



OPEN Cross-lagged panel relationship between physical activity atmosphere, psychological resilience and mobile phone addiction on college students

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Mobile phone addiction (MPA) is widespread on university campuses and has many negative effects on individuals. A good physical activity atmosphere (PAA) has been shown to be effective in improving individuals' mental health, including psychological resilience (PR), but it is not clear whether it can alleviate MPA. Therefore, this study investigates the effects of both on MPA through a longitudinal study and provides a theoretical basis for reference. A total of 964 international students from different countries were selected from 8 colleges and universities in Beijing, and 2 longitudinal follow-up surveys were conducted using the Physical Activity Atmosphere Scale, the Psychological Resilience Scale, and the Mobile Phone Addiction Scale. Correlation and path model analyses were conducted using Pearson and cross-lagged panel model (CLPM). The correlation results showed that T1-PAA, T2-PAA were significantly positively correlated with T1-PR, T2-PR ($r = 0.577, 0.306, P < 0.001$) and T1-PR, T2-PR were significantly negatively correlated with T1-MPA, T2-MPA ($r = -0.225, -0.236, P < 0.001$). CLPM results showed that college student PAA stably positively predicted PR ($t = 0.518, P < 0.001$). PAA ($t = -0.131, P < 0.001$) and PR ($t = -0.159, P < 0.001$) negatively predicted MPA levels. (1) Improving PAA not only alleviates MPA in college students, but also improves PR levels. (2) PR also has an inhibitory effect on MPA, so increasing PR will enhance the effect of PAA. (3) PAA negatively predicts MPA and positively predicts PR in college students.

Keywords Physical activity, Exercise, Psychological resilience, Mobile phone addiction, Cross-lagged panel model

With the development of modern society and science and technology, people's frequency and time of using electronic screens and smart devices have gradually increased, which has caused some negative effects. Among them, mobile phone addiction (MPA) is a representative negative phenomenon, especially in university campuses where MPA is more common¹. According to the World Health Organization (WHO), the global MPA rate among the youth population is as high as 14.3 per cent.² In China, the rate rose to 24 per cent during the epidemic, according to two large Chinese surveys^{2,3}. Particularly on university campuses, students are less constrained by their families or schools, which has led to a gradual increase in the proportion of MPAs among students, making them the largest potential population⁴. Studies have shown that gender, anxiety, depression, loneliness, stress, well-being, social support and resilience are all predisposing factors for MPA⁵. For college students, although the constraints from their families are reduced, academic pressures, interpersonal interactions and employment

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demands may lead to a gradual increase in the incidence of MPA⁶. Therefore, there is an urgent need to prevent and intervene in MPA among college students.

A large body of research has shown that physical activity (PA), as a non-pharmacological intervention, has a significant effect on improving individuals' mental health and problem behaviours⁷. However, few studies have examined the factors that contribute to individuals engaging in PA. The WHO Mental Health Gap Action Programme (mhGAP) 2023 suggests that the effects of PA on individuals' mental health are significant, but are influenced by a number of factors. Among these factors, the physical activity atmosphere (PAA) is an important determinant of an individual's level of PA⁸. A positive PAA can encourage the surrounding population to actively engage in physical activity and develop regular fitness habits⁹. Behavioral theory suggests that students at the developmental stage of social adjustment are prone to develop psychological traits and behaviors in a peer-supportive environment. PAA covers sports information, peer support and the benefits of a good sports environment for social development and healthy behaviour¹⁰. On the other hand, psychological resilience (PR) refers to an individual's ability to cope positively with stress and frustration in social life¹¹. Research has shown that team sports such as basketball and football, which are played in a teamwork and competitive environment, require more effort from participants and have a positive effect on students' PR¹². Individuals with higher levels of PR, on the other hand, tend to be emotionally stable, have strong social adaptability and emotional management skills, are better able to focus on their goals in the face of a task, and are able to cope with negative life learning events even when they are encountered with positive attitudes, and do not experience MPA behaviors and academic procrastination¹³.

In conclusion, there may be interaction between PAA, PR and MPA among students. At the same time, there may also be gender differences. Previous cross-sectional studies have only shown correlation between variables, and it is difficult to show unidirectional causality, which makes the findings not generalizable. Therefore, this study uses the cross-lagged panel model (CLPM) to examine the causal relationship between variables in terms of time series, which overcomes the limitations of cross-sectional studies and makes the conclusions more representative and stable¹⁴. Specifically, this study investigated and constructed a causal model of PAA, PR, and MPA among college students through a two-phase longitudinal survey conducted over a six-month period, with the aim of exploring the intrinsic relationship between variables affecting college students' MPA and providing evidence for a scientific intervention on college students' MPA. Based on previous literature, the following hypotheses were proposed: (I) PAA, PR and MPA are significantly correlated. (II) PAA and PR can negatively predict MPA.

