scientific reports

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A chain mediation model reveals the association between physical exercise and sense of meaning in life in college students

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Exploring the relationship between and the sense of meaning in life among college students, as well as the mediating roles of time management disposition and achievement motivation in this association. A convenience sampling method was used to survey 517 university students in Liaoning Province, employing scales measuring , time management disposition, achievement motivation, and sense of meaning in life. (1) Physical exercise showed a significant positive correlation with meaning in life, demonstrating clear direct predictive effects; (2) Physical exercise positively predicted time management disposition, which in turn positively predicted both achievement motivation and meaning in life, with achievement motivation also positively predicting meaning in life; (3) Time management disposition and achievement motivation served as significant mediators between physical exercise and meaning in life, with three identified mediation pathways: physical exercise → time management disposition → meaning in life; physical exercise → achievement motivation → meaning in life; and physical exercise → time management disposition → achievement motivation → meaning in life. (1) Physical exercise significantly and positively predicts college students' sense of meaning in life; (2) Time management disposition and achievement motivation each serve as mediators, while also functioning as sequential mediators in the relationship between physical exercise and sense of meaning in life.

Keywords Physical exercise, A sense of meaning in life, Time management inclination, Achievement motivation

Mental health problems such as anxiety and depression among college students have been increasing year by year in recent years[1], suicidal behaviors caused by mental health problems show an upward trend[2]. The reason why college students have multiple adverse psychological problems is caused by the lack of a sense of meaning in life[3]. The sense of meaning in life is an essential psychological quality of an individual, an important internal factor for maintaining a positive psychological state and overcoming the difficulties of reality[4]. Sense of meaning in life affects the mental health of individuals; individuals with a higher sense of meaning in life have higher levels of mental health, and individuals with a lower sense of meaning in life experience more suicidal and antisocial behaviors[5]. College students are in a critical period of physical and mental development and personality shaping. College students with a high sense of meaning in life are more likely to adapt to college life with an optimistic and proactive attitude of self-encouragement in the face of goals and tasks in life[6]. Physical exercise, as a positive form of behavioral intervention, can enhance the sense of life meaning[7]. The Self-Determination Theory (SDT) points out that human behavior is driven by three basic psychological needs: autonomy, competence, and relatedness. Time management tendency reflects an individual's ability to autonomously plan for life goals (the need for autonomy), while achievement motivation reflects an individual's pursuit of ability improvement (the need for competence)[8]. Research shows that physical exercise can transform external motor behaviors into internal drives by satisfying these psychological needs, thereby promoting individual mental health[9]. Further research has found that the satisfaction of these basic psychological needs not only directly improves the level of mental health but also has a significant positive impact on the sense of life meaning[10]. Based on this, time management tendency and achievement motivation are selected as key mediating variables to explain the relationship between physical exercise and the sense of life meaning. By constructing the chained mediating path of "physical exercis e→time

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management (autonomy) → achievement motivation (competence) → sense of life meaning", new evidence is provided for the application of SDT in the field of healthy behaviors.

Therefore, this study innovatively integrates the two mediating variables of time management tendency and achievement motivation, which not only reveals the internal psychological mechanism by which physical exercise enhances the sense of life meaning, but also provides a theoretical basis and practical guidance for colleges and universities to carry out mental health education.

Theoretical foundations and hypotheses

The relationship between physical exercise and a sense of meaning in life

A sense of meaning in life refers to an individual's perception of the meaning and value of life that he or she possesses in the present and the search for meaning and purpose in future life[11]. The sense of meaning in life consists of meaning experience and meaning-seeking, meaning experience refers to the individual's evaluation of life in the present, and meaning-seeking indicates the degree of the individual's effort in pursuing the meaning of life[12]. Physical exercise is a sport that enhances physical fitness, promotes physical and mental health, and improves the organism's ability to wellness and fitness, recreation and leisure, health care and rehabilitation, and mental intelligence exercises[13]. Studies have shown that sports exercise can be invigorating[14], adherence to exercise is closely related to meaning in life[15]. Physical exercise has a positive impact on the sense of meaning in life[16]. Physical exercise is effectively improves adolescents' mood and sense of meaning in life[17]. Therefore, hypothesis H1 of this paper is proposed: physical exercise can positively affect the sense of meaning in life.

