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Physical exercise promotes prosocial behavior in college students through a chain mediation of peer relationships and positive empathy

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Grounded in the person-context interaction theory, this study aimed to investigate the relationship between physical exercise and prosocial behavior among college students, with a specific focus on examining the parallel and chain mediating roles of peer relationships and positive empathy within this relationship. A convenience sampling method was employed. Surveys were conducted using the Physical Activity Rating Scale, the Prosocial Tendencies Measure, the Peer Rating Scale, and the Positive Empathy Scale among undergraduate students from five universities in China. A total of 991 valid questionnaires were collected. (1) Significant positive correlations were observed between physical exercise, prosocial behavior, peer relationships, and positive empathy. (2) Regression analysis and mediation effect tests revealed that physical exercise not only directly and positively predicted college students' prosocial behavior but also exerted significant influence through three indirect pathways: first, through the independent mediating role of peer relationships; second, through the independent mediating role of positive empathy; and third, through a chain mediating pathway involving peer relationships followed by positive empathy. This study demonstrates that physical exercise promotes prosocial behavior in college students by enhancing the quality of peer relationships and fostering positive empathy. This mechanism indicates that physical exercise contributes to the cultivation of a positive interpersonal environment, thereby building social capital, while simultaneously facilitating the development of internal emotional competencies, or psychological capital. These findings hold significant practical value for promoting college students' physical and mental health, nurturing their sense of social responsibility, and contributing to a harmonious society.

Keywords College students, Physical exercise, Physical activity, Prosocial behavior, Antisocial behavior, Peer relationships, Positive empathy, Negative empathy

prosocial behaviors refer to all kinds of actions that benefit others and that are carried out voluntarily[1] This behavior holds significant implications across multiple levels. For individuals, it serves as a key factor in enhancing subjective well-being[2], buffering against negative emotions such as anxiety and depression[3], and increasing life satisfaction and overall mental health[4]. At the group level, prosocial behavior acts as a lubricant for improving interpersonal communication and fostering harmony and adaptation[5]. For society, it embodies public morality and social responsibility, forming a cornerstone for building and maintaining a harmonious society[6].

As future pillars of society, the physical and mental health and moral development of college students are of paramount importance. However, in today's fast paced social context, multiple stressors related to academics, employment, and social interactions continue to intensify. This has led to a marked increase in the incidence of depression, anxiety, and various maladaptive issues among college students[7]. Research indicates that prosocial

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behavior can effectively help college students alleviate interpersonal tension, enhance their perceived social support, and serve as a robust buffer against stress and the negative emotions associated with competition[3]. Therefore, investigating the mechanisms influencing prosocial behavior in college students is of urgent practical significance for promoting their individual socialization process and moral growth.

According to the person-context interaction theory, the development of individual psychological behavior is the product of the combined effects of environmental and individual factors[8]. Within this theoretical framework, physical exercise, as a significant situational activity, may provide an ideal platform for fostering prosocial behavior. Within this platform, interpersonal peer relationships and the individual's internal capacity for positive empathy are likely key bridges connecting physical exercise to prosocial behavior. Peer relationships, a core topic in positive psychology, offer social functions such as mutual recognition, shared joy, and the sharing of fears[9]. Empathy, defined as an emotional response stemming from understanding and sharing the affective states of others[10], has been established as a core motivational factor directly eliciting prosocial behavior[11]. Although existing research has preliminarily confirmed the positive impact of physical exercise on prosocial behavior, most studies focus solely on team sports or intervention programs themselves. There remains a lack of in-depth exploration into the potential dual mediating mechanisms involving both interpersonal and individual emotional factors, particularly the synergistic effects of peer relationships and positive empathy. Therefore, this study aims to systematically examine the impact of physical exercise on prosocial behavior among college students, with a specific focus on revealing the parallel and chain mediating roles of peer relationships and positive empathy in this relationship.

The relationship between physical exercise and prosocial behavior

Physical exercise refers to physical activity that is accomplished at a certain intensity, frequency, and duration, with the aim of benefitting physical and mental health[12]. In the context of campus life, it serves not only as an important leisure activity but also as a significant pathway for enhancing college students' psychological well-being, optimizing interpersonal relationships, and improving social adaptation capabilities. Empirical studies consistently demonstrate that physical exercise can significantly and positively predict students' prosocial behavior[6]. The underlying mechanisms for this relationship may be explained as follows. First, engagement in physical exercise can produce sustained positive feedback, thereby elevating an individual's self-confidence and self-efficacy. This virtuous cycle contributes to the formation of a positive outlook on life and the world[13]. Second, it fosters the development of socially oriented personality traits and strengthens an individual's capacity to manage negative emotions[14]. Compared to their sedentary peers, adolescents who actively participate in physical activities exhibit lower levels of social anxiety and a higher propensity for prosocial behavior[15]. From a neuroscientific perspective, this association may stem from exercise induced neuroplastic changes, such as increased gray matter volume in brain regions like the prefrontal cortex and hippocampus, which are critically involved in social cognition and emotional regulation[16,17]. In summary, physical exercise represents a potent means of promoting prosocial behavior; however, a deeper analysis of its intrinsic pathways of influence remains necessary. Based on this, the present study proposes Hypothesis H1: Physical exercise positively predicts prosocial behavior among college students.