Materials and methods

Participants

Using the cluster random sampling method, 964 international students from different countries from 8 universities in China were initially selected as the subjects of the study, taking the international student classes in each university as the unit. The inclusion criteria for the subjects were: (1) Current exchange or international students, including undergraduate, master's, and doctoral students. (2) They were conscious and able to complete the questionnaire without difficulty and had no history of intellectual disability or mental illness. (3) Subjects volunteered to participate in this study and did not refuse to complete the survey. (4) Informed consent for the survey was given by the counselor (classroom teacher), and the questionnaire was completed after signing it. The procedures were conducted in accordance with the National Institutes of Health Guidelines and were approved by the Ethics Committee of Human Experimentation of Beijing Normal University (Authorization no. TY20220905). A statement to confirm that all methods were carried out in accordance with relevant guidelines and regulations. Informed consent form was obtained from all subjects. The detail is shown in Table 1.

Procedures

In this study, the subjects PAA, PR and MPA parameters were measured using scales based on various indicators. During the testing process, all indicators were distributed through SoJum Software (Tencent Holdings Ltd.). Prior to data collection, the purpose and methodology of the survey were explained to the respondents in person, and any questions were answered in person, with the consent of the counsellor (class teacher) and the consent of the participant. The scale was completed anonymously, without personal information such as ID number or student number, excluding invalid answers, short time (less than 200 s), 10 consecutive questions with the same option, and questionnaires with high homogeneity.

Measurements

Physical activity atmosphere assessment

The PAA scale used in this study was revised by Liu et al.¹⁵. The initial version of the scale was in Chinese, but considering that most of the participants were international students, the scale was translated into English, and after proofreading and reliability testing, the scale was finalised in English. The reliability of the scale was also confirmed by Li's study¹⁶. The scale consists of five dimensions: interpersonal association, natural association, access to information, interpersonal barriers and conditional barriers, with a total of 17 items. The scale is scored on a 5-point Likert scale ranging from '1' (strongly disagree) to '5' (strongly agree), with higher scores indicating higher PAA. Cronbach's α for the scale in the pre- and post-tests of this study were 0.804 (T1) and 0.839 (T2) respectively.

Psychological resilience survey

The PRS scale used in this study was originally co-developed by Hu et al.¹⁷. The original version of this scale is in English, so there is no need to translate it. The reliability of the scale was also confirmed in Lau's study¹⁸. The scale consists of 27 questions in 5 dimensions, which students are asked to complete according to their

Parameter		Value
Total		964
Male		579
Female		385
Type of specialization	Science student	434
	Humanities student	530
Age (yr)		20.36 ± 1.78
Body mass (kg)		75.29 ± 7.52
Height (m)		1.74 ± 4.69
BMI (kg/m ²)		24.91 ± 1.82
Screen usage time (h/day)		8.17 ± 2.45
Sedentary behavior (h/day)		8.47 ± 1.38
History of exercise	Yes	78%
	No	22%
History of smoking	Yes	19%
	No	81%
History of drinking	Yes	64%
	No	36%
Only child family	Yes	77%
	No	23%

Table 1. Participants’ physical characteristics.

actual situation. The scale uses the Likert 5-point scale to assess students’ PR level, ranging from “1” (not at all compliant) to “5” (fully compliant), with higher total scores indicating higher PR levels. The Cronbach’s α of the scale was 0.775 (T1) and 0.816 (T2) at the pre- and post-test of this study.

Mobile phone addiction evaluation

The MPA scale used in this study was developed by Wang et al.¹⁹. As mentioned above, the scale was initially written in Chinese and, after translation and proofreading, it was administered to participants via an English questionnaire. The scale was also used in Feng’s study²⁰. The scale consists of 16 questions with 3 dimensions, namely withdrawal, salience and compulsivity. The scale uses a 5-point Likert scale to assess MPA in secondary school students, with scores ranging from ‘1’ (extremely non-compliant) to ‘5’ (very compliant), and a total score of more than 45 points is the criterion for MPA. The Cronbach’s alpha for the pre- and post-test scales in this study were 0.879 (T1) and 0.862 (T2) respectively.

