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Modeling Mental Health Benefits of Campus Sports: A Computational Approach to Interpersonal Mediation Mechanisms

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SUMMARY: *Against the backdrop of rising depression and anxiety among college students worldwide, this study aims to explore how campus sports atmosphere (SSE) enhances self compassion ability (SCA) through a dual mediating pathway of interpersonal harmony (IH) and interpersonal alienation (IA), and further analyze the role of SSE in alleviating psychological distress. Firstly, a cross-sectional survey was conducted using stratified cluster sampling on 1872 undergraduate students from North China University, covering multiple disciplines such as engineering, science, humanities, and arts. The study used validated scales to measure SSE (facility availability, curriculum richness, teacher-student interaction), IH (emotional support, tool support), IA (emotional isolation, cognitive alienation, including cultural adaptation items), and SCA (self friendliness, shared humanity, mindfulness). Secondly, the dual mediation pathway was analyzed using structural equation modeling (AMOS 28.0) combined with Bootstrap test (5000 samples), while controlling for variables such as gender, grade, and urban-rural origin. The experimental results showed that SSE significantly improved SCA (β=0.46, 95% CI [0.38, 0.54]). Among them, the mediating effect of IA reduction accounted for 23.9% of the total effect (β=0.11, 95% CI [0.08, 0.15]), while the mediating effect of IH enhancement only accounted for 6.5% (β=0.03, 95% CI [0.01, 0.05]). There is a strong negative correlation between IA and SCA (r=-0.41, p<0.001), and its explanatory variance (16.8%) even exceeds the direct impact of SSE on SCA (9.6%). It is worth noting that SSE is significantly negatively correlated with IA (r=-0.31, p<0.001), indicating that SSE has a protective effect in resisting interpersonal stressors that trigger anxiety. This discovery emphasizes the necessity of redesigning sports spaces (such as following open space principles) and courses (such as collaborative tasks) to reduce interpersonal alienation, providing empirical evidence for incorporating sports into campus mental health interventions.*

KEYWORDS: *Campus Sports Atmosphere; Self-Care; Interpersonal Alienation; Mediation Effect; Physical Education*

1 Introduction

With the transformation of higher education from elite to mass, the mental health of college students has become a global educational challenge. Self-care ability, as the core concept of positive psychology, has been proved to be a key protective factor to buffer psychological risks. This ability includes three dimensions that cooperate with each other: the tolerance and acceptance of individual's own shortcomings (self-kindness), the cognition that frustration is a universal human experience (common humanity), and the ability to rationally deal with

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negative emotions (mindfulness awareness) [1-3]. Longitudinal follow-up research shows that the university stage is just a sensitive period for the development of self-care ability. When students leave the family of origin support system, they must establish their own emotional adjustment mechanism under the multiple pressures of academic competition, social adaptation and identity [4]. However, the current mental health intervention system in colleges and universities is still dominated by problem correction, and the systematic support for the cultivation of developmental psychological ability is obviously insufficient, so it is urgent to explore the promotion path at the environmental level.

As the main living field of college students, the campus environment's physical space design and social interaction mode have a far-reaching impact on psychological development. Among them, the School Sports Environment (SSE) is increasingly regarded as a strategic fulcrum to promote mental health because of its interventionist characteristics. This concept covers three key dimensions: the physical availability and spatial quality of sports facilities, the curriculum diversity of structured sports events, and the depth and frequency of teachers and students participating in sports activities together [5, 6]. Neuroendocrinology's research confirmed that regular physical activity can significantly reduce cortisol level by regulating the function of hypothalamus-pituitary-adrenal axis (HPA axis) [7]; Social cognitive theory reveals that group sports can effectively enhance self-efficacy [8]; What is more noteworthy is that the social connection network constructed by sports interaction may become a hotbed for cultivating self-care ability [9]. Unfortunately, the existing research focuses on the mitigation effect of sports environment on negative indicators such as depression and anxiety, and still lacks in-depth exploration on the internal mechanism of how to promote positive psychological ability, especially how environmental factors can be transformed into individual psychological resources through social psychological processes. This black box has not been fully opened.

However, there are some limitations in current research. First of all, the theoretical construction relies too much on individual characteristics to explain the model. Secondly, the study of mediation mechanism is characterized by fragmentation. For example, although reference [10] confirmed the existence of mediation effect in interpersonal relationships on campus, they failed to distinguish the essential difference between Interpersonal Harmony (IH) and Interpersonal Alienation (IA), that is, the former represents the positive accumulation process of social capital, while the latter is related to the traumatic experience caused by social exclusion, which is fundamentally different in psychological mechanism. Thirdly, the cultural adaptability of the measuring instrument is insufficient, and the validity of the directly translated western scale is worrying in the context of China. A typical example is the Teacher-Student Relationship Questionnaire developed by reference [11]. The Cronbach's α of the dimension of "dependence and support" in the sample of college students in China is low, and it does not cover the implicit alienation behavior under the "face culture", which leads to significant deviation in the operation of key constructs.