The mediating role of peer relationships

Peer relationships refer to interpersonal connections established and developed through social interactions among individuals at similar levels of physical and mental development, serving as an important indicator of an individual's social adaptation[18]. For college students in the late adolescence to early adulthood stage, the influence of peer relationships on their socialization process becomes increasingly prominent[19]. Extensive research confirms that physical exercise can effectively expand an individual's scope of interpersonal communication and deepen mutual understanding and trust among friends, thereby significantly enhancing the quality of peer relationships[20]. Conversely, perceived disparities in physical competence relative to peers during sports activities may lead to difficulties in forming friendships[21]. According to social support theory, emotional support and care from the peer environment can stimulate college students' sense of social identity, making their social behaviors more enthusiastic and dynamic[22]. Consequently, by creating contexts for cooperation and interaction, physical exercise establishes favorable conditions for building high-quality peer relationships. These positive peer relationships, in turn, encourage individuals to exhibit more positive social behaviors in their interactions[23] and may even reduce the likelihood of antisocial behaviors such as bullying[24]. This evidence indicates that peer relationships play a crucial mediating role between physical exercise and prosocial behavior[25]. Based on this rationale, the present study proposes Hypothesis H2: Peer relationships mediate the relationship between physical exercise and prosocial behavior among college students.

The mediating role of positive empathy

Positive empathy refers to understanding and vicariously sharing others' positive emotions, which can manifest either as a transient emotional state or as a stable personality trait[26]. According to the empathy-altruism hypothesis, empathic emotions can evoke purely altruistic motivation, thereby driving prosocial behavior[27]. Individuals with high levels of positive empathy demonstrate greater interest and enthusiasm toward their peers' positive experiences and exhibit a stronger willingness to support their peers' growth and development[28]. Furthermore, prosocial behavior itself exhibits a self-reinforcing effect. After receiving positive emotional feedback from recipients, perpetrators transform this feedback into internal pleasure through their own positive empathy, consequently establishing a virtuous cycle that sustains prosocial engagement[29]. As an important social activity, physical exercise provides individuals with a channel for emotional release and an environment conducive to developing primary relationships based on empathy and trust[30]. During physical activities, observing peers' states more readily triggers corresponding emotional responses in individuals, thereby exercising and enhancing

their empathic capacities[31]. Empirical research has also demonstrated that physical exercise interventions can significantly improve individuals' awareness of others' situations and their capacity for compassion[21]. Consequently, positive empathy represents another crucial internal mechanism through which physical exercise fosters prosocial behavior. Based on this reasoning, the present study proposes Hypothesis H3: Positive empathy mediates the relationship between physical exercise and prosocial behavior among college students.

The chain mediating role of peer relationships and positive empathy

Peer relationships are closely intertwined with the development of empathic capacities. Meta-analytic evidence indicates that high quality peer relationships positively correlate with empathy, encompassing both cognitive and affective components, with this association potentially exceeding the strength of the relationship between parents and children in this context[32]. During their university years, college students typically spend the most time and maintain the closest relationships with their peers[33]. The characteristics of peer relationships, which are marked by high degrees of equality, intimacy, and trust[32], provide ample opportunities for individuals to observe and emulate warm and supportive behaviors. This directly fosters the development of affective empathy. Simultaneously, the frequent sharing of feelings and thoughts among peers significantly enhances an individual's cognitive empathy, specifically the capacity to understand others' perspectives[32]. Within the collective setting of physical exercise, individuals establish connections with peers by learning rules and emulating roles[34]. In this process, the capacity to feel and accept others' emotions, namely empathic ability, constitutes a core element for forming positive interpersonal relationships[35]. Ultimately, this enhanced empathic capacity, facilitated by positive peer relationships, can in turn further improve relationship quality by generating more frequent prosocial behaviors[36] and promoting better strategies for conflict resolution[37], thereby creating a positive upward spiral. This study proposes Hypothesis H4: Peer relationships and positive empathy mediate the relationship between physical exercise and prosocial behavior among college students in a sequential chain.

The hypothetical model for this study is shown in Fig. 1.

Methods

Participants and procedure

Participants

This study employed a cross-sectional survey design, and participants were recruited using a convenience sampling method. The sample size was estimated using G*Power 3.1 software. For multiple regression analysis (with an effect size $f^2 = 0.15$, $\alpha = 0.05$, statistical power = 0.95, and 3 predictor variables), the calculated minimum required sample size was 764. Data collection was conducted from March 20 to April 20, 2024. Participants were recruited from five universities across three geographical regions in China (North China, East China, and South China) to enhance the sample's representativeness. Specifically, these included one university in Beijing, three in Anhui Province, and one in Guangdong Province.

The inclusion criteria for participants were: (1) full-time undergraduate students; (2) voluntary participation in the study with a commitment to respond based on their true circumstances; and (3) absence of severe physical diseases diagnosed by a hospital, as well as the absence of depression, mental disorders, or unclear consciousness that might affect questionnaire responses.

A total of 1503 questionnaires were initially collected. A rigorous data cleaning process was then conducted, during which invalid questionnaires were excluded. This included questionnaires with patterned responses, such as those providing identical answers across all items or displaying discernible patterns like alternating between options. Questionnaires with missing demographic information or incomplete responses in key sections were also removed. Ultimately, 991 valid questionnaires were obtained, yielding an effective response rate of 65.93%. The final sample size of 991 participants exceeded the minimum requirement. The demographic characteristics of the valid sample are detailed in Table 1.