The mediating role of time management tendency

Time management tendency is a more stable personality tendency formed by individuals in the process of managing time, which refers to the psychological and behavioral characteristics of individuals in treating the function and value of time and in the way of using time, including three dimensions: a sense of the value of time, view of time monitoring, and sense of time effectiveness[18]. Recent studies have demonstrated that the mechanisms through which physical exercise influences executive functions—particularly time management abilities—remain insufficiently explored[19]. As a core dimension of self-regulation, the tripartite structure of time management (encompassing time value perception, monitoring perspective, and efficacy belief) has been empirically validated to systematically account for behavioral adaptation processes[20]. Neuroscientific research further reveals that exercise can enhance temporal monitoring capacity by improving prefrontal cortex functionality, offering novel insights into the exercise-cognition transformation mechanisms[21].The three dimensions of time management tendency, i.e., time efficacy, time monitoring view, and time value, were significantly improved through physical exercise intervention[22]. Adolescents' weekly Physical exercise positively correlates with total Physical exercise time management ability[23]. The study showed that the participants who adhered to physical exercise more than three times a week for more than 12 months had the highest ability of time management tendency[24]. When people manage their time poorly, they cannot experience the value and meaning of life well[25]. Time management tendency is one of the influencing factors of a sense of life meaning[26]. A more significant positive correlation between time management tendency and a sense of life meaning[27]. Therefore, it is hypothesized that physical exercise affects college students' sense of the meaning of life through time management tendencies. Hypothesis H2 of this paper is proposed: time management tendency plays a mediating role in physical exercise and sense of meaning of life.

The mediating role of achievement motivation

Achievement motivation refers to an individual's motivation to pursue the desired realization of a goal. It is the internal driving force that aspires to reach the goal[28], which can be divided into two different natures of motivation: the pursuit of success and the avoidance of failure[29]. Current research has identified fundamental differences in how achievement motivation operates in sports contexts compared to academic settings[30]. Recent advancements in Self-Determination Theory emphasize that the satisfaction of autonomy needs within athletic environments plays a distinctive role in motivation internalization[31]. This context-specific characteristic establishes achievement motivation as a crucial variable for elucidating the psychological mechanisms underlying physical exercise participation. Physical exercise serves as an effective pathway for fostering the development of individual achievement motivation[32]. Exercise behavior influences achievement motivation of college students[33]. Physical exercise can stimulate boys' achievement motivation in sports, and the physical education program is used to guide boys to participate actively in physical exercise and generate achievement motivation to actively participate in sports[34]. Meanwhile, there is a significant positive correlation between achievement motivation and a sense of meaning in life[35], the higher the achievement motivation, the higher the sense of meaning. According to research, the achievement motivation goal of narcissistic personality is related to a sense of meaning in life[36], achievement motivation exerts a significant positive influence on the sense of meaning in life[37]. Based on the above obtained, hypothesis H3 of this paper is proposed: achievement motivation plays a mediating role in Physical exercise and a sense of meaning in life.

Chain mediation of time management tendencies and achievement motivation

According to research, college students' time management tendency is predictive of achievement motivation, and the sense of time value may influence achievement motivation through time monitoring and the sense of time efficacy[38]. Training college students in time management improves academic achievement and motivation[39]. Secondary school honors students' time management tendency significantly predicts achievement motivation, indicating that time management tendency is an important factor influencing students' achievement motivation[40]. At the same time, time management tendency and achievement motivation are significantly positively correlated, which is a positive influence relationship[41]. Therefore, it is hypothesized that Physical

exercise affects college students' sense of meaning in life through the chain mediation of time management tendency and achievement motivation. Based on this, this study proposes a fourth hypothesis, H4: Time management tendency and achievement motivation act as chain mediators in the relationship between Physical exercise and a sense of meaning in life.