Cross-lagged panel model construction

The cross-lagged panel model (CLPM) will be constructed based on the results of the 2 measurements by taking 2 longitudinal follow-up measurements of all participants at the following points²¹: T1: September 2022 and T2: March 2023. Specifically, the 2 measurements of PAA will be used as the main variable and PR will be used as a mediator variable to observe the positive or negative predictive effect of PAA on MPA, which is the main dependent variable. The results obtained on two occasions were tested for consistency according to Andersen’s method and the PAA, PR, and MPA of the international students were tested for gender and age equivalence by baseline equivalence, load equivalence and intercept equivalence in that order²². Andersen’s consistency test is mainly used to verify that measurement models (e.g. factor structures) are equivalent across time points or groups, and to avoid biases in the estimation of structural models (e.g. cross-lagged effects) due to differences in measurement instruments. The process requires configural invariance, metric invariance, scalar invariance, and strict invariance. Finally, the significance of the model is determined using the fit indices (e.g., $\Delta CFI \leq 0.01$ or $\Delta RMSEA \leq 0.015$). The specific reason for this is because of the need to exclude measurement bias (in this study, e.g., T1-PAA→T2- MPA) during the CLPM building process, to ensure the validity of the measurement-equivalent latent variable model, and to verify that the results support the time-series effect among variables (e.g., from T1→T2). In this study, Model-1 is the baseline equivalent model, Model-2 is the load equivalent model.

Statistical analysis

In this study, we mainly used comparison of differences, correlation analysis and CLPM to analyze the different indicators. First, SPSS 21.0 was used to test the normality of PAA, PR, and MPA one by one, and descriptive statistics were performed after determining the types of data. Bartlett’s test of sphericity, for data that did not meet the assumptions, the Greenhouse-Geisser method was used to correct the data²³. To explore the correlation and effect size between variables, Pearson’s test was used to analyze the results and r and P values were reported. After screening the correlation results, valid variables were included in the CLPM by AMOS 24.0 for fitting to explore the path characteristics between variables. After standardizing each result, the CLPM test and confidence interval estimation were performed using model-6 in the SPSS process canonical macro plug-in. The

significance of each path was then tested using the bootstrap method²⁴. Finally, the Bonferroni test was used for post hoc testing of all indicators, with a significant threshold of $P < 0.05$.

Results

The results of this study were collected twice over a period of six months. Of these, the first collection (T1) had a compliance of 95.74% with a loss of 41 samples. The second collection (T2) had a compliance of 89.83% and a loss of 57 samples. The researchers also reported that no risky events occurred during the entire experiment.

Common method deviation test results

In this study, the use of multiple self-report questionnaires to measure the same group of people can easily lead to the problem of common methodological bias. In this paper, we train the subjects before distributing the questionnaires and use various methods to minimize the influence of the self-assessment methods on the results of the study, such as standardized instructions, strict control of the time taken to complete the questionnaires, mixing the distribution of positive and negative questions, and controlling demographic variables. Meanwhile, an exploratory factor analysis of all question items of the PAA, PR and MPA scales for college students was conducted using Harman’s one-way test, and a total of 13 factors had eigenvalues greater than 1 when the factors were not rotated, and the first factor explained 14% of the variance, which did not reach the required critical level of 40%. Therefore, there is no general methodological bias in this study.

Correlation test results between variables

The correlation results showed that, by Pearson correlation test for PAA, PR, and MPA of college students (see Table 2): T1-PAA and T2-PAA, T1-PR and T2-PR, and T1-MPA and T2-MPA showed significant positive correlation. Simultaneous correlation tests: T1-PAA, T1-PR, T1-MPA were significantly correlated; T2-PAA, T2-PR, T2-MPA were significantly correlated. College students’ PAA, PR and MPA showed significant correlations in both pre-test and post-test, indicating that PAA, PR and MPA satisfy the inter-temporal stability and synchronous correlation of 6 months, which is suitable for cross-lagged analysis. The results also indicate that more than 90% of the main variables and sub-indicators are significantly correlated with each other, which can be further tested for mediation effects²⁵. See Table 1; Fig. 1 for more information.