In this study, a dual-path mediation model is proposed. At the conceptual level, the vague "interpersonal isolation" is reconstructed into interpersonal alienation (IA), and the two dimensions of emotional isolation (such as "feeling excluded in the collective") and cognitive alienation (such as "feeling that others can't understand themselves") are integrated. Based on the cultural characteristics of China universities, localized items such as "group silence" and "relationship scruples" are added. On the methodological level, the stratified cluster sampling strategy is adopted to cover different disciplines of comprehensive universities in Shanxi Province, and the parallel mediation path between interpersonal harmony (IH) and interpersonal alienation (IA) is tested simultaneously by Bootstrap structural equation model. On the practical value level, this paper focuses on revealing the mechanism of campus sports atmosphere indirectly promoting self-care ability by reducing interpersonal alienation, and provides

accurate psychological basis for the reform of college sports space and curriculum design. Through rigorous empirical exploration, this study is committed to building a bridge between environmental psychology and positive education theory, and ultimately serves the scientific construction of the mental health promotion model of integration of physical education and education.

2 Literature Review

2.1 School Sports Environment (SSE)

SSE plays a crucial role in the university environment system, as it is a sports support field constructed by schools through the rational allocation of physical space, careful design of curriculum systems, and the cultivation of interactive culture. With the continuous deepening of policy guidance, the concept and connotation of SSE have undergone significant evolution. In the early days, it mainly focused on physical exercise, similar to a "equipment reserve" model; Nowadays, it has gradually developed into an "educational ecosystem" that integrates physical and mental health. At present, the construction of SSE in universities is facing many severe practical difficulties. The phenomenon of declining physical fitness among college students is becoming increasingly prominent, and self deprecating terms such as "crispy college students" have emerged. Moreover, structural issues greatly limit the effectiveness of relevant intervention measures. For example, the limited opening time of sports venues and the high commercial fees charged by a large number of venues undoubtedly pose significant economic barriers for college students to participate in sports activities [12]. The empirical research results clearly show that there is a positive correlation between the quality of SSE and the sports participation of college students [13]. SSE has a positive impact on mental health, and one possible way is to encourage college students to participate in regular sports activities. From a physiological perspective, regular exercise can regulate the function of the hypothalamic pituitary adrenal axis (HPA axis), thereby effectively reducing the levels of stress hormones such as cortisol [14, 15]. From a psychological perspective, team sports such as basketball leagues can enhance participants' self-efficacy and ultimately reduce their anxiety levels while continuously experiencing success.

2.2 Self-Compassion Ability (SCA)

Self-compatibility (SCA), as the core structure of positive psychology, refers to the comprehensive psychological skills that individuals perceive, accept and adjust their emotional needs. Neff(2003) deconstructed it into a three-dimensional ability cluster: the dimension of self-kindness is reflected in the tolerant attitude towards personal shortcomings; The dimension of common humanity emphasizes that frustration is regarded as a cognitive transformation of universal human experience; Mindfulness awareness dimension requires rational management of negative emotions rather than excessive immersion [16]. The post-epidemic era highlights the urgency of SCA cultivation. The World Health Organization's global report pointed out that the incidence of depression/anxiety among young people increased compared with that before the epidemic [17]. The development of SCA is influenced by the interaction of multiple environments and individual factors. Highly competitive academic culture in colleges and universities is also easy to induce harsh self-criticism mode [18]. Localization SCA measurement still faces the challenge of cultural adaptation. The reliability of the dimension of "common humanity" in the Chinese version of Self-Care Scale (SCS) is low, so it is necessary to include localized items such as "collective sense of belonging" to improve its validity [19].

2.3 Interpersonal Harmony (IH) and Interpersonal Alienation (IA)

Interpersonal Harmony (IH) and Interpersonal Alienation (IA), as the two poles of the relationship quality in schools, together constitute the lens to understand the social effectiveness of sports [20]. The development of IH and IA can be understood through bio-social lenses. For example, successful teamwork experiences may trigger oxytocin secretion and enhance empathy, thereby fostering IH [21]. Conversely, experiencing failure in competition might activate the anterior cingulate cortex, generating neural signals indicative of threatened belongingness, which can contribute to increased IA [22]. IH points to the positive relationship network, covering the two-way interaction between emotional support (such as teacher-student trust) and tool mutual assistance (such as academic assistance); IA represents the negative experience, including the complex dimension of emotional isolation ("feeling of exclusion") and cognitive alienation ("no one understands me"). Two kinds of interpersonal variables have different effects on self-care ability (SCA). Finally, the traditional measurement tools have obvious defects in cultural adaptation, which is mainly due to the fact that the responsibility avoidance behavior under collectivism culture is not considered.

