

A Cross-Lagged Analysis of the Relationships Between College Students' Physical Exercise, Psychological Resilience, School Adaptation, and Mental Health

Menghan Zhang

Nanning University

Chenguang Gu

ssgcg@126.com

Nanning University

Research Article

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Abstract

Objective

This study uses a longitudinal tracking design to investigate physical exercise, mental health, psychological resilience, and school adaptation among college students. It explores the correlations among these four variables, and examines their longitudinal predictive relationships to understand how physical exercise influences college students' mental health.

Method

A four-month longitudinal follow-up survey was conducted among 2,177 undergraduate students at Nanning University. The study utilized the Physical Activity Rating Scale (PARS-3), Symptom Checklist-90 (SCL-90), Adolescent Resilience Scale (CD-RISC), and College Student School Adaptation Scale (CCSAS). Descriptive statistics and intergroup difference analyses were performed with SPSS and Pearson correlation analyses. AMOS 24.0 was used to analyze the longitudinal predictive relationship between physical exercise and mental health

Results

Physical exercise, mental health, psychological resilience, and school adaptation were all significantly correlated with each other ($p < 0.01$). A unidirectional predictive relationship was observed between physical exercise and mental health. Physical exercise significantly and positively predicted psychological resilience and school adaptation. Psychological resilience significantly and positively predicted school adaptation. School adaptation significantly and positively predicted mental health.

Conclusion

Physical exercise is an antecedent variable of mental health. It can enhance an individual's psychological resilience and improve their school adaptation level, which in turn positively impacts on mental health. The research findings provide a theoretical basis for optimizing design of university physical education programs and implementing mental health education practices.

Background

As an important talent resource for the nation's future development, the mental health of college students is closely related not only to their personal growth and development, but also directly effects the quality of higher education and social harmony and stability. However, mental health problems among college students have become increasingly prominent and have emerged as a major public health issue requiring urgent attention. According to statistics, the total number of patients suffering from various mental disorders in China has reached 173 million^[1], among whom 75% of severe mental illnesses occur before the age of 24. Meanwhile, the detection rate of mental health problems among college students has shown a year-by-year increase a^[2]. Multiple factors, such as academic burden, interpersonal relationship challenges, and employment pressures have contributed to the frequent occurrence of anxiety, depression and other psychological problems on university campuses^[3].

Therefore, exploring effective approaches to improving the mental health of college students has become an urgent and important issue in current higher education research and practice.

Physical exercise, as a low-cost and high-benefit health promotion method, plays an important role in maintaining students' mental health^[4]. Extensive research indicates that regular physical activity effectively alleviates stress and reduces levels of anxiety and depression, thereby exerting positive effects on adolescent mental health^{[5][6]}. However, according to the biopsychosocial model, individual's internal psychological state and external behavioral manifestations are often jointly shaped by physiological characteristics, environmental and social factors, and cognitive processing^[7]. Therefore, the influence of physical exercise on mental health is not simply a direct effect but is jointly realized through the mediating transmission of a series of psychosocial factors. From the perspective of positive psychology, psychological resilience—as a key psychological resource enabling individuals to cope with adversity, trauma, and stress—is a critical protective factor for mental health^[8]. The challenges involved in physical activities, such as enduring setbacks and persisting in training, are consistent with the mechanisms underlying psychological resilience development^[9]. Studies have shown that college students who engage in long-term physical exercise demonstrate higher levels of psychological resilience, and individuals with strong psychological resilience are generally better able to cope with academic pressures and interpersonal challenges, thereby maintaining good mental health^[10]. From a sociological perspective, school adaptation—a key indicator of the quality of interaction between college students and the campus environment—also plays a mediating role in the relationship between physical exercise and mental health^[11]. For college students undergoing transitional developments, school adaptation represents an important aspect of their social functioning. Participation in physical exercise, particularly team sports activities, enhances peer interaction, improves interpersonal communication skills, and strengthens students' sense of school belonging^[12]. In turn, good school adaptation serves as a crucial protective factor for college students' mental health. Therefore, psychological resilience and school adaptation may constitute key internal mechanisms through which physical exercise influences mental well-being.