Cross-lagged panel model consistency test results

In order to test the measurement consistency of the model, the study was conducted in three steps (baseline equivalence, loaded equivalence, and intercept equivalence) to test the equivalence of PAA, PR, and MPA across gender and age. The results showed that PAA and PR were consistent across gender and age, while MPA was consistent across age. There were differences in MPA loadings and intercepts by gender, but no statistically significant differences were found between the 2 adjacent time points ($\Delta CF1 < 0.01$), so the model fit indices were good. In conclusion, the subjects PAA, PR, and MPA measurement items, latent factor meanings, and measurement reference points were highly consistent across gender and age, and the results were comparable across gender and age.

The data were also tested for common method bias using the Harman one-way test²⁶. A total of 3 tests were conducted, the 1st measurement eigenvalue greater than 1 factor total 17, the maximum factor variance explained rate is $< 40\%$. The 2nd test measured 12 factors with eigenvalues greater than 1, and the maximum factor variance explained was $< 40\%$. The third measurement had 11 factors with eigenvalues greater than 1, and the maximum factor variance explained was $< 40\%$. There is no serious common method bias problem in all three measurements. See Table 3.

Cross-lagged panel model path and fitting degree results

In this study, we used AMOS software to construct CLPM to test the cross-lag model of PAA, PR and MPA in college sports. The model fit metrics showed that $X^2/df = 2.205$ ($P < 0.001$, $n = 964$), and the goodness-of-fit metrics: CFI = 0.941, NFI = 0.934, CFI = 0.945. This result indicated that the cross-lagged model fit was high. In particular, T1-PAA had a significant effect on T2-PAA ($\beta = 0.423$, $P < 0.01$), T2-PR ($\beta = 0.135$, $P < 0.01$), and T2-MPA ($\beta = -0.163$, $P < 0.01$); T1-PR had a significant effect on T2-PAA ($\beta = 0.411$, $P < 0.01$), T2-PR ($\beta = 0.557$, $P < 0.01$), and T2-MPA ($\beta = -0.148$, $P < 0.01$). T1-MPA had a significant effect on T2-PR ($\beta = -0.140$, $P < 0.05$), T2-MPA ($\beta = 0.512$, $P < 0.01$), and a non-significant effect on T2-PAA ($\beta = -0.019$, $P > 0.05$).

Variable		T1			T2		
		Physical activity atmosphere	Psychological resilience	Mobile phone addiction	Physical activity atmosphere	Psychological resilience	Mobile phone addiction
T1	Physical activity atmosphere	1					
	Psychological resilience	0.602	1				
	Mobile phone addiction	-0.334	-0.276	1			
T2	Physical activity atmosphere	0.415	0.389	-0.212	1		
	Psychological resilience	0.468	0.443	-0.267	0.318	1	
	Mobile phone addiction	-0.354	-0.231	0.506	-0.214	-0.373	1

Table 2. Correlation results between different variables. All P-values were less than 0.01 after testing.