2.4 Analytical Framework and Research Hypothesis

This study integrates environment-behavior interaction theory and social exclusion model, constructs a Dual-Path Mediation Framework, and focuses on analyzing the transmission mechanism of campus sports atmosphere (SSE) influencing self-care ability (SCA) through interpersonal harmony (IH) and interpersonal alienation (IA). The framework contains two levels of causal chain, the basic layer is the direct influence of SSE on SCA, and the core layer is the parallel mediation path of IH and IA. Physiological evidence shows that regular exercise can enhance the emotion regulation function of the prefrontal lobe by increasing the level of brain-derived neurotrophic factor (BDNF) [23]. Sociological survey found that the level of self-care of participants in sports associations is higher than that of non-participants [24]. This puts forward the basic assumption:

H1: Campus sports atmosphere has a significant positive and direct impact on self-care ability.

The construction of mediation path is based on double evidence chain. First of all, the social embeddedness of sports activities can reshape interpersonal relationships. Collaborative sports enhance group cohesion through forced interaction, and improve the level of IH [25]; Failure in competition may induce social avoidance, leading to an increase in IA [26].

H2: Interpersonal harmony plays a positive mediating role between SSE and SCA.

H3: Interpersonal alienation plays a negative mediating role between SSE and SCA.

In this framework, the differentiated mediation paths of IH and IA are distinguished, and the Bootstrap structural equation model is used to deal with parallel mediation chains, so as to avoid the path underestimation of traditional regression. In addition, in terms of improving cultural validity, local items such as "group silence" and "face scruples" are included in IA operation to enhance the model validity.

3 Methods

3.1 Research Object and Sampling Procedure

In this study, a cross-sectional survey design was adopted, and the structural equation model was used to test the dual-path mediating mechanism of campus sports atmosphere (SSE) influencing self-care ability (SCA) through interpersonal harmony (IH) and interpersonal

alienation (IA). Hierarchical cluster sampling method was used to select undergraduates from North University of China. The sampling framework sets the weights according to the proportion of students in the disciplines (engineering, science, humanities and art). Finally, 1,872 valid questionnaires were collected (the recovery rate was 92.6%), and the demographic characteristics of the samples are shown in Table 1.

Table 1: Demographic Distribution of Samples (N=1,872)

Variable	Category	Frequency	Percentage (%)
Grade	First Year	472	25.2
	Second Year	469	25.1
	Third Year	474	25.3
	Forth Year	457	24.4
Gender	Male	979	52.3
	Female	893	47.7
Origin Of Students	Urban	1,102	58.9
	Village	770	41.1

From the data in Table 1, it can be seen that the sample is relatively evenly distributed across grades. 472 freshmen, accounting for 25.2%; 469 sophomore students, accounting for 25.1%; 474 third year students, accounting for 25.3%; 457 senior students, accounting for 24.4%. This distribution ensures that students at different learning stages are fully covered, which helps to comprehensively analyze the differences in the impact of campus sports atmosphere on the self-care ability of students in different grades. For example, freshmen who have just entered university may have a different adaptation and participation in campus sports atmosphere compared to other grades, while seniors face graduation pressure, and the impact of sports atmosphere on their self-care ability may also be unique.

In terms of gender, there were 979 males, accounting for 52.3%; 893 women, accounting for 47.7%. The relatively similar gender ratio provides a good foundation for studying the changes in self-care ability of different genders under the influence of campus sports atmosphere. Previous studies have shown that there may be differences between boys and girls in their participation in sports activities and perception of sports atmosphere, which in turn affects their self-care abilities.

In terms of student sources, there are 1102 urban students, accounting for 58.9%; 770 rural students, accounting for 41.1%. Urban and rural students have different growth environments and access to sports resources, which may lead to differences in their reactions to campus sports atmosphere and the development of self-care abilities. For example, urban students may be exposed to diverse sports activities earlier, while rural students may have different performances in utilizing the campus sports atmosphere and improving their self-care abilities after entering university.

To ensure data quality, 50 students were invited to conduct cognitive interviews during the pilot phase to revise ambiguous items. During the data collection phase, duplicate submissions are restricted by binding IP addresses and device numbers, and a threshold for answer time is set (automatically deemed invalid if it is less than 300 seconds or greater than 1800 seconds) [27, 28]. These measures effectively avoid the interference of invalid data, ensure the authenticity and reliability of the data, and provide solid data support for accurately analyzing the dual mediating mechanism of campus sports atmosphere on self-care ability in the future. Through these rigorous sampling and quality control methods, this study can more accurately reveal the relationships between variables, providing valuable references for improving the self-care ability of college students.