In summary, although previous studies have confirmed the association between physical exercise and mental health, understanding of the underlying mechanisms remains insufficient. Most existing studies have relied on cross-sectional designs, making it difficult to clarify the causal relationship between physical exercise and mental health. Theoretically, the concept of synergistic interactions among multiple mechanisms proposed by the biopsychosocial model has not been adequately tested in studies on the relationship between physical exercise and mental health. Psychological resilience and school adaptation are both significant protective factors for mental health; however, whether they exert longitudinal mediating effects between physical exercise and mental health, and whether temporal sequences exist among these variables, still require further clarification through longitudinal research designs. Cross-lagged analysis can control prior levels of variables and effectively infer causal temporal ordering. Based on the integrated perspective of the biopsychosocial model, this study proposes a chain-mediated hypothesis model: Physical exercise, as a positive health behavior, enhances psychological resilience through mechanisms such as coping with challenges and persisting in training; enhanced psychological resilience further promotes college students' school adaptation in academic, interpersonal, and emotional domains; and better school adaptation ultimately contributes to improvements in mental health. This study intends to examine this longitudinal chain pathway through a two-wave cross-lagged design, aiming to reveal the internal mechanisms through which physical exercise affects college students' mental health, and providing theoretical support and practical implications for optimizing mental health intervention programs and fully utilizing the educational function of physical education in universities.

Methods

Participants and procedure

The study selected undergraduate students from Nanning University as the research sample, and online data were collected using the McQuartile tool. A follow-up survey was conducted in March 2025 and July 2025, with a four-month interval between the two assessments. A total of 2,792 participants were successfully matched across the two survey waves. After excluding invalid responses, 2,177 valid paired samples were retained, resulting in an effective questionnaire response rate of 77.9%. The final sample consisted of 1,134 male students (52.01%) and 1,043 female students (47.9%), with a mean age of 19.82 ± 1.24 years.

Table 1
Descriptive Statistical Analysis

variable	option	number of people (N)	percentage (%)
sex	man	1134	52.1
	woman	1043	47.9
grade	freshman	1166	53.6
	sophomore	1011	46.4
urban/rural status	town	615	28.2
	rural area	1562	71.8
the only child	yes	366	16.8
	deny	1811	83.2

Measures

Physical Activity

The Physical Activity Rating Scale (PARS-3) was used to assess participants' total amount of physical activity during the 30 days prior to measurement. The scale evaluates exercise participation across three dimensions: intensity, duration, and frequency. Physical activity volume is calculated using the formula:

Physical activity level = intensity × duration × frequency.

The scores for intensity and frequency are rated on a 1–5 scale, while the duration dimension is scored differently, with values from 0 to 4 corresponding to levels 1 through 5. The criteria for evaluating exercise volume are as follows: 19 points or lower indicate low exercise volume; 20–42 points indicate moderate exercise volume; and 43 points or above indicate high exercise volume^[13].

Mental Health

The Symptom Checklist 90-Revised (SCL-90) is one of the most widely used self-assessment instruments in psychiatric outpatient clinics and psychological disorder screening. The scale consists of 90 items rated on a 5-

point rating scale from 1 (none) to 5 (severe). It covers nine common dimensions of psychological symptoms: somatization, obsessive-compulsive disorder, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, and psychoticism.

Participants' level of psychological distress can be classified according to the total symptom index: scores between 1–1.5 indicate no significant discomfort; 1.5–2.5 suggest occasional symptoms with low frequency; 2.5–3.5 reflect mild to moderate symptom; 3.5–4.5 indicate moderate to severe symptoms; and scores above 4.5 suggest frequent and intense symptoms. Higher total scores indicate poorer mental health. Numerous studies using exploratory factor analysis and correlation analyses have demonstrated that the SCL-90 possesses high reliability and validity^[14]. In this study, the Cronbach's α coefficients for the two measurements were 0.988 and 0.987, respectively.

Psychological Resilience

The Connor-Davidson Resilience Scale (CD-RISC) was originally developed by Connor and Davidson in 2003, and the Chinese version was revised by Professors Xiao Nan and Zhang Jianxin in 2007. The scale consists 25 items rated on a 5-point Likert scale (0 indicating "never"; 1 indicating "rarely"; 2 indicating "sometimes"; 3 indicating "often"; 4 indicating "almost always"). It includes three dimensions: resilience, strength, and optimism. Item 20 is reverse-scored, while all other items are positively scored.

The tenacity dimension includes questions 11–23; the strength dimension includes questions 1,5,7,8,9,10,24 and 25; and the optimism dimension includes questions 2,3,4, and 6. The primary measurement indicators are the total score and the average scores of each dimension. Higher scores indicate stronger psychological resilience. The scale has demonstrated good reliability and validity across different populations^[15]. In this study, the Cronbach's α coefficients for the two measurements were 0.951 and 0.978, respectively.

