaining sufficient deep sleep, as supported by previous research[19]. Regular participation in physical exercise among adolescents can lower stress levels, thereby reducing the severity of insomnia and improving sleep quality.

The pathway from psychological inflexibility to stress plays a crucial mediating role in the impact of physical exercise on adolescent insomnia, confirming Hypothesis (4) psychological inflexibility positively predicts stress levels in adolescents. Individuals with higher psychological inflexibility can adapt more quickly to new environments and situations, adjusting their behaviors and thought processes to manage stress more effectively[36]. Regular physical exercise enhances psychological flexibility, reduces stress levels, mitigates insomnia severity, and thereby improves sleep quality.

This study constructs a chain mediation model where physical exercise serves as the independent variable, insomnia as the dependent variable, and psychological inflexibility and stress as mediating variables. It further elucidates the relationships among physical exercise, insomnia, psychological inflexibility, and stress in adolescents. Engaging in physical exercise helps improve emotional and cognitive functions, reduce psychological inflexibility, and better equip adolescents to cope with life and academic stressors, thereby reducing sleep onset and enhancing sleep quality. Based on these findings, it is recommended that schools and parents encourage adolescents to explore various sports to find suitable ways to release stress and enhance physical fitness. Establishing realistic exercise plans with achievable goals can boost physical health, confidence, and willpower. Furthermore, integrating physical activities with health education emphasizes their dual benefits in enhancing both physical and mental health. Physical activities relieve bodily tension, promote dopamine and endorphin secretion in the brain, alleviate stress and anxiety, and improve sleep quality.

Additionally, this study has some limitations. Firstly, the sample size was relatively small, suggesting that future research should consider increasing sample sizes to enhance representativeness and generalizability. Secondly, the universality of these findings may be limited due to variations in economic development and racial distribution. Future studies could broaden the scope of sampling to include data from more regions to increase the applicability of the results. Thirdly, relying on questionnaire surveys as the primary measurement tool may introduce subjective biases among respondents, potentially impacting result interpretation and generalization.

Conclusion

This study establishes significant correlations among physical exercise, insomnia, psychological inflexibility, and stress in adolescents. It demonstrates that physical exercise significantly predicts adolescent insomnia,

regular physical exercise can alleviate adolescent insomnia, and psychological inflexibility and stress mediate the relationship between physical exercise and sleep quality. Recommendations are provided for government and school interventions to promote adolescent participation in physical exercise, aiming to reduce psychological inflexibility, alleviate stress and insomnia issues, and enhance overall adolescent physical and mental health.

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.

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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-2023-0086). And informed consent was obtained from the participants before starting the program.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Additional information
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