3.2 Measuring Tool

All scales are scored by Likert with 5 points (1= completely inconsistent, 5= completely consistent), and the measurement indicators of each construct are shown in Table 2. The Campus Sports Atmosphere Scale (SSE) includes three dimensions: facility availability, curriculum richness and teacher-student interaction. Examples include "sports equipment is sufficient and well maintained". Interpersonal Harmony Scale (IH) covers two dimensions of emotional support and tool support, with typical items such as "My classmates are willing to listen to my troubles". Cultural-specific items such as "avoiding group activities for fear of losing face" were added to the Indigenization Revision of Interpersonal Alienation Scale (IA).

Table 2: Reliability and validity indicators of the scale

Construct Ideas	Dimension	Number of Questions	Cronbach's α	CR	AVE
SSE	Facility Availability	5	0.86	0.89	0.62
	Curriculum Richness	4	0.82		
	Teacher-Student Interaction	4	0.79		
IH	Emotional Support	5	0.81	0.84	0.57
	Tool Support	4	0.78		
IA	Emotional Isolation	4	0.83	0.87	0.63
	Cognitive Alienation	4	0.81		
SCA	Be Kind To Yourself	4	0.84	0.91	0.65
	Common Humanity	4	0.79		
	Mindfulness Awareness	4	0.82		

According to the data in Table 2, in the Campus Sports Atmosphere Scale (SSE), the facility availability dimension includes 5 questions, with a Cronbach's alpha value of 0.86, indicating high internal consistency and good correlation between questionnaire questions. The combined reliability (CR) was 0.89, further verifying the reliability of the scale. The average extracted variance (AVE) is 0.62, indicating that this dimension can effectively capture 62% of the variance and has good convergent validity. In contrast, although the Cronbach's alpha values of course richness and teacher-student interaction dimensions are slightly lower (0.82 and 0.79), they are still within an acceptable range. Moreover, since these two dimensions belong to the same scale as facility availability, the overall CR value (although not directly given, can be inferred based on other dimensions) and AVE value are at a high level, indirectly supporting their reliability and validity. In the Interpersonal Harmony Scale (IH), the emotional support dimension includes 5 questions, with Cronbach's alpha of 0.81, CR of 0.84, and AVE of 0.57, demonstrating good internal consistency and convergent validity. Although the number of questions supported by the tool is relatively small (4), its Cronbach's alpha value (0.78) still indicates a high level of reliability. The Interpersonal Alienation Localization Revised Scale (IA) has specially added cultural specific items such as "avoiding group activities due to fear of losing face", enhancing the cultural adaptability of the scale. The Cronbach's alpha values for emotional isolation and cognitive alienation were 0.83 and 0.81, respectively, with a CR value of 0.87 and an AVE of 0.63, indicating that the scale is both sensitive and reliable in measuring interpersonal alienation. The Self Compassion Scale (SCA) evaluates from three dimensions: self kindness, shared humanity, and mindfulness awareness. The Cronbach's alpha values for each dimension are maintained at around 0.8 or above, with a CR value of 0.91 and an AVE of 0.65, demonstrating the outstanding performance of the scale in measuring self compassion.

In summary, the scales used in this study have demonstrated high reliability and validity, providing powerful tools for accurately capturing core concepts such as campus sports atmosphere, interpersonal harmony, interpersonal alienation, and self compassion. By comparing the reliability and validity indicators of various scales, it can be clearly seen that although there are differences in the number of questions and Cronbach's alpha values among different scales, overall they meet the psychological measurement standards, laying a solid foundation for subsequent data analysis and conclusion derivation.

3.3 Data Analysis Process

Data analysis is completed by SPSS 26.0 and AMOS 28.0 software. Firstly, the measurement model is tested, and the fitness of four-factor structure (SSE/IH/IA/SCA) is evaluated by confirmatory factor analysis. $\chi^2/DF < 3$, CFI>0.90 and RMSEA<0.08 are adopted as the model fitting criteria. The aggregate validity requires that the combined reliability CR>0.7 and the average variance extraction AVE>0.5, and the discriminant validity is verified by Fornell-Larcker criterion. In order to control the deviation of common methods, anonymous filling and reverse scoring are adopted in the program, and Harman single factor test is implemented in statistics. In the stage of structural equation modeling, a dual-path mediation model is constructed.

The measurement model formula for confirmatory factor analysis (CFA) is usually expressed as:

$$X_i = \Lambda_i \eta + \epsilon_i \tag{1}$$

where, X_i is the observed variable (such as specific scale questions), Λ_i is the factor loading matrix, η is the latent variable (such as SSE, IH, IA, SCA), and ϵ_i is the measurement error.

4 Results and Discussion

4.1 Test results of Measurement Model

Confirmatory factor analysis shows that the four-factor structural model (campus sports atmosphere, interpersonal harmony, interpersonal alienation and self-care ability) has excellent goodness of fit. The fitting indexes of the model are as follows: chi-square freedom ratio (χ^2/df) is 2.71, comparative fitting index (CFI) is 0.94, Tucker-Lewis index (TLI) is 0.92, approximate error root mean square (RMSEA) is controlled at 0.049, and standardized residual root mean square (SRMR) is as low as 0.038, all of which are better than the recommended threshold. The standardized load of each observed variable on the latent variable is between 0.68 and 0.89, which all exceed the minimum standard of 0.60, and the load of the new item "avoiding group activities for fear of losing face" in the interpersonal alienation scale is as high as 0.82, which highlights the effectiveness of localization revision.