School Adaptation

The Chinese College School Adaptation Scale (CCSAS), developed by Fang Xiaoyi and colleagues based on international scales, consists of 60 items across seven dimensions: academic adaptation, interpersonal adaptation, emotional adaptation, self-adaptation, campus adaptation, career adaptation, and satisfaction. The scale adopts a 5-point Likert scale (Strongly disagree = 1, Disagree = 2, Uncertain = 3, agree relatively = 4, Agree = 5) 19 items are reverse scored. Higher scores indicate stronger adaptability and adjustment ability among college students. Multiple studies using exploratory factor analysis and correlation analysis have shown that the CCSAS demonstrates high reliability and validity^[16]. In this study, the Cronbach's α coefficients for the two measurements were 0.932 and 0.921, respectively.

Statistical Analysis

SPSS 27.0 was used for descriptive statistics and common method bias testing for the key variables. Pearson correlation analysis was conducted to examine relationships among variables. Difference analysis was performed to compare group differences in physical exercise and mental health. AMOS 24.0 was used to construct the cross-lagged model and examine the autoregressive and cross-lagged paths among variables at Time 1(T1)and Time 2 (T2).

Results

Common Method Bias Test

Harman's single-factor test was conducted to examine common method bias in the data ($N = 2,177$). The results showed that, under the unrotated condition, 18 and 16 principal components with eigenvalues greater than 1 were extracted, respectively. The first principal component accounted for 27.753% and 29.955% of the total variance, respectively, both of which were below the critical threshold of 40%. Therefore, it can be concluded that no serious common method bias existed in this study.

Descriptive Statistics and Correlation Analysis

Descriptive statistical analyses were conducted for all variables among college students at two time points. Regarding physical exercise, the mean total score at T1 was 16.83 ($SD = 17.52$), while for the mean total score at T2 was 18.43 ($SD = 16.74$), indicating that the overall level of physical exercise was relatively low and that substantial individual differences existed. From T1 to T2, the total physical exercise score showed an increasing trend. However, the relatively large standard deviations suggest significant individual variability in college students' physical exercise behaviors.

Regarding psychological resilience, the mean total resilience score at T1 was 57.04 ($SD = 15.42$), while the mean score at T2 was 57.47 ($SD = 16.95$), indicating an overall moderately high level of resilience. The resilience scores showed a slight upward trend over time, suggesting that psychological resilience demonstrates stability and potential for development.

Regarding school adaptation, the mean total score at T1 was 64.79 ($SD = 9.07$), whereas the mean score at T2 was 64.03 ($SD = 8.36$), indicating a slight decline in school adaptation from T1 to T2. Overall, the level of school adaptation remained at a moderate level.

Regarding mental health, the mean total score at both T1 and T2 were approximately 135, reflecting that the overall mental health status of the college students was relatively good.

The correlation analysis of physical exercise, interpersonal relationships, psychological resilience, and mental health at the two time points is presented in Table 2. The autocorrelation results showed that physical exercise, psychological resilience, school adaptation, and mental health scores at both T1 and T2 were all positively correlated (all $p < 0.01$), indicating that the developmental trends of the four variables remained relatively stable during the four-month follow-up period. In addition, the cross-lagged correlation analysis between the two measurements demonstrated statistically significant relationships among all variables ($p < 0.01$).

Table 2
Correlation analysis of variables across two measurements

variable	M ± SD	1	2	3	4	5	6	7	8
1. T1 Physical Exercise	16.83 ± 17.52	1							
2. T1 Psychological Resilience	57.04 ± 15.42	0.202**	1						
3. T1 School Adaptation	64.79 ± 9.07	0.140**	0.552**	1					
4. T1 Mental Health	135.21 ± 47.54	-0.121**	-0.293**	-0.372**	1				
5. T2 Physical Exercise	18.43 ± 16.74	0.438**	0.169**	0.122**	-0.116**	1			
6. T2 Psychological Resilience	57.47 ± 16.95	0.151**	0.548**	0.451**	-0.270**	0.201**	1		
7. T2 School Adaptation	64.03 ± 8.36	0.156**	0.473**	0.659**	-0.281**	0.174**	0.526**	1	
8. T2 Mental Health	135.9 ± 47.92	-0.127**	-0.222**	-0.336**	0.633**	-0.157**	-0.322**	-0.294**	1

Note: **At the 0.01 level (two-tailed), the correlation is significant.