In summary, this study takes college students as the investigative population. It proposes the following hypotheses: (I) Physical exercise has a direct effect on the sense of meaning in life (H1), (II) Physical exercise has a role in the sense of meaning in life through the tendency of time management (H2), (III) Physical exercise has a role in the sense of meaning in life through the motivation of achievement (H3), and (IV) Physical exercise has a chain mediation on the sense of meaning in life through the tendency of time management and the motivation of achievement role (H4). Based on this, a chain mediation model was constructed in this study (Fig. 1).

Survey objects and research methods

Survey objects

The study strictly followed the principle of "informed protection" of the Declaration of Helsinki, and the protocol was approved by the Ethics Review Board (IRB) of Liaoning Normal University (Approval No. LL2024085; Approval Date: May 29, 2024). All student participants provided informed consent voluntarily after receiving full disclosure of the study details, while retaining the right to withdraw from the research at any time.

To determine the appropriate sample size, an a priori power analysis was conducted using G*Power 3.1 software. Based on a linear multiple regression model with a medium effect size ($f^2 = 0.15$), significance level ($\alpha = 0.05$), and statistical power ($1-\beta = 0.80$), the results indicated a minimum required sample size of 82 participants to detect the proposed chain mediation effects. Employing a convenience sampling method, 517 undergraduate students from a university in Liaoning Province were recruited for the questionnaire survey, yielding 484 valid responses (response rate: 93.6%). The final sample comprised 234 males (48.3%) and 250 females (51.7%), with class year distribution as follows: 123 freshmen (25.4%), 132 sophomores (27.3%), 118 juniors (24.4%), and 111 seniors (22.9%).

Research methods

The scales used in this study have completed reliability and validity tests in a large number of previous studies, and after multidimensional empirical analyses, their validity and reliability have performed well, ensuring the reliability and validity of data collection. In addition, the manuscripts used in the study were obtained from open and public resources, following the norms of resource use. All authors can access and use them in accordance with the regulations, and the research process strictly complies with the requirements of academic ethics and resource use.

Physical exercise scale

The study employed the physical Exercise Scale, originally developed by Japanese psychologist Kimio Hashimoto[42], and subsequently adapted by Chinese scholar Deqing Liang in 1994, to assess college students' physical exercise behaviors through measurements of exercise intensity, duration, and frequency[43]. For example,"Please indicate the intensity of your extracurricular physical exercise participation." The "intensity × time × frequency" was used to calculate the Physical exercise status, higher scores indicate higher levels of Physical exercise. The Cronbach's α coefficient of this scale in this study was 0.774.

Time management tendency scale

The scale was adopted from Huang Xiting, Zhang Zhijie et al.[44] developed the Time Management Scale in 2001, which consists of 44 items and is divided into three subscales, i.e., the Sense of Time Value subscale (10