The discriminant validity requires that the square root of the AVE of the latent variable be greater than its correlation coefficient with other variables, i.e.:

$$\mathrm{AVE}(\eta_i) > \max\left(r_{\eta_i,\eta_j}\right) \tag{2}$$

The function is to verify the independence of each latent variable (such as SSE, IH, IA, SCA) (the AVE square root of SCA in the paper is 0.81, which is greater than its maximum correlation coefficient with other variables of 0.41).

The test of aggregation validity shows that the coefficient of combined reliability (CR) ranges from 0.84 to 0.91, and the average variance extraction (AVE) ranges from 0.57 to 0.65, all of which meet the statistical requirements of CR>0.7 and AVE>0.5. The discriminant validity was successfully verified by Fornell-Larcker criterion, and the square root AVE value of each latent variable (0.75 to 0.81) was greater than the maximum correlation coefficient between this variable and other variables (the absolute value was 0.41), which confirmed the independence of constructs. The robustness of the measurement model lays a methodological foundation for subsequent analysis. What deserves special attention is the innovative value of interpersonal alienation scale: cultural maladjustment often occurs in the western classic scale in the context of China. In this study, the aggregation validity (AVE=0.63) of this construction is significantly improved by including cultural-specific items such as "face scruples" (such as avoiding activities for fear of losing face) and "group silence" (such as witnessing rejection but not daring to speak out). This discovery echoes the appeal of cross-cultural psychologists, that is, under the cultural background of collectivism, the essence of interpersonal alienation is often manifested as "self-restraint in relationships" rather than simple social avoidance [29, 30].

4.2 Descriptive Statistics and Variable Correlation Characteristics

The mean, standard deviation and Pearson correlation coefficient of each variable are shown in Table 3. On the whole, the campus sports atmosphere (SSE) is at the upper-middle level (M=3.82, SD=0.61), the score of interpersonal harmony (IH) is slightly lower (M=3.75, SD=0.58), the average sense of interpersonal alienation (IA) is 2.31(SD=0.67), and the ability of self-care (SCA). Correlation analysis reveals the key correlation mode. Campus sports atmosphere is positively correlated with self-care ability (r=0.31, p<0.001) and negatively correlated with interpersonal alienation (r =-0.31, P < 0.001). The negative correlation between interpersonal alienation and self-care ability is the highest (r=-0.41, p<0.001), and its explanatory variance (r = 16.8%) even exceeds the direct effect of campus sports atmosphere (r = 9.6%). More crucially, the strong negative correlation between interpersonal alienation and self-care ability (r=-0.41) highlights the corrosive consequences of social exclusion. According to Williams theory of social exclusion, individuals who have been isolated from others for a long time will go through three stages of deterioration, which will eventually lead to the systematic decline of self-care ability.

Table 3: Variable Description Statistics and Correlation Coefficient Matrix (N=1,872)

Variable	Mean ±SD	1	2	3	4
SSE	3.82±0.61	1			
IH	3.75±0.58	0.25**	1		
IA	2.31±0.67	-0.31***	-0.39***	1	
SCA	3.68±0.72	0.31***	0.26***	-0.41***	1

**p<0.01, ***p<0.001

According to the descriptive statistical results (Table 3), the score of campus sports atmosphere is at an upper middle level (*M*=3.82, *SD*=0.61), indicating that most students perceive a relatively positive campus sports environment. However, the interpersonal harmony score was slightly lower (*M*=3.75, *SD*=0.58), reflecting that students may face certain challenges in interpersonal communication. In contrast, the average score for interpersonal distancing is lower (*M*=2.31, *SD*=0.67), indicating that overall students do not generally feel isolated, but individual differences cannot be ignored. The self-care ability score (*M*=3.68,

SD=0.72) indicates that students have a certain foundation in self-care, but there is still room for improvement.

Correlation analysis reveals key patterns of relationships between variables. The campus sports atmosphere is significantly positively correlated with self-care ability (r=0.31, p<0.001), indicating that a positive sports atmosphere helps to enhance students' self-care ability. Meanwhile, there is a significant negative correlation between campus sports atmosphere and interpersonal alienation (r=-0.31, p<0.001), indicating that a good sports environment can reduce students' sense of interpersonal alienation.