Cross-Lagged Analysis of Physical Exercise and Mental Health

To determine the dynamic relationship between physical exercise and mental health, AMOS 24.0 was used to conduct a cross-lagged analysis and establish a cross-lagged model between the two variables. The model fit indices showed: $\chi^2/df = 7.628$, CFI = 0.974, GFI = 0.923, NFI = 0.971, IFI = 0.974, TLI = 0.971, and RMSEA = 0.055. Given the relatively large sample size (N = 2,177), the chi-square/degree of freedom ratio is potentially inflated by sample size effects. Following Wu Minglong's recommendations, model evaluation was primarily based on fit indices that are less sensitive to sample size, such as RMSEA, CFI, TLI, and SRMR. All indices reached standards for good model fit, indicating that the model was acceptable. All hypothesized paths achieved statistical significance ($p < 0.01$), and the robustness of the model results was verified through 5,000 Bootstrap samples.

As shown in Fig. 1, the regression path from T1 physical exercise to T2 mental health is significant ($p < 0.001$), whereas the regression path from T1 mental health to T2 physical exercise is not significant ($p > 0.05$). This indicates that T1 physical exercise significantly predicts T2 mental health.

Cross-lagged Analysis of Psychological Resilience and School Adaptation in the relationship Between Physical Exercise and Mental Health

To determine the dynamic relationships among physical exercise, psychological resilience, school adaptation, and mental health, a cross-lagged model was constructed using AMOS 24.0, as shown in Fig. 2. The model fit indices indicate: $\chi^2/df = 5.604$, CFI = 0.997, GFI = 0.998, NFI = 0.997, IFI = 0.997, TLI = 0.976, and RMSEA = 0.046, demonstrating that the model fitted well to the data and was therefore acceptable.

The model's autoregressive path in Table 3 showed that the autoregressive coefficients of physical exercise, psychological resilience, school adaptation, and mental health across the two time points were all statistically significant, indicating temporal stability in these variables: physical exercise ($\beta = 0.44, p < 0.001$), psychological resilience ($\beta = 0.53, p < 0.001$), school adaptation ($\beta = 0.57, p < 0.001$), and mental health ($\beta = 0.59, p < 0.001$) .

The results of the cross-lagged regression showed that T1 physical exercise significantly predicts T2 psychological resilience ($\beta = 0.04, p < 0.05$), T2 school adaptation ($\beta = 0.05, p < 0.01$), and T2 mental health ($\beta = -0.05, p < 0.01$). In addition, T1 psychological resilience significantly predicts T2 school adaptation ($\beta = 0.15, p < 0.001$); and T1 school adaptation significantly predicts T2 mental health ($\beta = -0.13, p < 0.001$). Notably, the direct predictive path from T1 psychological resilience to T2 mental health did not reach statistical significance ($\beta = 0.04, p = 0.082$).

Table 3
Path Coefficients of the Cross-Lag Model

T2 Physical Exercise ← T1 Physical Exercise	β	S.E.	C.R.	P
	0.44	0.018	22.722	<0.001
T2 Psychological Resilience ← T1 Psychological Resilience	0.53	0.020	29.247	<0.001
T2 school adaptation ← T1 school adaptation	0.57	0.017	29.993	<0.001
T2 Mental Health ← T1 Mental Health	0.59	0.018	33.069	<0.001
T2 Psychological Resilience ← T1 Physical Exercise	0.44	0.018	2.371	<0.05
T2 School Adaptation ← T1 Psychological Resilience	0.15	0.010	7.559	<0.001
T2 Mental Health ← T1 School Adaptation	-0.13	0.001	-6.229	<0.001
T2 School Adaptation ← T1 Physical Exercise	0.05	0.008	2.889	<0.01
T2 Mental Health ← T1 Physical Exercise	-0.05	0.001	-2.706	<0.01
T2 Mental Health ← T1 Psychological Resilience	0.04	0.001	1.739	0.082

Discussion

Correlation Analysis Between Physical Exercise, Psychological Resilience, School Adaptation, and Mental Health

Based on the cross-sectional survey data, the results showed that physical exercise, psychological resilience, school adaptation, and mental health among college students were all significantly correlated with one another ($p < 0.001$). These findings are consistent with those reported in a large body of related studies.

Physical exercise was significantly positively correlated with psychological resilience, indicating that college students who frequently engage in physical activity tend to demonstrate higher levels of psychological resilience. Hu Qiuan evaluated changes in psychological resilience and mental health among college students under different exercise loads and found that both moderate and high-intensity exercise significantly promoted psychological resilience, with moderate-intensity exercise showing a more pronounced positive effect^[17]. Research by Zhao Renda and colleagues further confirmed that college students' physical exercise behaviors were

significantly associated with parenting style and psychological resilience^[18]. The experiences facing setbacks, overcoming difficulties, and persisting in training during physical activities may help students cultivate perseverance and develop the ability to coping with challenges.