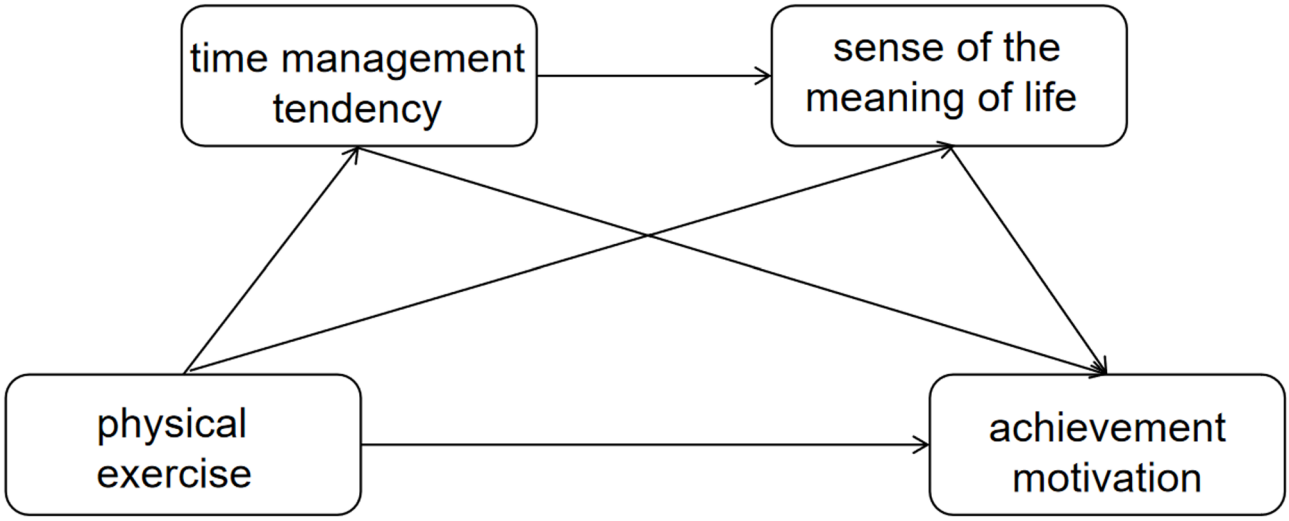

Fig. 1. Chained intermediary hypothetical model.

questions), the Time Monitoring View subscale (24 questions), and the Sense of Time Efficacy subscale (10 questions). For example, "I usually schedule my daily activities into a timetable", "I set specific goals before the start of each week", "I can effectively utilize classroom learning time". A 5-point Likert scale was used, with higher scores indicating higher levels of time management tendencies and lower scores indicating lower levels of time management tendencies. The Cronbach alpha coefficient for this scale in this study was 0.976.

Achievement motivation scale

The Achievement Motivation Scale (AMS) was used, compiled by Gjesme, T and Nygard, R[45], and revised by Yeh Renmin[46]. The Achievement Motivation Scale (AMS) was revised in 1992. It consists of 2 dimensions, the pursuit of success and the avoidance of failure, with 15 questions in each dimension. For example, "I feel happy when completing challenging tasks", "I feel anxious about work I'm uncertain of completing successfully". A higher total score indicates a higher level of achieve -ment motivation in the participants, and a lower total score indicates a lower level of achievement motivation. The Cronbach alpha coefficient for this scale in this study was 0.956.

Sense of meaning of life scale

The Sense of Meaning of Life Scale developed by Steger et al.[47]. and revised by Xinqiang Wang and Yayuan You[48] in 2016 was used. The scale comprises two subscales: the Presence of Meaning and the Search for Meaning, totaling 10 items. For example, "I comprehend the meaning of my life", "I am actively pursuing the meaning of my life". Higher scores indicate greater levels of meaning in life, while lower scores reflect weaker perceived meaning. In comparison, lower scores indicate lower levels of the sense of meaning in life. The Cronbach alpha coefficient for this scale in this study was 0.856.

Statistical processing

SPSS 27.0 and PROCESS plug-in were used to analyze the data in this study. The study employed the following analytical procedures: First, the reliability of scales was examined using Cronbach's α coefficient, with Harman's single-factor test applied to control for common method bias. Subsequently, descriptive statistics and Pearson correlation analyses were conducted to investigate the relationships among physical exercise, sense of meaning in life, time management disposition, and achievement motivation. A chain mediation model was constructed using the PROCESS macro (Model 6), with mediation effects verified through Bootstrap sampling (5000 iterations, 95% CI). All analyses adopted two-tailed tests with a significance level of $\alpha = 0.05$.

Results

Common method bias test

Since this study used four measurement tools for the same participants, and the data came from the participants' self-report, to reduce the common method bias, all the items were analyzed by exploratory factor analysis using Harman's one-way test when processing the data. The results showed that there were 13 factors with eigenvalues greater than 1, and the explained variance of the first factor was 39%, which was lower than the critical value of 40%, indicating no severe problem of common method bias.

Descriptive statistics and correlation analysis

Independent samples t-test was used to analyze gender differences in Physical exercise, sense of meaning in life, time management tendency, and achievement motivation. The results showed that males were better than females in Physical exercise, and the differences were significant in Physical exercise and time management tendency (Table 1).

