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Effects of physical activity on smartphone addiction in Chinese college students-chain mediation of self-control and stress perception

Zicong Ye $^{1\dagger},$ Ting Zhang $^{3^{\ast}\dagger},$ Ying Peng 2, Wei Rao 1 and Peng Jia 3

Abstract

Purpose With the advancement of technology and widespread smartphone use, addiction to these devices has escalated, particularly among college students. This issue transcends mere habit, impacting physical, psychological, and social well-being. Prolonged screen exposure and excessive app engagement contribute to vision and hearing deterioration, alongside heightened psychological stress and diminished social skills. The dual-process theory offers a unique lens to explore the intricate dynamics of smartphone addiction. Incorporating physical activity as a healthy lifestyle choice can bolster self-control and mitigate the allure of smartphones by enhancing physical engagement.

Methods A total of 559 college students from two universities, Wuhan University of Science and Technology and Central China Normal University, were surveyed using the Physical Activity Scale, Stress Perception Scale, self-control Scale, and smartphone Addiction Burnout Scale. The questionnaire was statistically analyzed using SPSS 27.0 statistical analysis software. Correlation analysis, regression analysis, and mediation model were used to evaluate the relationships among physical activity, self-control, stress perception, and smartphone addiction among college students.

Results Physical activity was a significant negative predictor of smartphone addiction among college students ($\beta = -0.038$, p < 0.001), and with the addition of the intermediate variables (self-control and stress perception), physical activity remained a significant negative predictor of smartphone addiction among college students ($\beta = -0.017$, p < 0.01).

Conclusion Physical activity and self-control negatively predicted smartphone addiction, and stress perception was a negative predictor of smartphone addiction;self-control mediates in physical activity and smartphone addiction;stress perception mediates physical activity and smartphone addiction;self-control and stress perception play a chain mediating role in physical activity and smartphone addiction.

Keywords Smartphone addiction, Physical activity, Self-control, Stress perception, Dual-process theory

[†]Zicong Ye and Ting Zhang contributed equally.

*Correspondence:

Ting Zhang

349442680@qq.com

¹ School of Physical Education and Sport (College of Evergrande Football), Wuhan University of Science and Technology, Wuhan, China
² Wuhan Qiaokou District Basketball Association, Wuhan, China

³ Physical Education College of Jiangxi, Normal University, Jiangxi, China

Background

With the widespread popularity of the internet, smartphones have evolved into the most advanced and vital communication tool in the world today. The Emergency Management Blue Book: China Emergency Management Development Report (2022) pointed out that the phenomenon of smartphone addiction has become a global universal problem, especially among young



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people. The survey data on internet user age in 2017 indicates that young users aged between 10 and 39 are the main force of China's internet users, accounting for 73.7% of the total user base. Among them, the user group aged between 20 and 29 has the highest proportion, reaching 30.3% [1]. Given the increasingly competitive social environment that current college students find themselves in, they are compelled to cope with pressures from environmental adaptation, academic research, employment entrepreneurship, interpersonal interactions, and other aspects. The continuous accumulation of these pressures can easily lead to significant psychological burdens on individuals [2]. In China, a severe phenomenon of smartphone dependency is widespread among college students, with the addiction rate exceeding 25% in 2021 [3]. By 2022, the latest survey results indicate that the rate of smartphone addiction among Chinese college students has risen to 36.6% [4]. smartphone addiction has had a profound impact on college students' lifestyles, behaviors, and health conditions. Prolonged and excessive use of smartphones or frequent use can lead to physical symptoms such as eye fatigue, hearing loss, arm numbness, wrist swelling, and neck pain, which in turn can affect academic performance and quality of life [5]. Studies suggest that excessive use of smartphones may also lead to health risk behaviors such as sleep disorders and insufficient physical activity [6]. The behavior of excessive smartphone use is classified as addictive behavior due to its core addictive characteristics, such as lack of self-control, tolerance, withdrawal symptoms, and recurrence [7, 8]. smartphone addiction has become a social public health issue hindering the healthy growth of young people [9]. Therefore, smartphone addiction has become one of the main factors affecting the mental health of college students at this stage.

Physical activities are aimed at promoting individual physical and mental health development, with physical exercise as the content and means, and have a positive impact on personal life satisfaction, with a certain intensity, frequency, and duration of body activities [10]. Canadian psychologist Davis proposed the cognitivebehavioral model [11] at the beginning of the twenty-first century. The model emphasizes the interaction between individual cognition (thinking) and behavior, considering these two as the core factors influencing emotions and behavioral outcomes. The model posits that by changing irrational cognitions and maladaptive behavior patterns, emotional issues, behavioral problems, and mental health conditions can be improved [12]. Therefore, this study predicts that college students' physical activity can directly influence smartphone addiction.