Physical exercise was also significantly positively correlated with school adaptation, indicating that exercise may facilitate college students' adaptation to campus life. From an ecosystem theory perspective, physical exercise provides students with a natural platform for peer interaction, helping students alleviate feelings of unfamiliarity and loneliness in new environments^[19]. Chen's research confirmed that physical exercise indirectly influences college students' loneliness through the chain mediating effect of interpersonal relationship quality, thereby supporting this theoretical mechanism. His longitudinal study further demonstrated a significant bidirectional dynamic relationship between physical exercise and interpersonal competence, indicating that regular participation enhances students' peer interaction and social communication skills^[20]. In addition, a systematic review by Eather also confirmed that sports participation positively affects adults' mental health and social outcomes, with social support playing a crucial mediating role between sports engagement and mental health^[21]. Specifically, team-based physical activities foster emotional connections and trust-building among individuals through shared goals and collaborative experiences, and such social interactions form an important foundation for interpersonal adaptation within school settings.

Psychological resilience was significantly positively correlated with school adaptation, suggesting that individuals with higher levels of psychological resilience are better able to cope with academic pressure, establish harmonious interpersonal relationships, and regulate emotional states, thereby achieving better adaptation in the school environment. This finding is consistent with numerous previous studies indicating that mindfulness indirectly promotes junior high school students' school adaptation through the mediating role of psychological resilience^[22]. Improvements in psychological resilience have also been shown to exert a positive influence on school adaptation^[23]. As a core psychological resource for coping with adversity, psychological resilience helps individuals mobilize internal and external resources more effectively and adopt proactive coping strategies when facing challenges such as academic pressure, interpersonal difficulties, and environmental changes, thereby facilitating faster adaptation to school settings.

Physical exercise was significantly positively correlated with mental health, indicating that college students with higher levels of physical activity tend to report lower levels of psychological symptoms. This finding is consistent with the analysis conducted by White, whose study found a significant negative correlation between physical exercise and symptoms of depression and anxiety, with these associations remaining stable across different age groups, genders, and populations^[24]. Research by Chen Zhenkai further demonstrated that physical exercise significantly and positively predicts adolescents' mental health, and that college students who engage in regular exercise demonstrate significantly better mental health than their less active peers^[25]. Similarly, Liu Manluo and colleagues found significant positive associations between physical exercise levels and mental health in their study on physical activity, mobile phone addiction, and mental health among college students^[26]. From physiological, psychological, and social interaction perspectives, physical exercise exerts positive effects on individuals' mental well-being.

It should be noted that the sample size in this study was relatively large. Under large-sample conditions, even weak correlation coefficients can easily reach the statistical significance level of $p < 0.001$, reflecting the statistical characteristic that the relationships genuinely exist but may be relatively weak in magnitude^[27]. From the

perspective of behavioral science, both college students' physical exercise behaviors and mental health status are jointly influenced by multiple factors, including genetics, personality, environment, and social support. As a single independent variable, physical exercise has limited explanatory power regarding mental health, which is a common phenomenon in psychological and behavioral research^[28]. Therefore, although the absolute values of the correlation coefficients were relatively small, the results remain robust and credible given the large sample size and multifactorial influences, and do not undermine the overall explanatory power of the longitudinal mediation model.

Based on cross-sectional survey data, this study preliminarily revealed the internal mechanisms through which physical exercise effects the psychological states of college students, thereby providing empirical support for understanding and alleviating psychological distress in this population. The findings also provide theoretical insights for developing intervention strategies aimed at enhancing psychological resilience and improving school adaptation skills.

The longitudinal correlation analysis showed that all variables are significantly positively correlated between T1 and T2. Physical exercise ($r = 0.602$), psychological resilience ($r = 0.637$), school adaptation ($r = 0.661$), and mental health ($r = 0.602$) all demonstrated stability during the four-month follow-up period. These findings are consistent with Buyalskaya's longitudinal study, which suggested that the formation of physical exercise habits generally requires more than six months and the early intervention is crucial for maintaining long-term exercise behaviors^[29]. Allan et al.'s longitudinal study of college students also found that psychological resilience among college students exhibited moderate stability over a six-month period, being influenced by both inherent personal traits and environmental factors^[30]. The relatively high temporal stability of school adaptation ($r = 0.661$) may be related to the relative stability of the educational environment and the gradual developmental characteristics of students' adaptive abilities.

Cross-Lagged Analysis of Physical Exercise and Mental Health

The cross-lagged analysis results indicated that T1 physical exercise significantly predicted T2 mental health, whereas T1 mental health did not significantly predict T2 physical exercise. The finding suggests a unidirectional predictive relationship between physical exercise and mental health.