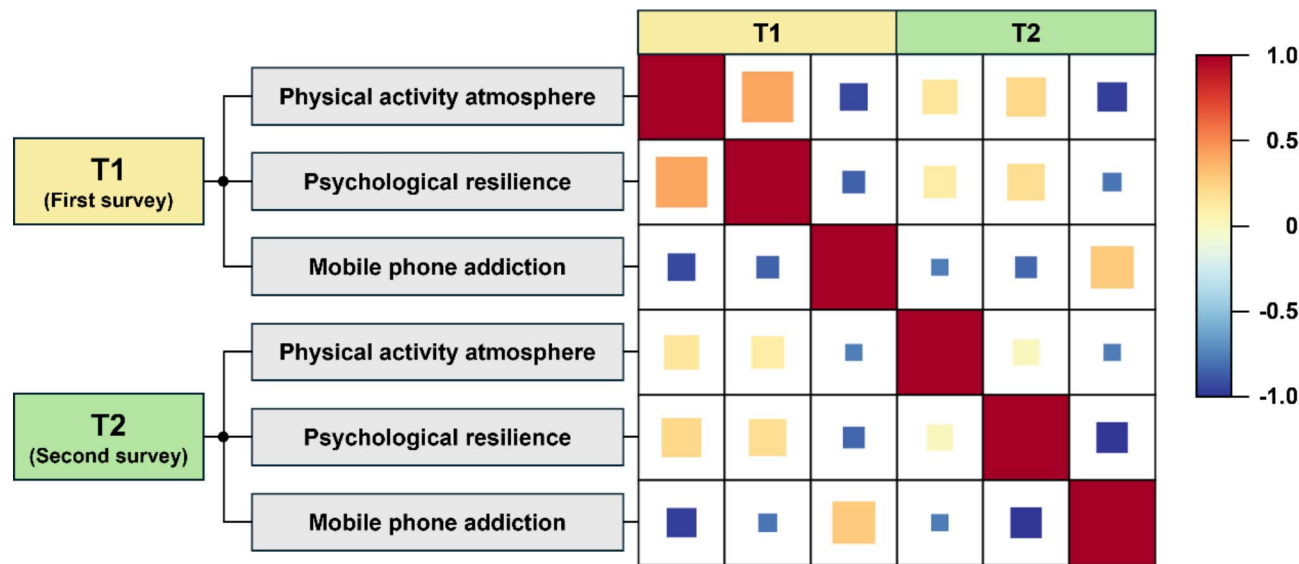


Fig. 1. Correlation heatmap between individual variables.

Group	Model	Physical activity atmosphere						Psychological resilience						Mobile phone addiction					
		χ^2	df	P	RMSEA	TLI	CFI	χ^2	df	P	RMSEA	TLI	CFI	χ^2	df	P	RMSEA	TLI	CFI
Gender	Model-1	13.02	2	<0.01	0.08	0.96	0.97	35.88	2	<0.01	0.19	0.93	0.95	6.02	2	0.06	0.06	0.95	0.99
	Model-2	15.98	4	<0.01	0.06	0.98	0.97	36.54	4	<0.01	0.15	0.94	0.95	7.54	4	0.09	0.06	0.96	0.98
Age	Model-1	96.21	27	<0.01	0.07	0.97	0.92	95.17	28	<0.01	0.06	0.97	0.93	63.79	28	<0.01	0.05	0.92	0.92
	Model-2	97.64	32	<0.05	0.09	0.94	0.94	96.45	30	<0.01	0.07	0.97	0.92	72.61	29	<0.01	0.04	0.92	0.96

Table 3. Cross-lagged panel model consistency test based on physical activity atmosphere, psychological resilience and mobile phone addiction. Model-1 is the baseline equivalence model (BEM), Model-2 is the load equivalence model (LEM).

According to the M.C.EISMA method²⁷, the causal relationship between variables A and B is examined, if the correlation between the pre-test variable A and the post-test variable B is greater than the relationship between the pre-test variable B and the post-test variable A, it can be inferred that there is a causal relationship between variables A and B, and that variable A is the cause variable of variable B. Combined with the path coefficients of the cross-lagged model, it can be seen that PAA is the cause variable of college students' PR, MPA, and PR is the cause variable of MPA, and from the relationship of the correlated variables, PR may be the mediator of college students' PAA affecting MPA, and the detailed information is shown in Fig. 2.

Multi-structural equation modeling results

Meanwhile, in this study, multiple sets of structural equations were used to model the baseline model (M0) and the restricted model (cross-lagged paths M1 for boys and girls, and structural intercept M2, structural covariance M3, etc.), and model comparisons were made to examine whether there were gender differences in the cross-lagged relationships of the variables. The results showed that the models M1 to M3 were well fitted and the differences from the baseline model (CFI = 0.941, TLI = 0.873, RMSEA = 0.12, 90%CI = [0.10, 0.14], $P < 0.01$) were not statistically significant ($\Delta CFI < 0.05$, $P > 0.05$), i.e., PAA, PR, and MPA for all participants There was no statistically significant difference in the cross-lagged relationship between the sexes. See Table 4.

Discussion

MPA is a maladaptive behavioral habit that is common on college campuses, and chronic MPA can trigger numerous risk factors, including symptoms such as decreased academic performance, impaired mental health, or the development of aggressive behavior²⁸. Numerous studies have shown that PA can effectively alleviate MPA symptoms in students and improve PR to help them establish better study habits^{29,30}. However, few studies have been able to clarify whether there is a longitudinal interaction between the three. Therefore, the present study was the first to examine the association between PAA, PR and MPA in college students through a longitudinal study with a cross-lagged research design over a period of 6 months and two phases to reveal the intrinsic influence of PAA on college students' MPA. The study concluded that PAA can directly affect MPA or indirectly improve MPA by increasing PR. Creating a good campus sports PAA can effectively improve college students'