One-way analysis of variance (ANOVA) was used to compare the differences in Physical exercise, sense of meaning in life, time management tendency, and achievement motivation among students of different grades. The results showed that there were significant differences in physical exercise, sense of meaning in life, time management tendency, and achievement motivation among college students of different grades. (Table 2).

The descriptive statistics and correlation analysis of each research variable are shown in Table 3. Physical exercise significantly and positively correlates with time management tendency, achievement motivation, and a sense of meaning in life. Since gender and grade were significantly positively correlated with Physical exercise, gender and grade were used as control variables for subsequent regression analyses.

	Sex	Number	M ± SD	F	*p*
Physical exercise	Male	234	3.08 ± 1.09	0.008	0.031
	Female	250	2.88 ± 0.95		
Sense of meaning in life	Male	234	3.61 ± 0.60	0.19	0.057
	Female	250	3.71 ± 0.57		
Time management tendency	Male	234	3.59 ± 0.57	0.634	0.011
	Female	250	3.73 ± 0.58		
Achievement motivation	Male	234	3.33 ± 0.68	0.913	0.061
	Female	250	3.44 ± 0.64		

Table 1. Differences in gender. N = 484.*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

	Grade	Number	M ± SD	F	*p*
Physical exercise	Freshman	123	2.83 ± 1.15	3.914	0.009
	Sophomore	132	2.84 ± 0.94		
	Junior	118	3.21 ± 0.99		
	Senior	111	3.06 ± 0.97		
Sense of meaning in life	Freshman	123	2.98 ± 1.03	11.902	< 0.001
	Sophomore	132	3.48 ± 0.69		
	Junior	118	3.61 ± 0.54		
	Senior	111	3.91 ± 0.47		
Time management tendency	Freshman	123	3.65 ± 0.56	15.523	< 0.001
	Sophomore	132	3.66 ± 0.59		
	Junior	118	3.50 ± 0.64		
	Senior	111	3.66 ± 0.57		
Achievement motivation	Freshman	123	3.95 ± 0.45	16.697	< 0.001
	Sophomore	132	3.55 ± 0.53		
	Junior	118	3.67 ± 0.58		
	Senior	111	3.16 ± 0.74		

Table 2. Differences in grades. N = 484.*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Variables	M ± SD	1	2	3	4
Physical exercise	2.98 ± 1.03	1			
Time management tendency	3.67 ± .058	.474**	1		
Achievement motivation	3.39 ± 0.66	.476**	.678**	1	
Sense of meaning in life	3.66 ± 0.59	.479**	.713**	.595**	1

Table 3. Descriptive statistics and correlation analysis (n = 484). *$P < 0.05$, **$P < 0.01$.

The problem of multicollinearity

Since all the variables are significantly correlated, the problem of multicollinearity may exist. Therefore, this study performed covariance diagnosis by standardized analysis. The results showed that the variance inflation factor (VIF) values of 1.367–1.965 for each predictor variable were less than 5. Therefore, the data did not have serious multicollinearity and could be further tested for a chained mediation effect.

Chain mediation effect analysis

According to the correlation analysis, it can be obtained that there is a significant correlation between Physical exercise, time management tendency, achievement motivation, and sense of meaning in life, which meets the statistical requirements for further mediation effect analysis. According to the SPSS macro program PROCESS model 6 provided by Hayes to test the chain mediation effect, all variables were standardized, with Physical exercise as the independent variable, the sense of meaning in life as the dependent variable, time management tendency and achievement motivation as the mediator variables, and grade and gender as the control variables, and the results of the mediation effect analysis are shown in Fig. 1.