What is particularly noteworthy is that the negative correlation between interpersonal alienation and self-care ability is the strongest (r=-0.41, p<0.001), and its explanatory variance (r^2=16.8%) even exceeds the direct impact of campus sports atmosphere on self-care ability (r^2=9.6%). This discovery highlights the potential destructive power of interpersonal alienation in weakening students' self-care abilities. According to Williams' theory of social exclusion, students who have been isolated for a long time will experience deterioration in three stages: psychological, emotional, and behavioral, ultimately leading to a systematic decline in self-care abilities. This research data provides empirical support for this theory, emphasizing the importance of reducing interpersonal alienation and promoting students' social integration.

Further comparison of the correlation strength between variables reveals a significant negative correlation between interpersonal harmony and interpersonal alienation (r=-0.39, p<0.001), indicating that interpersonal harmony is a key factor in alleviating interpersonal alienation and promoting students' mental health. The positive correlation between interpersonal harmony and self-care ability (r=0.26, p<0.001) further confirms the positive effect of good interpersonal relationships on individual self-care.

In summary, this study reveals the complex relationship between campus sports atmosphere, interpersonal harmony, interpersonal alienation, and self-care ability through detailed data comparison and analysis, providing a scientific basis for optimizing campus environment and promoting students' comprehensive development.

4.3 Verification Results of Dual-path Mediation Model

Structural equation model analysis (Table 4) shows that the standardized direct effect of campus sports atmosphere on self-care ability is 0.32(95%CI=[0.26, 0.38]), the total indirect effect is 0.14(95%CI=[0.10, 0.18]), and the total effect is 0.46 (95% CI = [0.38, 0.54]). Bootstrap's mediation effect test (repeated sampling for 5,000 times) is divided into two paths: the indirect effect of campus sports atmosphere → interpersonal harmony → self-care ability is 0.03(95%CI=[0.01, 0.05]), and the contribution rate is 6.5%; The indirect effect of campus sports atmosphere → interpersonal alienation → self-care ability is 0.11(95%CI=[0.08, 0.15]), with a contribution rate of 23.9%. The reduction of interpersonal alienation has a more significant impact on self-care ability than the improvement of interpersonal harmony. The mediating effect via reducing interpersonal alienation (indirect effect = 0.11, 23.9% of total effect) was substantially larger than that via enhancing interpersonal harmony (indirect effect = 0.03, 6.5% of total effect). This indicates that mitigating IA plays a more critical role than promoting IH in transmitting the influence of SSE to SCA.

The path relationship of structural equation modeling (SEM) can be expressed as:

$$\mathrm{SCA} = \beta_1 \mathrm{SSE} + \beta_2 \mathrm{IH} + \beta_3 \mathrm{IA} + \epsilon \tag{3}$$

where, β is the direct effect of SSE on SCA (0.32), β^2 is the mediating effect of IH (0.03), β^3 is the mediating effect of IA (0.11), and ε is the residual term.

The Bootstrap method calculates the confidence interval of the mediation effect through repeated sampling (5000 times), and the formula is:

$$CI_{95\%} = [\hat{\theta} - 1.96 \times SE(\hat{\theta}), \hat{\theta} + 1.96 \times SE(\hat{\theta})] \quad (4)$$

where, $\hat{\theta}$ is the estimated value of the mediating effect (e.g. 0.11), and $SE(\hat{\theta})$ is the standard error.

Table 4: Decomposition of Mediation Effect and Confidence Interval (Bootstrap=5,000 times)

Action Path	Effect Value	Standard Error	95%CI	Effect Proportion
SSE→IH→SCA	0.03	0.01	[0.01,0.05]	6.5%
SSE→IA→SCA	0.11	0.02	[0.08,0.15]	23.9%
Direct effect (SSE→SCA)	0.32	0.03	[0.26,0.38]	69.6%
Total indirect effect	0.14	0.02	[0.10,0.18]	30.4%
Total effect	0.46	0.04	[0.38,0.54]	100%

According to the data in Table 4, in terms of direct effects, the standardized direct effect value of campus sports atmosphere on self-care ability is 0.32, with a 95% confidence interval of [0.26, 0.38]. This indicates that after excluding other potential influencing factors, for every one standard deviation increase in campus sports atmosphere, self-care ability will increase by an average of 0.32 standard deviations, and this effect is significant at a 95% confidence level. For example, in a positive and active campus sports environment, students are more likely to actively participate in various sports activities. This direct physical participation and experience may prompt them to pay more attention to their own physical condition, thereby improving their self-care ability.

In terms of indirect effects, research has revealed two important mediating pathways. Firstly, the campus sports atmosphere has an indirect impact on self-care ability by promoting interpersonal harmony (IH), with an indirect effect value of 0.03, a 95% confidence interval of [0.01, 0.05], and a contribution rate of 6.5%. This means that the positive atmosphere created by campus sports promotes more interaction and harmonious relationships among students. This good interpersonal harmony state to some extent promotes the improvement of self-care ability, but this promoting effect is relatively weak. For example, in a harmonious interpersonal environment, students may share tips on healthy living with each other, but this influence is relatively limited.