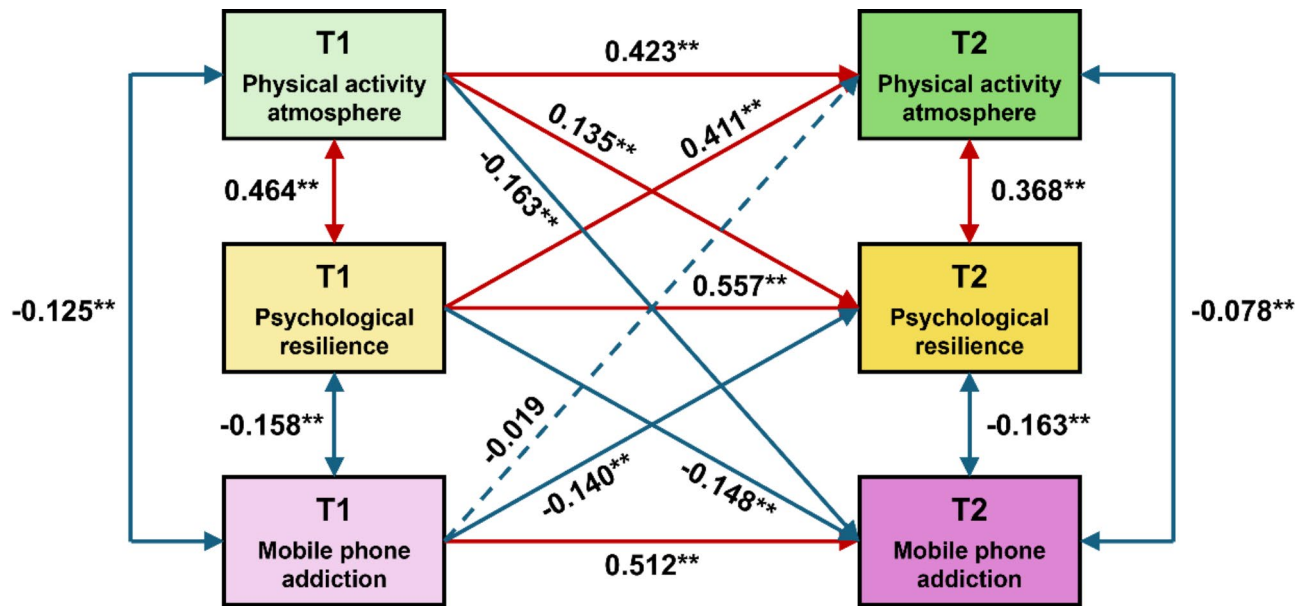


Fig. 2. Chained intermediary model and path between variables. *Note* * = significant fit, $P < 0.05$; ** = highly significant fit, $P < 0.01$.

Model	CMIN	df	P	CMIN/DF	NFI	RFI	IFI	TLI	CFI	RMSEA (95%CI)
Model-1	195.64	55	< 0.01	3.45	0.94	0.9	0.94	0.91	0.95	0.08 (0.06, 0.10)
Model-2	204.17	60	< 0.01	3.76	0.93	0.92	0.94	0.93	0.96	0.09 (0.07, 0.11)
Model-3	210.76	61	< 0.01	3.38	0.93	0.91	0.95	0.94	0.96	0.11 (0.09, 0.14)

Table 4. Bootstrap analysis of the mediating effect test.

MPA phenomenon, which is conducive to the development of interpersonal relationships and the improvement of college students' PR level.

The first finding of this study is that PAA can stably and positively predict the PR of college students. In this study, PAA was significantly and positively correlated with individuals' PR and was not affected by the factors of gender and age. At the same time, the effect sizes of the positive influence of PAA on PR were all greater than 0.4, so it can be judged that the benign influence of PAA on individual PR is very effective. So far, hypothesis (I) can be accepted. Contrary to previous studies, college students' PAA has a significant predictive effect on individual PR levels, and PAA as a supporting element can improve college students' knowledge and understanding of physical activity^{31,32}. The higher the PAA, the more information about sport the individual receives, the more the individual feels the exercise environment of peer encouragement, support and supervision, and the more the individual recognizes the multiple physical and mental health values of exercise and the positive experience of exercise, which strengthens the participant's mastery of health knowledge and exercise skills, and integrates exercise into the individual's life and healthy lifestyle³³. When college students have good PAA, they get more peer support factors and a relaxing and pleasant exercise environment, overcome more of their own physiological and psychological barriers during exercise, reduce tension and anxiety, improve stress resistance and interpersonal relationships, strengthen the honing of their willpower, and thus improve the level of college students' PR³⁴. In good PAA, college students have to mobilize more attention and cognitive capacity to cope with situations in sport, and the constraints of the rules of sport expose the individual to a collective and jointly supervised environment, which in the long run leads to an increase in students' PR levels³⁵. If students do not have a good PAA, individual exercise lacks a supportive environment with a supervised atmosphere, and if they encounter difficulties during exercise, they may choose to procrastinate, avoid challenging exercises and have lower PR levels³⁶.