Procedure

Data collection was administered via the professional online survey platform "Wenjuanxing". The procedure was as follows: Firstly, the researchers contacted course instructors or counsellors from the participating universities, explaining the study's purpose, significance, and ethical considerations. Upon securing their

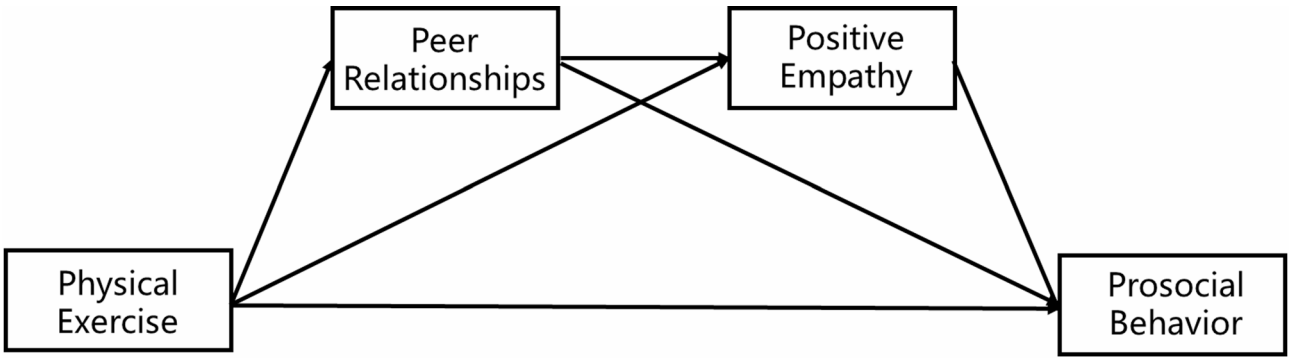

Fig. 1. Chain mediation effect model of peer relationships and positive empathy.

Characteristics	Category	Sample Size	Percentage
Gender	Male	546	55.10%
	Female	445	44.90%
Grade	Freshmen	310	31.28%
	Sophomores	253	25.53%
	Juniors	322	32.49%
	Seniors	106	10.70%
Place of Origin	Urban Areas	373	37.64%
	Rural Areas	618	62.36%
One-child Family	Yes	261	26.34%
	No	730	73.66%

Table 1. Participants' demographic information ($N = 991$).

support, the questionnaire was distributed on a class-by-class basis. Prior to participation, a standardized instruction script was read aloud to the students by uniformly trained research assistants or class representatives. This script explicitly informed participants about: (1) the academic nature of the research; (2) the voluntary nature of their participation and their right to withdraw unconditionally at any time; (3) the anonymous and confidential handling of all data, which would be used solely for aggregate analysis. Submission of the completed questionnaire was taken as implied informed consent.

Subsequently, a questionnaire link or QR code, which included the informed consent statement, was distributed through class group chats. Under the guidance of the researchers, participants independently completed the electronic questionnaire either during or after class. The entire process took approximately 5 min on average (ranging from 3 to 7 min). Upon submission, responses were automatically collected and stored by the platform.

Research tools

Physical activity rating scale (PARS-3)

The participants' levels of physical exercise were investigated using the PARS-3 compiled by Liang[38]. This scale is unidimensional and consists of three items measuring the intensity, frequency, and duration of physical exercise. Items are rated on a 5 point scale from 1 to 5. The total physical exercise score was calculated using the formula provided by Liang[38]: Total score of physical exercise = score of exercise frequency × (score of exercise time − 1) × score of exercise intensity. The total score ranges from 0 to 100, with higher scores indicating higher levels of physical exercise. This scale has been widely validated and demonstrates good reliability and validity among Chinese college student populations[39]. The test retest reliability of this scale is 0.82[40].

Prosocial tendencies Measure(PTM)

The PTM compiled by Carlo and Randall was used[41]. It contains 23 items divided into six dimensions: public (e.g., "When other people are around, it is easier for me to help needy others."), anonymous (e.g., "I tend to help needy others most when they do not know who helped them."), dire (e.g., "I tend to help people who are in a real crisis or need."), compliant (e.g., "When people ask me to help them, I do not hesitate."), emotional (e.g., "It is most fulfilling to me when I can comfort someone who is very distressed."), and altruism (e.g., "I feel that if I help someone, they should help me in the future"). The scale uses a 5-point Likert scale (1 = "strongly disagree", 5 = "strongly agree"). All items are positively scored, with the total score ranging from 23 to 115. A higher total score indicates a stronger tendency for prosocial behavior. In this study, the overall Cronbach's alpha coefficient for the PTM was 0.943. The Cronbach's alpha coefficients for the subscales were 0.739, 0.852, 0.680, 0.847, 0.778, and 0.812, respectively. Confirmatory factor analysis results indicated acceptable fit indices: $\chi^2/df = 4.870$, RMSEA = 0.063, RFI = 0.906, TLI = 0.924. These results indicate that the PTM demonstrated good reliability and validity in this study.

Peer rating scale (PRS)

The PRS from the Delaware School Climate Survey (Student Version) was used to assess students' perceptions of their peer relationships[42]. This is a unidimensional scale comprising 5 items (e.g., "Students get al.ong well with each other"). Responses are given on a 5-point Likert scale, where 1 represents "strongly disagree" and 5 represents "strongly agree". Higher scores reflect better quality of peer relationships among college students. The scale showed high internal consistency, with a Cronbach's α coefficient of 0.906. In this study, due to its unidimensional structure and small number of items, the confirmatory factor analysis model had low degrees of freedom, leading to inflated fit indices ($\chi^2/df = 15.833$, RMSEA = 0.122, TLI = 0.953, RFI = 0.950). Consequently, convergent validity was further examined. All standardized factor loadings ranged from 0.739 to 0.864, meeting or exceeding the recommended threshold of 0.70. The composite reliability (CR) was 0.909, and the average variance extracted (AVE) was 0.666, both of which surpassed the critical values[43,44]. These findings indicate that the PRS possessed good reliability and convergent validity in the current study.