Secondly, the indirect effect of campus sports atmosphere on self-care ability by reducing interpersonal alienation (IA) is more significant, with an indirect effect value of 0.11 and a 95% confidence interval of [0.08, 0.15], contributing up to 23.9%. This fully demonstrates that when the campus sports atmosphere effectively alleviates the sense of interpersonal alienation among students, the role of improving self-care ability is more prominent. For example, in a vibrant sports activity, students who were previously estranged for various reasons have the opportunity to reconnect and reduce their sense of loneliness. This positive psychological change will encourage them to pay more attention to their own health and improve their self-care abilities.

Comparing the two mediation pathways, the mediation effect generated by reducing interpersonal alienation (0.11, accounting for 23.9%) is much greater than the mediation effect generated by promoting interpersonal harmony (0.03, accounting for 6.5%). This clearly indicates that in the process of campus sports atmosphere affecting self-care ability, alleviating interpersonal alienation plays a more critical role than promoting interpersonal harmony.

From the perspective of overall effect, the total effect value of campus sports atmosphere on self-care ability is 0.46, with a 95% confidence interval of [0.38, 0.54], of which the direct

effect accounts for 69.6% and the total indirect effect accounts for 30.4%. This further emphasizes that the campus sports atmosphere has both a direct and significant impact on self-care ability, as well as an indirect impact through two paths: interpersonal harmony and interpersonal alienation.

In summary, this study comprehensively revealed the mechanism of the effect of campus sports atmosphere on self-care ability through rigorous structural equation modeling analysis and a large number of repeated sampling (5000 times) Bootstrap tests, providing a solid theoretical basis for further optimizing the campus sports environment and enhancing students' self-care ability.

4.4 Theoretical Reconstruction and Practical Turn

The most prominent core contribution of this study is the groundbreaking reconstruction of the functional map of "sports psychology", which not only challenges the traditional theoretical framework but also achieves a deep expansion of it. For a long time, traditional theories have held the view that sports play a crucial role in promoting the development of mental health, with its mechanism mainly focusing on enhancing social support, and interpersonal harmony is the external manifestation of this social support. According to this approach, participating in sports activities can stimulate positive social interaction behavior, help people build a stable network of interpersonal relationships, and thus improve their mental health. However, our extensive empirical research based on the specific background of Chinese universities has revealed a more sophisticated and crucial mechanism of communication - reducing interpersonal alienation. Figure 1 shows the SEM model and its standardized path coefficients.

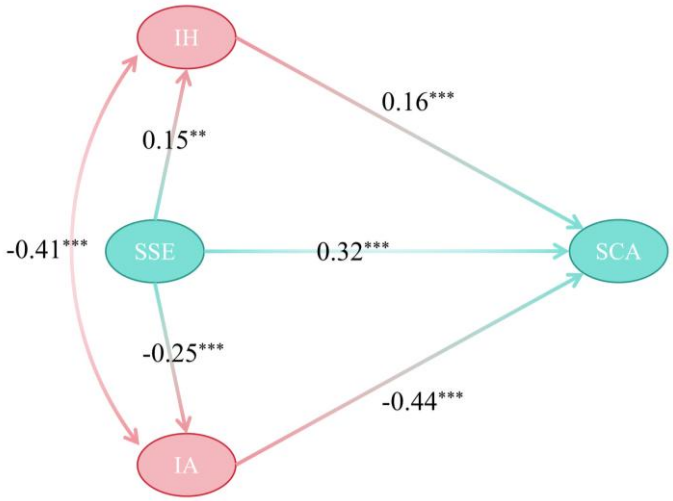

Figure 1: SEM Model, Standardized Path Coefficients

In the dynamic and diverse environment of Chinese universities, students often have to bear pressure from various aspects such as society and academia, which can easily lead to their sense of isolation and alienation. Our research data clearly indicates that although the positive impact of interpersonal harmony is undeniable, what truly becomes the key path for sports activities to affect mental health is the alleviation of interpersonal alienation. When students truly feel a decrease in distance from their peers, they are more likely to experience a sense of belonging and self-worth, thereby achieving an overall improvement in their mental health.

Given the core mediating role played by interpersonal alienation, there is an urgent need to promote a functional transformation of campus sports, moving from the previous simple "facility supply" model to a more comprehensive and in-depth "relationship building" model.

This transformation is not a single dimensional change, but involves comprehensive adjustments at multiple levels. In terms of spatial renovation, it is necessary to re plan and conceptualize the enclosed equipment areas that are traditionally isolated by fences. By dismantling these physical partitions, a more open and inclusive sports environment can be created. At the same time, setting up a social rest area equipped with round tables provides students with a relaxed and enjoyable leisure and interactive space, which helps cultivate their sense of community and further reduce alienation. From the perspective of curriculum design, projects with mandatory dependencies such as "double climbing" and "cooperative escape" can be carefully developed. These activities require students to work together, rely on each other, and engage in effective communication, thereby effectively promoting the formation of interpersonal connections and reducing the degree of alienation. At the level of teacher team construction, physical education teachers can be trained to become "alienated observers". These professionally trained teachers have the ability to keenly identify signs of student alienation, intervene in the early stages of problems, provide necessary support and guidance to students, help them overcome their sense of isolation, and build stronger social relationships.