The direct path from Physical exercise to sense of meaning of life is significant (β = 0.149, $P < 0.001$) hypothesis 1 is established; the direct path from Physical exercise to time management tendency is significant (β = 0.487, $P < 0.001$), and the direct path from time management tendency to sense of meaning of life is significant (β = 0.531, $P < 0.001$), which indicates that the existence of a mediating role for time management tendencies between Physical exercise and sense of meaning in life, Hypothesis 2 was tested; the direct path of physical exercise to achievement motivation was significant (β = 0.200, $P < 0.001$), and the direct path of achievement motivation to meaning of life was significant (β = 0.152, $P < 0.001$), indicating that the mediating role of achievement motivation between physical exercise and meaning of life existed, and hypothesis 3 was tested; and the time management tendency to achievement motivation was direct path was significant (β = 0.574, $P < 0.001$), indicating the existence of chain mediation and hypothesis 4 was validated, see Table 4.

According to Cohen's benchmark[49], the effects of physical exercise on time management tendency (β = 0.487), the effect of time management tendency on the sense of life meaning (β = 0.531), and the effect of time management tendency on achievement motivation (β = 0.574) all meet the criteria for a large effect (> 0.35). This indicates that strengthening physical exercise can significantly improve students' time management ability, and thus effectively promote the formation of a sense of life meaning. The effect of physical exercise on achievement motivation (β = 0.200) and the effect of achievement motivation on the sense of life meaning (β = 0.152) show a moderate effect (0.15–0.35), suggesting that stimulating achievement motivation through physical exercise is also effective. In practice, physical exercise can be deeply integrated with time management training. For example, phased

Outcome variables	Predictor variables	R	R^2	F	β	t
Time management tendencies	Gender	0.501	0.251	53.627	0.162	4.052
	Grade				0.020	0.507
	Physical exercise				0.487	12.177
Achievement motivation	Gender	0.705	0.498	118.546	0.034	1.011
	Grade				0.070	2.136
	Physical exercise				0.200	5.321
	Time management tendency				0.574	15.333
Sense of meaning in life	Gender	0.744	0.554	118.583	0.022	0.694
	Grade level				0.071	2.283
	Physical exercise				0.149	4.092
	Time management tendency				0.531	12.315
	Achievement motivation				0.152	3.523

Table 4. Regression analysis of Physical exercise, time management tendencies, and achievement motivation on sense of meaning in life.

Mediated pathways	Efficiency value	BootSE	95% confidence interval		Ratio of total effect (%)
			BootLLCI	BootULCI	
Total effect	0.276	0.023	0.231	0.321	100%
Direct effect	0.086	0.021	0.045	0.127	31.02%
Ind1	0.149	0.018	0.115	0.185	53.83%
Ind2	0.017	0.0056	0.007	0.029	6.30%
Ind3	0.024	0.0072	0.011	0.039	8.83%
Total indirect effect	0.191	0.0184	0.155	0.228	68.95%

Table 5. Bootstrap analysis of mediation effects.

exercise plans can be set up to cultivate students' planning and execution abilities simultaneously, to efficiently enhance their sense of life meaning.

A further test for multiple mediating effects between variables was done using the Bootstrap sampling method with 5000 repetitions. It was known to be significant at a 95% confidence interval, not containing 0, indicating significance. The significance of the mediating and chained mediating effects between Physical exercise and a sense of meaning in life were tested, where the direct effect value was 0.086, 31.02% of the total effect value. The total indirect effect value is 0.191, 68.95% of the total effect value. As can be seen through Table 5, Ind1: the mediation effect is significant in the path mediated by time management tendency, accounting for 53.83% of the total effect; Ind2: the mediation effect is significant in the path mediated by achievement motivation, accounting for 6.30% of the total effect; and Ind3: the chain mediation effect is significant in the path mediated by chain mediation of time management tendency and achievement motivation, accounting for 8.83% of the total effect.

Comparative data analysis revealed that the mediating effect of achievement motivation was significantly weaker than time management disposition. Mechanistically, distinct pathways emerged in how physical exercise influences meaning in life: time management disposition directly enhances life meaning by satisfying autonomy needs through efficient and straightforward pathways. At the same time, achievement motivation requires prolonged competence accumulation through gradual processes that are more susceptible to external interference. These findings substantiate the Self-Determination Theory's proposition regarding the more fundamental and pervasive impact of autonomy needs (versus competence needs) on psychological well-being[8].