Positive empathy Scale(PES)

PES was measured using the Chinese version of the Positive Empathy Scale, which was originally developed by Morelli et al.[26] and subsequently revised by Yue Tong et al.[45]. This unidimensional scale consists of 7 items (e.g., "When I see others receiving an unexpected surprise, I feel as excited as they do"). Items are rated on a 5-point Likert scale (1 = "Strongly disagree", 5 = "Strongly agree"). All items are positively scored, with the total score ranging from 7 to 35. Higher scores indicate a greater capacity for positive empathy. In this study, the scale's Cronbach's alpha coefficient was 0.946. Confirmatory factor analysis results showed good model fit: χ^2/df = 3.906, RMSEA = 0.054, RFI = 0.986, TLI = 0.990. This indicates that the PES demonstrated good reliability and validity in this study.

Data processing

Data analysis was performed using SPSS 26.0 and the PROCESS macro (version 4.2). First, following data cleaning and preprocessing, reliability and validity tests were conducted on all measurement tools to ensure data reliability and validity. Subsequently, common method bias was assessed using both Harman's single-factor test and the common latent factor method; the results indicated no severe common method bias. Then, Pearson correlation analysis was employed to conduct a preliminary examination of the main variables, clarifying the basic relational patterns among them.

Following this, to test the core hypotheses of the study, a chain mediation analysis was conducted using Model 6 from the PROCESS macro developed by Hayes. During the analysis, bootstrap sampling with 5000 iterations was applied to calculate confidence intervals. A significant effect was determined if the 95% confidence interval did not include zero. $p < .05$ was set to represent the statistical result with significance.

Ethics statement

This study involves research methodology and research procedures that follow the Declaration of Helsinki. The study was approved by the Human Research Ethics Committee of Capital university of Physical Education and Sports(Approval No. 2023A0203). We confirm that all methods were performed in accordance with the relevant guidelines and regulations. All participants agreed to participate in this research voluntarily; they provided informed consent when they completed the survey and were able to withdraw from the study freely at any time. In addition, our data were anonymized to ensure the privacy of all participants.

Results

Common method bias tests

To examine potential common method bias, two statistical approaches were systematically employed. First, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity were conducted to assess the data's suitability for factor analysis. The results indicated a KMO value of 0.955, and Bartlett's test was significant (χ^2 = 24076.542, df = 703, $p < .001$), confirming the presence of common factors among the variables and establishing that the data were highly suitable for factor analysis. Subsequently, Harman's single-factor test was performed. An exploratory factor analysis including all 38 measurement items was conducted, forcing the extraction of a single unrotated principal component. The results revealed six factors with eigenvalues greater than 1. The first factor accounted for 35.321% of the total variance, which did not exceed the critical threshold of 40%[46].

To further validate these findings, a more rigorous bifactor test was implemented. The results, presented in Table 2, demonstrated that the model fit indices of the bifactor model, which incorporated a common method factor in addition to the theoretical model, did not show improvement. This indicates that the introduction of the common method factor failed to enhance the model's fit. Combined, the results from these two testing methods confirm that common method bias is not a severe issue in this study, and the measurement results possess satisfactory validity.

Model	χ^2/df	RMR	RFI	TLI
Single-factor model	17.331	0.128	0.501	0.516
Four-factor model	6.129	0.072	0.823	0.848
Theoretical model	4.691	0.061	0.865	0.891
Bifactor model	6.049	0.071	0.826	0.850

Table 2. Confirmatory factor analysis and model comparison. Note: Single-Factor Model: All 38 measurement items were loaded onto a single common factor for the purpose of Harman's single-factor test. Four-Factor Model: The six dimensions of the Prosocial Tendencies Measure were combined into one latent variable, which, together with physical exercise, positive empathy, and peer relationships, formed four correlated factors. Theoretical Model: This model included the six dimensions of the Prosocial Tendencies Measure as six independent factors, plus the three factors of physical exercise, positive empathy, and peer relationships, resulting in nine correlated factors in total. Bifactor Model: A common method factor loading on all 38 items was added to the baseline nine theoretical factors from the theoretical model to test for common method bias.