The second finding of this study was that PAA was a stable predictor of MPA in college students. In this study, PAA showed a significant negative correlation with MPA and remained independent of gender and age factors. Meanwhile, the magnitude of the negative effect of PAA on MPA exceeded that of PR, so it can be judged that good PAA is an important way to improve individual MPA. The validity of hypothesis (I) was also tested again. Previous studies have shown that PAA is a motivational factor that promotes the refinement of exercise information, enriches individual exercise experiences and forms active exercise habits. Good PAA can internalize students' understanding of the value of sport and stimulate the individual's emotional experience to actively integrate into the exercise environment³⁷. Good PAA can also lead to harmonious peer relationships, providing students with informational, emotional and behavioral support for physical activity. Students can

improve their motor skills and self-esteem through frequent peer interactions, build exercise expectations in a supportive environment with peers, share exercise information and form an exercise circle with common interests, so that students feel a sense of belonging to exercise and are more likely to have a pleasurable exercise experience³⁸. There is also a greater tendency to engage in repeated and sustained physical activity to satisfy individual social needs and exercise psychology³⁹. A good PAA provides a positive and supportive environment with rich and varied sports information so that students can increase their motivation to exercise, focus their attention on sport, actively experience the enjoyment of sport, and actively overcome the negative consequences of MPA on the individual in order to develop a healthy lifestyle⁴⁰. Poor PAA do not get support and guidance from teachers and peers on exercise emotions, exercise behavior, lack of common exercise, mutually supportive exercise environment and sufficient exercise information, and when they encounter difficulties in exercising, they prefer to use mobile phones to vent their emotions or relieve stress through entertainment and interpersonal communication⁴¹.

The final finding of this study was that students' PR predicted MPA over a long period of time. In this study, the negative effect of PR on MPA was significant. Meanwhile, the longitudinal results showed that the degree of negative effect of PR on MPA did not decrease but increased at T1 and T2 stages separated by 6 months. Therefore, this study concluded that the inhibitory effect of PR on MPA is long-lasting. Previous studies have shown that PR is an individual's positive ability to cope with frustration or stress, and that regular participation in physical activity leads to an increase in PR, while individuals with high PR have strong self-management and discipline, and show strong adaptive capacity in life and study⁴². Individuals have greater control over maladaptive behaviors when they have a strong PR, and their good self-management skills avoid spending more time on their mobile phones, which in turn reduces the incidence of MPA⁴³. Individuals with high PR tend to be emotionally stable, have strong social adaptability and emotional management skills, are better able to focus on goals when faced with tasks, and are able to cope with negative life learning events even when they are faced with positive attitudes, and do not experience MPA behaviors and academic procrastination⁴⁴. However, those with low PR are unable to cope with the pressures and frustrations of life, study and tend to indulge in mobile phone use to avoid the obstacles of reality. When faced with setbacks in exercise, they tend to avoid, cannot control their own emotions and behavior, lack the ability to organize and manage the exercise tasks set, are easily distracted, and often turn to mobile phones to relieve their negative psychology, which is prone to the development of MPA⁴⁵.