Discussion

Through the direct effect analysis, it is known in this study that the direct effect of physical exercise and college student's sense of the meaning of life accounts for 33% of the total effect, indicating that physical exercise can significantly predict college students' sense of the meaning of life, which verifies hypothesis 1. Previous studies have shown that college students' Physical exercise positively correlates with their sense of meaning in life[14]. Exercise promotes the secretion of endorphins, which makes people feel happy and uplifted and promotes the individual's energy and satisfaction[13]. It has positive effects on college students' sense of meaning in life[50]. Self-determination theory[51] suggests three basic psychological needs: competence, relationships, and autonomy. The quest for the fulfillment of basic psychological needs is the central motivation for the construction of a sense of meaning in life[52]. Measuring individuals' basic psychological needs through physical exercise effectively improves adolescents' mood and sense of meaning in life[53]. Effective in improving adolescents' mood and sense of meaning in life[17]. Meanwhile, the regression analysis results show that the more Physical exercise they do, the more their sense of meaning in life improves, and vice versa[16]. Through the process of physical exercise,

the will of college students is sharpened, and they are encouraged to gain a sense of life experience in daily life and realize their self-worth. These results not only quantified the direct predictive effect of physical exercise on sense of meaning in life, but also established a benchmark for subsequent exploration of indirect mechanisms, laying a quantitative foundation for deeper understanding of their relationship. In light of this, promoting college students' physical exercise and fostering their sense of meaning in life requires concerted efforts from schools, parents, and society to collectively monitor their progress. For instance, schools could collaborate with communities to implement exercise check-in reward programs; parents might participate in parent–child fitness challenges; and social organizations could host exclusive outdoor events for college students, facilitating their discovery of life's meaning through sports participation.

This study found that time management tendencies mediated the relationship between Physical exercise and a sense of meaning in life, which tested hypothesis 2. It showed that Physical exercise positively predicted time management tendency and time management tendency positively predicted a sense of meaning in life. This is consistent with previous research that states that Physical exercise significantly increases time management tendencies[22]. At the same time, time management tendencies can positively affect the sense of meaning in life[27]. Studies have shown that exercise can affect time management ability through physiological functions[21]. The more optimistic the individual's perception of time, the more it affects their sense of meaning in life. The individual's structure and perception of time involves the individual's reflection and planning of life[54]. Unlike previous studies that focused solely on the unidirectional relationship between physical exercise and time management disposition, this study reveals the bridging role of time management disposition in connecting physical exercise with sense of meaning in life. This discovery significantly expands the theoretical framework for understanding the relationship between health behaviors and psychological experiences. Building on this, universities could deeply integrate time management training into physical education curricula by implementing progressive exercise goals and periodized training plans to guide students in effectively scheduling workout time. This approach should be complemented with time management workshops and exercise log tracking activities, enabling students to genuinely enhance time management skills through sports practice while achieving synergistic growth in both physical-mental health and self-efficacy.

The results of this study indicate that achievement motivation mediates the relationship between Physical exercise and a sense of meaning in life, validating Hypothesis 3, which suggests that Physical exercise positively predicts achievement motivation and that achievement motivation predicts a sense of meaning in life. This is consistent with the findings of previous studies that state that Physical exercise effectively enhances college students' achievement motivation[32]. Exercise behavior influences changes in achievement motivation in college students[33]. Meanwhile, the Self-Determination Theory posits that the satisfaction of self-needs in the exercise environment can lead to the internalization of motivation[9]. The study has found that achievement motivation positively predicts the sense of meaning in life[35]. This study makes novel contributions by incorporating achievement motivation into the examination of the relationship between physical exercise and sense of meaning in life. By explicitly identifying its mediating pathway between these variables, the research provides a new theoretical perspective for understanding how physical exercise influences mental health outcomes. Based on these findings, universities could implement tiered physical challenge programs featuring skill-based obstacle courses and team point competitions, coupled with phased achievement feedback and certification incentives, to effectively enhance students' achievement motivation and foster psychological growth.