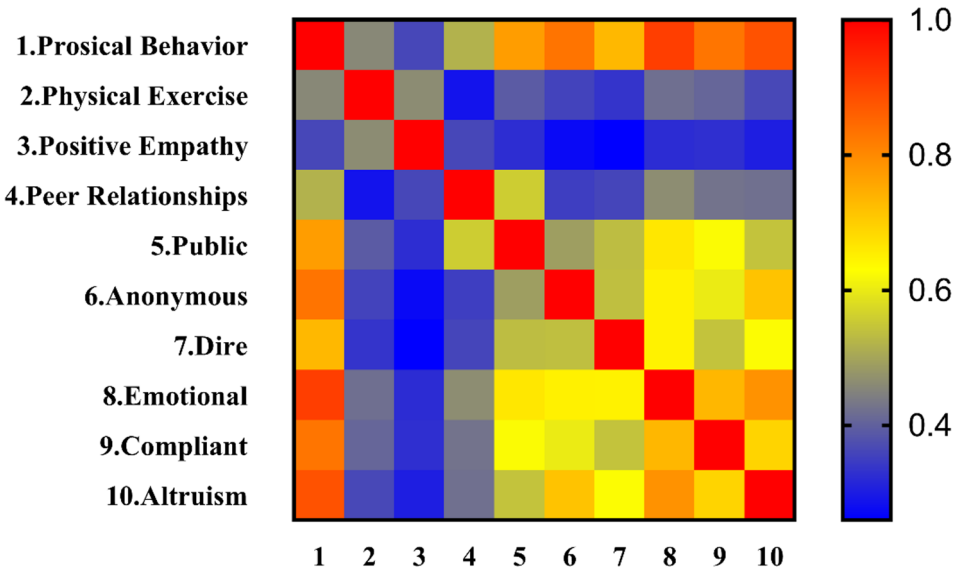

Fig. 2. Descriptive statistics and correlation analysis of variables.

Variable	Peer Relationships			Positive Empathy			Prosocial Behavior		
	β	SE	t	β	SE	t	β	SE	t
Gender[a]	−0.087	0.260	−0.336	−0.594	0.395	−1.504	2.062	0.753	2.737
Grade[b]	−0.020	0.122	−0.161	−0.015	0.186	−0.081	0.062	0.355	0.174
Place of Origin[c]	−0.343	0.265	−1.292	−0.356	0.404	−0.881	−0.212	0.770	−0.276
One-child Family[d]	0.197	0.297	0.663	0.003	0.453	0.006#	−0.583	0.862	−0.677
Physical Exercise	0.054	0.006	9.012&	0.122	0.009	11.504&	0.213	0.019	11.012&
Peer Relationships				0.425	0.048	8.774&	1.413	0.096	14.743&
Positive Empathy							0.162	0.061	2.676#
	R = .290			*R* = .523			*R* = .617		
	$R^2 = 0.084$			$R^2 = 0.274$			$R^2 = 0.380$		
	F = 18.114&			F = 61.791&			F = 86.249&		

Table 3. Regression analysis of the chain mediation model between physical exercise and prosocial behavior. Note: $N = 991$, a: gender is a dummy variable, with 1 for boys and 2 for girls; b: grade is a dummy variable, with 1 for freshmen, 2 for sophomores, 3 for juniors and 4 for seniors; c: Place of Origin is a dummy variable, with 1 for urban areas and 2 for rural areas. d: One-child Family is a dummy variable, with 1 for one child and 2 for the non-one child, # $p < .01$,& $p < .001$.

Correlates of physical exercise, peer relationships, positive empathy, and prosocial behavior

The results of the correlation analysis are shown in Fig. 2, which indicate that physical exercise is significantly and positively correlated with prosocial behavior; physical exercise is significantly and positively correlated with peer relationships, and with positive empathy; peer relationships are significantly and positively correlated with prosocial behavior, and with positive empathy; and positive empathy is significantly and positively correlated with prosocial behavior.

Mediation and chain mediation effects analysis

Using the Process plug-in, with physical activity as the independent variable, prosocial behavior as the dependent variable, and peer relationships and positive empathy as the mediating variables for mediation and chain mediation effect analyses. The results show (Table 3) that physical exercise has a positive predictive effect on prosocial behavior ($\beta = 0.213$, $p < .001$); physical exercise has a positive predictive effect on peer relationships ($\beta = 0.054$, $p < .001$); physical exercise has a positive predictive effect on positive empathy ($\beta = 0.122$, $p < .001$); peer relationships has a positive predictive effect on prosocial behavior ($\beta = 1.413$, $p < .001$); peer relationships has a positive predictive effect on positive empathy ($\beta = 0425$, $p < .001$); positive empathy has a positive predictive effect on prosocial behavior ($\beta = 0.162$, $p < .01$).

The mediation effect test shows that the direct effect of physical exercise on prosocial behavior is 0.213 (95% CI=[0.175,0.251]), accounting for 68.05% of the total effect. Therefore, H1 is verified; physical exercise impacts prosocial behavior through peer relationships, with a mediation effect of 0.076 (95% CI=[0.068,0.135]),

Path	Standardizedβ	Boot SE	95%CI	
			Lower limit	Upper limit
Physical Exercise→Prosocial Behavior	0.213	0.019	0.175	0.251
Physical Exercise→Peer Relationships →Prosocial Behavior	0.076	0.017	0.068	0.135
Physical Exercise→Positive Empathy →Prosocial Behavior	0.020	0.009	0.003	0.039
Physical Exercise→Peer Relationships→Positive Empathy→Prosocial Behavior	0.004	0.002	0.001	0.008
Total Effect	0.313	0.019	0.275	0.351
Indirect Total Effect	0.099	0.017	0.068	0.135

Table 4. Chain mediation effect test of peer relationships and positive empathy on physical exercise and prosocial Behavior.