This result is consistent with the cross-lagged study conducted by Dong Baolin and colleagues among adolescents, which demonstrated a reciprocal causal relationship between role identity and exercise behavior, while intrinsic motivation showed a unidirectional predictive effect on exercise behavior^[31]. The predictive relationship between physical exercise and mental health can be explained from multiple perspectives. From a physiological perspective, exercise promotes the secretion of neurotransmitters such as endorphins, dopamine, and serotonin, all of which are closely associated with emotional regulation and subjective well-being^[32]. From a psychological perspective, goal achievement, self-transcendence, and coping with setbacks during exercise can enhance individuals' self-efficacy and psychological resilience^[33]. From a social perspective, participation in physical exercise can increase social interaction, expand social networks, and strengthen social support^[34]. These physiological, psychological, and social mechanisms are interwoven, collectively forming the complex network underlying the mental health benefits of physical exercise.

It should be noted that, although this study revealed a unidirectional predictive relationship between physical exercise and mental health, the findings cannot be equated with strict causality. Firstly, the study's follow-up period

was only four months, and therefore the conclusions cannot yet be generalized to longer time spans. Secondly, the self-report measurement approach may also have influenced the results. In addition, although the predictive path from T1 physical exercise to T2 psychological resilience reached statistical significance ($\beta = 0.04, p < 0.05$), the effect size was relatively small, which may indicate that the influence of physical exercise on psychological resilience requires long-term accumulation before becoming fully apparent.

The non-significant predictive effect of T1 mental health on T2 physical exercise differs from some previous studies. Liu Hanping's cross-lagged study among adolescents found that cognitive reappraisal strategies could unidirectionally predict interpersonal relationship distress and physical exercise, while interpersonal distress could unidirectionally predict physical exercise behavior^[35]. Such discrepancies may be related to differences in sample characteristics, measurement periods, and assessment instruments. The four-month follow-up period adopted in this study may have been insufficient to capture the long-term effects of mental health on physical exercise behavior. Furthermore, college students' physical exercise behaviors are influenced by multiple factors, including academic pressure, time management, and exercise interest, with mental health representing only one of many influencing factors.

Cross-lagged Analysis of Psychological Resilience and School Adaptation Between Physical Exercise and Mental Health

The Cross-lagged analysis further examined the longitudinal chain process of "physical exercise → psychological resilience → school adaptation → mental health." T1 physical exercise significantly and positively predicted T2 psychological resilience ($\beta = 0.04, p < 0.05$), T2 school adaptation ($\beta = 0.05, p < 0.01$), and T2 mental health ($\beta = 0.05, p < 0.01$); T1 psychological resilience significantly and positively predicted T2 school adaptation ($\beta = 0.15, p < 0.001$), while T1 school adaptation significantly and positively predicted T2 mental health ($\beta = 0.13, p < 0.001$). This pathway pattern reveals the longitudinal mechanism through which physical exercise influences mental health.

A study by Liu Liang and Wan Bo involving 700 college students from four universities in Wuhan confirmed that physical exercise significantly affects school adaptation, and that emotional regulation self-efficacy and psychological resilience play chain mediating roles, accounting for 8.23% of the total effect^[36]. Similarly, Liu's research found among college students that psychological resilience and positive coping styles exert chain mediating effects between physical exercise and negative emotions (indirect effect value: -0.0324), with the pathway "physical exercise → psychological resilience → negative emotions" contributing the most^[37]. Han further demonstrated that physical activity indirectly promotes college students' mental health by enhancing social adaptation, with social adaptability playing a key mediating role^[38].

The present study found a positive predictive effect of psychological resilience on school adaptation ($\beta = 0.15$), which is consistent with the findings of Kim. Their longitudinal study of Korean university students showed that students with higher levels of psychological resilience reported better school adaptation one year later^[39]. Individuals with stronger psychological resilience are generally more capable of utilizing supportive resources in their environment and adopting flexible coping strategies when dealing with interpersonal conflicts and academic setbacks, thereby achieving better adaptation outcomes in school settings. The positive predictive effect of school adaptation on mental health ($\beta = 0.13$) has also been widely supported by previous studies. Liu's longitudinal study of Chinese university students found that school adaptation partially mediated the relationship between psychological resilience and mental health, with psychological resilience indirectly reducing psychological symptoms levels through enhanced school adaptation^[40].

Limitations and Future Directions

This study employed a questionnaire survey method in which all questionnaires were completed through self-report by students. Therefore, the collected information may contain a certain degree of subjectivity. To improve the accuracy and rigor of future studies, experimental intervention methods could be employed, such as comparative studies between experimental and control groups, to further verify the related conclusions.