Cross-lagged analyses also revealed that PR may have a mediating effect in the process of students' PAA affecting MPA. In the present study, there was a direct effect of PAA on MPA and a positive moderating effect of PR on this pathway. This is mainly reflected in the fact that PR acts as a mediator and enhances the negative inhibitory effect of PAA on MPA. At this stage, hypothesis (II) can be accepted. Previous research has shown that the multiple supportive environments provided by PAA can promote individual psychological growth, and that the collective sense of belonging that PAA provides to students can also be beneficial⁴⁶. Adequate information about exercise and positive peer relationships can provide emotional support for students to continue to participate in exercise, helping them to understand the value and effectiveness of physical activity and to see exercise as a positive and beneficial lifestyle choice that is consistent with their self-development⁴⁷. The mutually supportive training environment enables students to overcome more of their own physical and psychological barriers, strengthens their willpower and effectively improves their PR levels⁴⁸. In a collaboratively supervised and supported environment, exercise behaviors have higher levels of autonomy and adherence, with significant improvements in students' resilience and interpersonal relationships, as well as the ability of individuals to remain positively engaged in exercise when faced with exercise difficulties or temptations to engage in entertainment, such as mobile phones⁴⁹. Improved PR will enable students to experience fun and positive emotions during exercise, become more confident when frustrated during physical activity, actively overcome the urge to overuse mobile phones, consciously change bad mobile phone use habits, improve individual internal motivation, consciously regulate emotions, behaviors, and reduce MPA⁵⁰. At the same time, actively creating a good PAA can not only improve the PR level of college students, but also improve the autonomy and persistence of physical exercise. If there is no good PAA, students' autonomy in exercise is not high, there is a lack of support and encouragement from parents, teachers and peers, and the interpersonal relationship between supervision and encouragement in exercise cannot be formed⁵¹. It is not easy for students to get appropriate information about exercise, students' perceptions of the value of exercise and sport are not clear, students' motivation to be active is weakened, and students' PR is weakened⁵². When physically challenged, they turn to relatively easy gaming entertainment to avoid negative evaluations, are less resistant to the virtual world, are more likely to seek alternative emotions via mobile phones, and are more likely to develop MPA⁵³.

In summary, students' PAA, PR and MPA have synchronous and stable correlations. Therefore, this study used cross-lag analysis to confirm the causal relationship of the variables, in which college students' PAA is the cause variable of PR and MPA, and PR is the cause variable of college students' MPA. Furthermore, the relationship between the variables suggests that PR may have a mediating effect in the process of college students' PAA influencing MPA. Therefore, combining the above results, this study concluded that creating a good PAA is conducive to reducing MPA, while effectively improving students' PR and helping them establish good mental health.

Limitations and suggestions for future research

In this study, we constructed a cross-lagged panel model to investigate whether PAA can influence college students' MPA and PR over time, with the aim of reducing and preventing the likelihood of college students' MPA and increasing PR to inhibit the occurrence of MPA or other problematic behaviors. At the same time, we included international students from eight universities in Beijing through a large-sample survey and follow-up

interviews, and constructed multiple horizontal and vertical pathways of significant effects among the variables. However, there are several limitations to this study.

Firstly, although the three indicators were included in this study and follow-up was carried out at six-month intervals. However, the experiment did not continue with the follow-up, so the whole process of investigation did not exceed 1 year and did not sufficiently prove the timeliness between the three variables. Therefore, we will continue to deepen this study in the future and strive for the collection and follow-up time to reach more than 3 years, which has fully proved the validity of the overall results, and construct the prediction model of the three indicators in a certain region by region. To prevent and suppress the incidence of MPA among college students.

Secondly, as to why PAA was chosen for this study rather than traditional physical activity (PA), this is because a large number of previous studies have shown that PA has a significant effect on individuals' mental health and quality of life. This is because many previous studies have shown that PA has a significant effect on individuals' mental health and quality of life. Therefore, this question does not require much empirical evidence from subsequent studies. However, the number of relevant studies on the influencing factors that contribute to individuals performing PA is limited. Therefore, this study shifted the main variable to PAA and went to explore how to create an exercise environment and atmosphere that helps college students reduce MPA and improve PR from the perspective of PAA.

Although the above issues cannot be ignored, this study illustrates the timeliness of PAA to improve MPA and PR from the perspective of rare longitudinal follow-up. Meanwhile, we will continue to follow up and collect longitudinal outcomes and other exploratory indicators for inclusion in analyses in future studies. Based on the current results, we will continue to improve the reliability and rigor of the study. We hope to provide college students with effective tools to improve problem behaviors and promote mental health.

Conclusion

(1) Improving PAA is not only effective in alleviating MPA in college students, but also in increasing PR levels. (2) Elevated PR levels also have an inhibitory effect on MPA, and elevated PR leads to a more significant effect of PAA. (3) PAA can provide a stable negative prediction of MPA and a positive prediction of PR in college students.

Data availability

Data is available on reasonable request. The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions

F.D. conceived, designed the study, performed the data analysis. Z.B. and Y.L. wrote the Chinese manuscript and

wrote and supplemented the English manuscript. S.J. participated in the manuscript revision. Y.L. and J.L. participated in the data collection and collation. J.L. and J.L. are responsible for data search and literature collection. All of the authors contributed to the article and approved the submitted version.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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