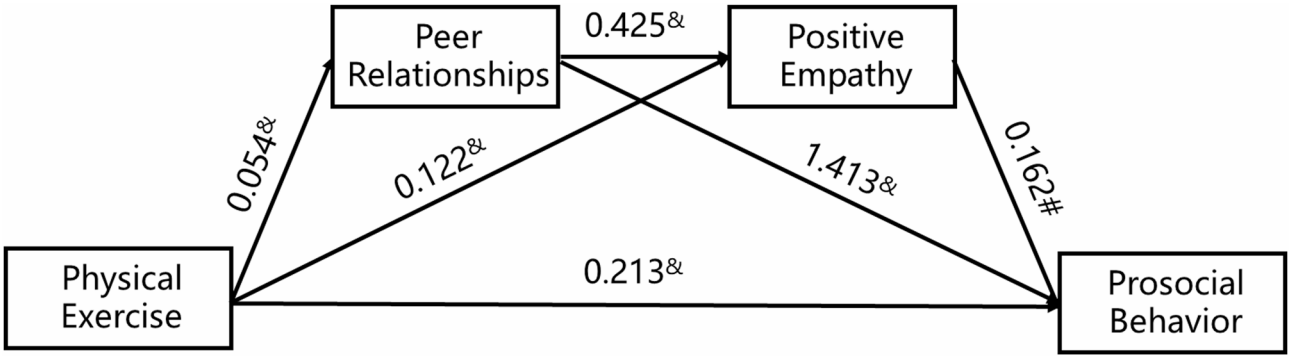

Fig. 3. The relationship between physical exercise and prosocial behavior: chain mediation between peer relationships and positive empathy.

accounting for 24.28% of the total effect. Therefore, H2 is verified; physical exercise impacts prosocial behavior through positive empathy, with a mediation effect of 0.020 (95% CI=[0.003,0.039]), accounting for 6.39% of the total effect. Therefore, H3 is verified; physical exercise has an impact on prosocial behavior through a chain mediation effect of peer relationships and positive empathy, with a mediation effect of 0.004 (95% CI=[0.001,0.008]), accounting for 1.28% of the total effect. Therefore, H4 is verified. The specific results are shown in Table 4; Fig. 3.

Discussion

The present study, utilizing a chain mediation model, elucidates the positive influence of physical exercise on prosocial behavior among college students and its underlying mechanisms. The results not only confirm the direct promotive effect of physical exercise on prosocial behavior but, more importantly, clarify that this influence is realized through two parallel and interrelated pathways: the interpersonal level factor of peer relationships and the individual level factor of positive empathy.

Direct effect of physical exercise on prosocial behavior: synergistic action of multidimensional mechanisms

This study reaffirms that physical exercise is a significant predictor of prosocial behavior. This finding aligns with previous research; however, the mechanisms underpinning this relationship are multidimensional and synergistic.

First, at the physiological and neurological level, physical exercise lays the necessary foundation for prosocial behavior. During exercise, neurochemicals such as endocannabinoids and opioids are released. This process not only improves central nervous system function and promotes a balance between neural excitation and inhibition[47,48] but also effectively enhances positive mood. Concurrently, neuroplastic changes induced by physical exercise, such as increased levels of brain-derived neurotrophic factor (BDNF), contribute to enhanced functionality in brain regions like the prefrontal cortex, which are closely associated with social cognition and emotion regulation[16]. Furthermore, the regulated deep breathing and high concentration inherent in physical activity can activate the parasympathetic nervous system, leading to greater stability in an individual's physical and mental state[35]. Collectively, these positive physiological changes create an optimized internal condition characterized by greater emotional stability and enhanced social cognitive capacity, thereby facilitating the emergence of prosocial behavior.

Second, at the psychosocial and behavioral level, physical exercise provides a crucial social context and learning opportunity for prosocial behavior. On one hand, sports activities often occur in public settings where

individuals are subject to the audience effect or implicit social monitoring. This sense of being observed can trigger self image management motives, increasing the tendency to exhibit socially approved behaviors such as cooperation and helping[34]. On the other hand, and more critically, the inherent characteristics of physical exercise, specifically its structured rules, cooperative nature, and goal orientation, establish it as a natural training ground for prosocial behavior. This is corroborated by evidence ranging from Condello and colleagues' multisport enriched physical education intervention, which demonstrated significant advantages in prosocial skills among the experimental group of children[49], to the finding that regular physical activity provides adolescents with opportunities for psychosocial development and the cultivation of prosocial values[50]. Participants in sports activities learn to adhere to rules, cooperate with others, and strive for common goals; these processes constitute repeated practice and reinforcement of prosocial behaviors themselves. Consequently, high frequency physical activity is associated with more mature prosocial tendencies, such as refraining from impulsive actions driven by fear of losing relationships[51].

In summary, the direct promotion of prosocial behavior among college students through physical exercise is not attributable to a single factor but is rather the inevitable result of the synergistic interaction of multiple physiological, psychosocial, and behavioral mechanisms.

The mediating role of peer relationships: Building prosocial social capital and behavioral norms

This study confirms that peer relationships play a crucial mediating role between physical exercise and prosocial behavior among college students, a finding highly consistent with previous research[13]. This pathway clearly reveals that physical exercise, as a powerful contextual factor, indirectly fosters prosocial behavior primarily by shaping the interpersonal environment.

First, physical exercise serves as an effective catalyst for constructing high-quality peer relationships. This premise is supported by large-scale empirical evidence; for instance, a survey of 58,976 adolescents by Mumcu et al.[52] demonstrated that moderate to vigorous physical exercise significantly and positively predicts the quality of peer relationships. The underlying mechanism lies in the structured interpersonal interaction platform created by physical exercise, which compulsorily or quasi-compulsorily increases the frequency and depth of college students' interactions with others[25]. In team sports or group exercise, individuals must engage in sustained communication, coordination, and mutual assistance to achieve common goals. This process not only helps expand an individual's friendship network but also greatly promotes the formation of interpersonal trust, a sense of belonging, and emotional connection[18,20], thereby establishing valuable social capital.