When exploring the mechanism of action between physical exercise and a sense of meaning in life, an important pathway was also found to be the chain mediation constituted by time management tendency and achievement motivation. The results showed that time management tendency and achievement motivation had a chain mediating role between Physical exercise and a sense of meaning in life, accounting for 8.83% of the total effect. This indicates that Physical exercise has a specific enhancement effect on the sense of meaning in life, and this effect is formed by the joint action of increasing time management tendency and achievement motivation, which verifies Hypothesis 4. Consistent with previous studies, time management tendency can positively predict achievement motivation[41]. Fragmented Time Management of College Students to Satisfy the Needs of Achievement Motivation and Promote the Sustainable Development of College Students[55]. This study is the first to validate the complete pathway through which physical exercise enhances sense of meaning in life by improving time management skills and strengthening achievement motivation, providing new theoretical foundations for mental health interventions among college students.

The findings of this study support the core proposition of Self-Determination Theory that fulfilling basic psychological needs facilitates individual development. The mediating effect of time management tendency primarily operates through satisfying competence needs, enhancing students' sense of control over academic life by improving time monitoring efficacy and task planning capabilities. In contrast, achievement motivation predominantly addresses autonomy needs by strengthening intrinsic goal pursuit rather than external pressure. This divergence stems from the fundamental characteristics of these mediators: time management, as a foundational self-regulatory capacity, exerts cross-contextual influence, while achievement motivation, as a specific goal-oriented trait, demonstrates more circumscribed effects. These results align with the need-supportive behavior classification system proposed by Ahmadi et al., providing theoretical foundations for designing differentiated intervention strategies[56].

Conclusions

In summary, this paper verifies that time management tendency and achievement motivation play a chain mediating role between physical exercise and a sense of meaning in life, and studies the influence mechanism between physical exercise and a sense of meaning in life to provide new ideas for improving college students' sense of meaning in life.

Limitations and future directions

This study elucidates the intrinsic mechanisms through which physical exercise influences college students' sense of meaning in life, offering significant theoretical and practical implications for enhancing this crucial psychological construct. However, several limitations should be acknowledged. Firstly, while the convenience sampling method yielded a statistically adequate sample size (N = 484), potential limitations in gender, grade level, and other demographic representativeness may constrain the external validity of findings. Future research could employ stratified or cluster sampling to improve sample representativeness. Secondly, due to the adoption of a cross-sectional research design, the research approach is relatively simple. Although the correlations among variables are supported by theoretical models and statistical methods (such as Bootstrap mediation tests), it is still impossible to rigorously establish causal relationships. In future research, a longitudinal tracking design can be adopted, and various variables can be measured at different time points to more accurately examine the long-term effects of physical exercise on the sense of life meaning and its dynamic mediating mechanisms. Finally, the exclusive reliance on self-report measures, although using validated scales, may introduce social desirability or recall biases. Subsequent research could incorporate objective measures such as accelerometer-recorded physical activity data, experimental tasks for assessing achievement motivation, and multi-informant reports from teachers or peers to enhance robustness. For instance, drawing on Ahmadi et al.[56] motivational behavior classification system that categorizes exercise motivation into autonomy, competence, and relatedness dimensions, researchers could design targeted "exercise-cognition" intervention programs combining experimental manipulations with wearable device monitoring and academic performance indicators to systematically evaluate how different motivational dimensions influence the mediation pathways.

Data availability

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding authors.

Received: 13 June 2024; Accepted: 25 July 2025
Published online: 04 August 2025

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Acknowledgements

We would like to express our gratitude to the students who were willing to participate in this study.

Author contributions

Yaqi Li conceptualized the ideas in this paper and Hongbo Zhao, Lei Shi provided the raw data and supervised the project. All authors designed the model and performed the modeling analysis. All authors contributed to the Discussion section. All authors reviewed the final version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/1

0.1038/s41598-025-13710-z.

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