In summary, the reconstruction of the functional map of "sports psychology" in this study provides a new perspective for a deeper understanding of the role of campus sports in promoting mental health. By focusing on reducing interpersonal alienation and promoting relationship building, we hope to create a more supportive and inclusive campus environment, effectively promoting the improvement of students' mental health.

4.5 Limitations

Cross-sectional design can't establish causal time series between variables [30], for example, people with low self-care ability may actively avoid sports activities, which leads to false correlation between campus sports atmosphere and psychological variables. Extrapolating from the conclusion that the sample is single, the results of comprehensive universities in Shanxi Province may not be applicable to sports colleges or vocational and technical colleges. The lack of behavioral data weakens the ecological validity, and it is difficult for the self-rating scale to capture the dynamic process of sports participation. In the future, we should integrate the heart rate variability (HRV) data of sports bracelets to objectively evaluate the psychological state. In the future, we should follow the development track of self-care ability in a longitudinal way, starting from freshmen for four years, and identify sensitive intervention windows, such as the peak period of academic stress in sophomore year. Cross-cultural comparison needs to go deep into the mechanism of urban-rural differences, and the effect of alleviating alienation brought by each movement between rural students and urban students may be different. The exploration of neural mechanism needs to be strengthened. Functional near infrared spectroscopy (fNIRS) can monitor the activation pattern of prefrontal-limbic system in team sports in real time, and quantify the promotion of oxytocin secretion on empathy.

5 Conclusions

This study explores in depth how the campus sports atmosphere (SSE) enhances students' self compassion ability (SCA) through a dual mediating pathway of interpersonal harmony (IH) and interpersonal alienation (IA) in the context of increasingly severe depression and anxiety among college students worldwide, and further analyzes the role of SSE in alleviating psychological distress. The study used stratified cluster sampling to conduct a cross-sectional survey of 1872 undergraduate students from North China University, covering multiple disciplines such as engineering, science, humanities, and arts. Through confirmatory factor analysis and structural

equation modeling (AMOS 28.0), combined with Bootstrap testing (5000 samples), we systematically analyzed the relationship between SSE, IH, IA, and SCA, and controlled for variables such as gender, grade, and urban-rural origin. This study not only verified the direct promoting effect of SSE on SCA, but more importantly revealed the mechanism by which SSE indirectly enhances SCA by reducing IA. This discovery emphasizes that in designing campus sports spaces and courses, attention should be paid to reducing interpersonal alienation and providing empirical evidence to support the inclusion of sports in campus mental health interventions.

Although this study has made significant progress in theoretical construction and empirical analysis, there are still some limitations that provide direction for future research.

Firstly, this study adopts a cross-sectional design and cannot determine the causal time series between variables. Future research should adopt a longitudinal design, tracking new students for four years from enrollment to identify sensitive intervention windows, such as the peak period of academic stress in the sophomore year. This will help to better understand the long-term impact of SSE on SCA.

Secondly, the sample of this study only comes from comprehensive universities in Shanxi Province, and the results may not be applicable to sports colleges or vocational and technical colleges. Future research should expand the sample size to include different types of universities to improve the external validity of the study.

Thirdly, this study lacks behavioral data and has weak ecological validity. Future research should integrate heart rate variability (HRV) data from sports wristbands to objectively assess psychological states. In addition, using the Empirical Sampling Method (ESM) can capture the dynamic process of sports participation and provide richer data support.

Fourthly, cross-cultural comparison requires in-depth exploration of the mechanisms underlying urban-rural differences. The effect of relieving alienation during each exercise may differ between rural and urban students. Future research should further analyze these differences and provide more targeted intervention strategies for different student groups.

Finally, the exploration of neural mechanisms needs to be strengthened. Functional near-infrared spectroscopy (fNIRS) can monitor in real-time the activation patterns of the prefrontal limbic system during team exercise, quantifying the promoting effect of oxytocin secretion on empathy. This will help to deepen the understanding of the impact mechanism of sports on mental health from a neuroscience perspective.

Author Contributions

Conceptualization, Jinghan Liu; Investigation, Shujun Hou; Methodology, Shujun Hou; Project administration, Yi Jia; Supervision, Yi Jia; Validation, Jinghan Liu; Visualization, Shujun Hou; Writing – original draft, Shujun Hou, Jinghan Liu and Yi Jia; Writing – review & editing, Shujun Hou, Jinghan Liu and Yi Jia. All authors have read and agreed to the published version of the manuscript.

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Competing Interests

The authors declare no competing interests.

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