Subsequently, this high-quality peer relationship drives prosocial behavior through two mechanisms. On one hand, according to social support theory, when individuals perceive themselves to be within a supportive and inclusive peer network, their sense of social identity and norms of reciprocity become significantly activated[22]. They not only become more willing to contribute to this network but also internalize the positive experiences gained from it into their own behavioral standards, thereby more naturally exhibiting prosocial behavior in social interactions[23]. On the other hand, peers play a vital role in the individual's social learning process[53]. As shown by Van Hoorn et al.[54], prosocial feedback from peers significantly increases an individual's prosocial behavior, whereas antisocial peer feedback inhibits it. This indicates that peer relationships not only provide emotional support but also establish clear behavioral norms for the individual through social reinforcement mechanisms.

Finally, within the context of physical exercise, the collective effect generated synergistically by all participants elevates this process. This effect causes disordered individual exercise behaviors to become more organized, creating an ideal supportive atmosphere. This atmosphere can generally enhance college students' social adaptation abilities, social cognitive skills, and social interpersonal relationships, motivating individuals to participate in collective activities with a more positive attitude and mood, thereby systematically strengthening their tendencies toward prosocial behaviors such as helping, courtesy, and comforting.

The mediating role of positive empathy: neurophysiological foundations and emotional motivation

This study confirms that positive empathy constitutes another significant mediating pathway connecting physical exercise to prosocial behavior, a finding consistent with previous research[49]. This pathway elucidates the psychological mechanism through which physical exercise promotes prosocial behavior by shaping an individual's internal emotional capacity.

First, physical exercise provides both a neurophysiological foundation and a training context for the development of positive empathy. Empathy, defined as an emotional response arising from understanding and sharing the affective states of others[10], has a clear biological basis. Regular physical exercise promotes the release of neurochemical substances such as beta-endorphins and BDNF. This not only contributes to improved cerebrovascular health and cognitive function but also provides the physiological prerequisites for sustaining positive mood and enhancing empathic capacity[16,55,56]. This mechanism is not limited to promoting prosocial behavior; it also plays a role in inhibiting antisocial behaviors such as bullying. A recent systematic review and meta-analysis indicated that physical exercise can significantly enhance an individual's empathic ability and may reduce experiences of bullying victimization through this pathway[57]. Empirical studies further indicate that regular exercisers indeed exhibit higher levels of positive emotion and greater empathic ability compared to non-exercisers[58]. At the behavioral level, according to the perception-action model of empathy, the perception of another's emotional state automatically activates a corresponding neural representation within the observer, leading to a congruent emotional response[59]. Within the emotionally charged context of physical exercise, observing a peer celebrating a victory or persevering through effort may activate the observer's mirror neuron system, facilitating an automatic and non-conscious sharing of the peer's joy[31]. This process essentially

functions as repeated empathy training, significantly enhancing an individual's empathic ability and sense of social responsibility[34].

Subsequently, this enhanced capacity for positive empathy becomes an intrinsic motivator driving prosocial behavior. This pathway strongly supports the empathy-altruism hypothesis[27] and extends its applicability from traditional empathy for distress to include positive empathy. Individuals with high levels of positive empathy not only better understand the positive situations of others[60] but also find intrinsic reward in feeling happy for others' successes. This positive emotional experience, derived from sharing in others' happiness, becomes a powerful internal motive, driving individuals to proactively engage in behaviors that maintain and create positive atmospheres[29]. Furthermore, prosocial behavior itself exhibits a self-reinforcing effect. After performing a prosocial act, positive feedback from recipients and peers is, through the individual's positive empathy, transformed again into positive personal feelings, thereby establishing a virtuous cycle.

Therefore, by optimizing an individual's neurophysiological state and providing a practice field rich with emotional resonance, physical exercise systematically cultivates positive empathy. This capacity enables students to better perceive peer acceptance and friendship, leading them to exhibit more positive attitudes and behaviors in interactions[61], and ultimately establishing it as a powerful emotional engine for driving prosocial behavior.

Chain mediating role: from interpersonal connection to emotional resonance

The finding of greatest theoretical significance is that peer relationships and positive empathy form a complete chain mediation pathway between physical exercise and prosocial behavior. This not only confirms that the influence of physical exercise follows a sequential process from improving the external interpersonal environment to enhancing internal emotional capacities, but also more fully reveals its intrinsic action chain.

First, the chain mediation model developed in this study provides an integrative perspective for understanding the social benefits of physical exercise, aligning with several classic theories. The model vividly embodies the core concept of person context interaction theory, which posits that the development of individual psychological behavior results from the combined effects of environmental and individual factors[8]. Simultaneously, group dynamics theory further indicates that individual behavior stems from the interaction between internal needs and external environmental forces[62]. In the context of this study, the collective environment created by physical exercise constitutes a powerful external environmental force, while peer relationships and positive empathy represent the key transformation mechanisms at the interpersonal and individual levels, respectively.

Specifically, this chain pathway clearly delineates a progressive process from the accumulation of social capital to the internalization of psychological capital. In the initial step, physical exercise, as a structured social activity, provides an ideal platform for college students to construct high quality peer relationships. This process helps individuals release emotions, alleviate stress, and significantly promote interpersonal harmony and friendship quality, thereby accumulating valuable social capital[6]. When individuals receive ample understanding, trust, and support within this supportive peer network, strong reciprocity norms are activated, motivating them to reciprocate with corresponding prosocial behaviors, thus initiating the initial cycle of prosocial action.