Due to research constraints, the participants in this study were mainly college students from selected universities in Guangxi Province, resulting in certain limitations in sample representativeness. To enhance the generalizability of the findings, future research should expand the scope, increase the sample size, and adopt more diversified research methods in order to more comprehensively reveal the mechanisms influencing college students' mental health and improve the credibility of the findings.

Although this study employed cross-lagged analysis, only two time points were included, with a relatively short interval of four months. As a result, the findings could only reflect short-term developmental trends among the variables and were unable to examine individual differences in rates of change over time. Future research should extend the follow-up period and collect data across at least three waves, while employing random intercept cross-lagged panel models to more accurately distinguish within-person variations from between-person variation. Such approaches would allow for a more rigorous methodological examination of the causal dynamic relationship between physical exercise and mental health.

Conclusion

This study employed a longitudinal tracking approach to investigate the influence of physical exercise on mental health, as well as the chain mediating roles of psychological resilience and school adaptation. The main findings are as follows:

The overall level of physical exercise among college students was relatively low, while psychological resilience and school adaptation were at moderate levels. Overall mental health status was generally good, although structural changes were observed across different symptom dimensions. Significant correlations were found among physical exercise, psychological resilience, school adaptation, and mental health. Specifically, physical exercise was significantly positively correlated with psychological resilience and school adaptation, and significantly and negatively correlated with mental health symptoms. Psychological resilience and school adaptation were also significantly negatively correlated with mental health symptoms, while psychological resilience and school adaptation showed a significant positive correlation with each other. In addition, a unidirectional predictive relationship was identified between physical exercise and mental health. Physical exercise significantly and positively predicted subsequent mental health levels, whereas the predictive effect of T1 mental health on T2 physical exercise was not statistically significant.

Declarations

Ethics statement

The studies involving humans were approved by The Ethics Committee of the School of Basic Medical Sciences Shandong University (ECSBMSSDU2023-1-091). The studies were conducted in accordance with the local

legislation, institutional requirements, and the ethical standards of the Declaration of Helsinki. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Consent to Participate

Informed consent was obtained from all individual participants included in the study.

Clinical Trial Number

Clinical trial number: not applicable.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Author Contribution

M.Z. analyzed the data and wrote the main manuscript text. C.G. collected the data and revised the manuscript. All authors reviewed the manuscript.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to ethical and privacy restrictions. This study involved the collection of sensitive mental health and psychological resilience information from college students. Participants were assured that their individual data would remain confidential and would not be shared outside the research team. Informed consent obtained from all participants did not include provision for public data archiving or sharing. Furthermore, the Institutional Review Board (IRB) that approved this study imposed restrictions on data sharing to protect participant privacy. As a result, the raw data cannot be deposited in a public repository. However, de-identified aggregated data or analytical summaries are available from the corresponding author upon reasonable request, subject to IRB approval and appropriate data transfer agreements.