Subsequently, these high quality peer relationships become fertile ground for cultivating positive empathy, accomplishing the crucial transformation from social capital to psychological capital. Peer relationships characterized by intimacy, equality, and trust provide individuals with extensive opportunities to observe, imitate, and share emotions. Regardless of exercise intensity, this sustained social interaction itself effectively enhances students' empathic capacity[35]. According to the theory of empathy and moral development, the ability to place oneself in another's emotional position and feel what they feel constitutes the moral emotional foundation for motivating prosocial behavior[63]. Within sports collectives, members engage in continuous "mentalizing" practice perceiving teammates' intentions and difficulties, sharing the euphoria of victory and the regret of defeat which systematically trains both their cognitive and affective empathy. The positive correlation between empathy and mental health[64], further implies that this transformation process itself holds significance for promoting overall well-being.

Ultimately, this internalized positive empathy drives more stable and spontaneous prosocial behavior. When an individual's empathic capacity is enhanced through positive peer relationships, they become more adept at keenly perceiving others' needs and respond more effectively to altruistic cues[36]. Furthermore, the awareness that positive empathy can bring joy to others provides the individual with sustained positive feedback and a sense of accomplishment, thereby further boosting their self-confidence and self-efficacy. This virtuous cycle facilitates the development of a more positive and healthy outlook on life and the world, continuously infusing their prosocial behavior with intrinsic motivation. Empirical research also demonstrates that implementing physical activity interventions can effectively enhance individual prosocial behavior through the aforementioned pathway[21], providing strong practical corroboration for the present model.

Conclusion

Grounded in the person-context interaction theory, this study constructed and validated a chain mediation model to systematically examine the intrinsic mechanisms through which physical exercise influences prosocial behavior among college students. The principal findings are summarized as follows.

(1) Physical exercise was identified as a significant predictor of prosocial behavior in college students. This study not only reaffirmed the direct positive relationship between these variables but also elucidated, from multiple dimensions including physiology, neurobiology, psychosocial factors, and behavioral norms, the essential nature of their synergistic multi-mechanistic action.

(2) Peer relationships and positive empathy played crucial parallel mediating roles between physical exercise and prosocial behavior. This finding reveals that the promotive effect of physical exercise on prosocial behavior is realized through two relatively independent yet complementary pathways. The first pathway involves building supportive, high-quality peer relationships, constituting social capital, thereby fostering an interpersonal

environment conducive to prosocial behavior. The second pathway involves shaping the individual's capacity for positive empathy, specifically the ability to understand and share others' positive emotions, thereby activating the intrinsic motivation that drives prosocial behavior.

(3) Peer relationships and positive empathy constituted a significant chain mediation pathway. This clearly demonstrates that the positive influence of physical exercise on prosocial behavior follows a sequential transformation process from external interpersonal interaction to internal psychological qualities. Specifically, the cooperative environment fostered by physical exercise helps college students accumulate high-quality peer relationships. These interpersonal connections, characterized by trust and intimacy, subsequently provide a vital social context and emotional training ground for further cultivating their positive empathy. This process culminates in the internalization of social capital into psychological capital, ultimately leading to more stable and spontaneous elicitation of prosocial behavior.

Research limitations and perspectives

While this study elucidates the internal mechanisms through which physical exercise influences college students' prosocial behavior via a chain mediation model, several limitations warrant consideration. These limitations also provide clear directions for future research.

First, regarding research design, this study employed cross-sectional data to examine associations between variables. While this approach can reveal intrinsic relationships, it cannot strictly infer causality. The influences among physical exercise, peer relationships, positive empathy, and prosocial behavior may involve more complex bidirectional or dynamic interactions. Future research could adopt longitudinal designs, measuring these variables at multiple time points to more clearly delineate their dynamic developmental trajectories and causal sequences. Furthermore, designing randomized controlled trials that implement physical exercise interventions of specific intensities and types across different groups would constitute the most robust approach for testing causal relationships within the proposed model.

Second, concerning the refined examination of research variables, this study did not differentiate between the specific characteristics of physical exercise, which may be key moderating factors influencing its social benefits. Existing research suggests that the intensity and type of physical exercise, along with individuals' participation motives, may differentially impact the construction of peer relationships and the development of empathic capacity. Future studies should systematically distinguish and measure these characteristics to provide precise theoretical reference for designing more targeted physical activity interventions aimed at promoting prosocial behavior.

Finally, regarding the generalizability of the sample and model, the proposed model requires testing across diverse populations. For instance, extant literature suggests that gender may play an important role in the relationship between physical exercise and prosocial behavior. Differences in sports participation and prosocial behavior manifestation between male and female students indicate that the underlying influencing mechanisms may vary. Future research should treat gender as a key moderating variable to thoroughly investigate the stability and specificity of our model across different gender groups. Additionally, extending the model to college students from diverse academic backgrounds and family socioeconomic statuses, as well as to adolescent groups of other age stages, would help evaluate the external validity and general applicability of this theoretical model.

Data availability

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Author contributions
P.W. and C.S. designed the study and written the original manuscript. J.T. and L.C. collected and analyzed the data. J.C. and X.W. revised the manuscript. All authors contributed to the article and approved the submitted version.

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Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Capital university of physical education and sports (2023A0203). All athletes signed informed consent to participate in this study.

Supplementary Information
The full item content of all measurement scales (PARS-3, PTM, PRS, PES) used in this study has been made available as part of the supplementary materials accompanying this manuscript.

Additional information
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