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Figures

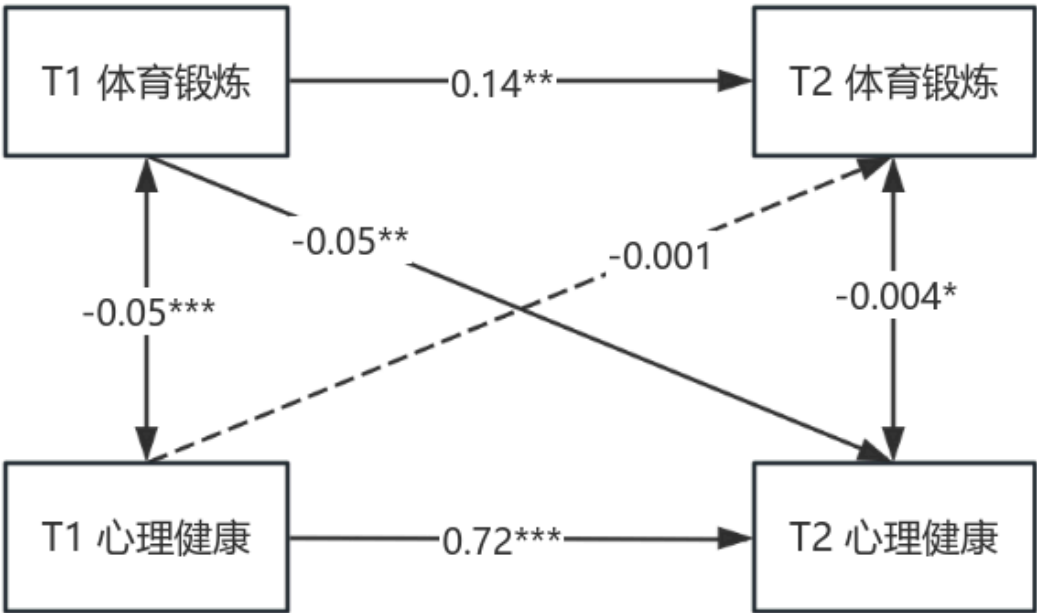


Figure 1

Cross-lagged Model of Physical Exercise and Mental Health

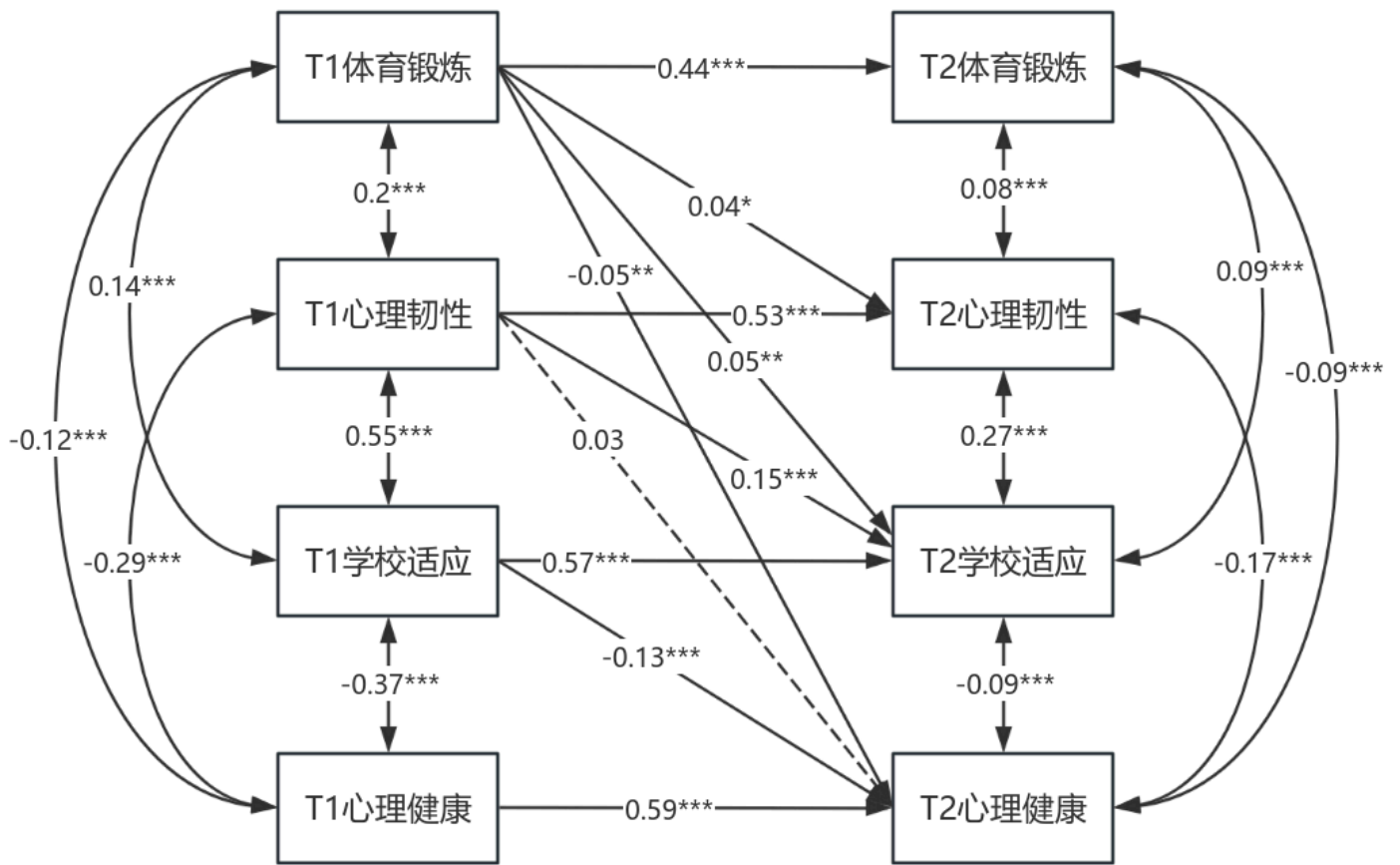


Figure 2

Cross-lagging Model of Physical Exercise, Psychological Resilience, School Adaptation, and Mental Health