Self-control is the ability to transcend instincts, and self-control enables individuals to support their pursuit of long-term goals [13] through conscious efforts that result in inhibiting or altering their instinctual responses, as well as preventing outcomes that are contrary to desired behaviors. Individuals with high self-control have better academic outcomes [14], better interpersonal relationships [15] and healthier behaviors [16] and negatively correlated with transgressive behaviors such as aggressive, antisocial and addictive behaviors [17]. According to the resource theory of self-control [18], an individual's self-control is regarded as a limited resource. The phenomenon of smartphone addiction is often associated with a lack of self-control, which makes it difficult for individuals to resist the immediate temptation of smartphones. However, by engaging in physical activity, individuals are able to enhance their self-control resources to more effectively resist such temptations, which in turn reduces over dependence on smartphones. This is further supported by the results of the Evaluation Stroop Intervention Trial, which demonstrated that long-term participation in physical activity can significantly enhance an individual's self-control [19]. Thus, by enhancing physical activity, individuals can manage smartphone use more effectively while maintaining self-discipline and rationality, thereby maintaining physical and mental health. Therefore, this study predicted that self-control plays a mediating role in physical activity and smartphone addiction among college students.

Stress perception is the subjective feeling and psychological response that an individual experiences when faced with various stimuli in the environment [20]. It is a cognitive and evaluative process that assigns a certain meaning to stress events. The perception of stress events by individuals determines the extent to which they are affected by stressful incidents. The greater the stress perceived by an individual, the more tension and a sense of loss of control they will exhibit [21].College students are vulnerable to stress in many aspects of their studies and lives [22]. They have to face a lot of pressures such as adapting to the environment, completing studies, interpersonal communication, love and friendship, and entrepreneurship and employment, etc. These tasks are intertwined, which makes college students have a large stress load [23]. High levels of stress can lead to negative emotions such as anxiety and depression, which are particularly common among college students [24]. According to the theory of "general stress" [25], stress causes problematic behaviors, such as school burnout [26] > anxieties [27] and depression [28]. It has been shown that there is a significant positive correlation between stress perception and the tendency of smartphone addiction [29–31]. Furthermore, physical activity may reduce smartphone

addiction by adjusting an individual's cognitive appraisal of stress. In other words, by engaging in physical activity, individuals may learn healthier and more positive stress coping strategies instead of relying excessively on smartphones as a means of avoiding stress. Studies have shown that physical activity helps alleviate negative emotions and stress in college students [32] while reducing their use of smartphones [33]. Research shows that exercise boosts dopamine signaling and influences addiction tendencies [34].Therefore, this study predicted that college students' stress perceptions play a mediating role in physical activity and smartphone addiction.

Further, according to the self-control resource theory, the ability of self-control is limited to certain energy resources. Any activity involving the consumption of psychological resources, such as emotional management, thought control, and behavioral guidance, if overconsuming a certain resource, may trigger a weakening or failure of individual self-control capabilities [35]. Additionally, the limited willpower theory also suggests that self-control is regarded as a limited form of energy. When an individual faces stress or perceives stress to be excessively high, it consumes willpower resources, which may lead to maladaptive responses, and even pathological symptoms [36]. Existing research has revealed that the higher the perceived stress level in learning and social activities, the greater the consumption of self-control resources.When self-control resources are scarce, it may lead to the failure of behavioral self-control, which in turn makes individuals more inclined to escape stress through problem behaviors, thereby increasing the risk of smartphone dependence [37]. When individuals are faced with stressinducing stimuli and negative emotions, their self-control ability will be hindered, which may lead to inappropriate behaviors [38], such as an increase in unreasonable smartphone usage [39]. Researchers point out that there is a significant negative correlation between self-control ability and stress perception, and the tendency towards smartphone dependence [40]. Therefore, self-control can significantly negatively predict smartphone addiction through the mediating effect of stress perception [41]. Furthermore, related studies indicate that for college students with weaker self-control, the perceived level of stress is positively correlated with the severity of smartphone addiction [42]. At the same time, only children [43] and urban children [44] may have more abundant family resources, but they may also experience greater academic pressure, and these variables may affect the research results. Based on this, the present study considers the identity of an only child as a covariate. Based on the above discussion, this study predicts that self-control and stress perception play a chain mediating role in physical activity and smartphone addiction.

The present study

Previous studies have focused on individuals' internal psychological factors, such as stress perception, social anxiety, and psychological states such as autism [45-48]. However, few studies have delved into the causes of smartphone addiction by simultaneously exploring both the implicit and explicit factors from an individual's perspective. Based on the dual-process theory of self-control [49], the formation of human behavior is the result of the combined effects of implicit and explicit processes, which operate in parallel and influence each other [49]. The implicit system, as part of the non-conscious or pre-conscious components, possesses characteristics of rapidity, parallel processing, low effort, and high capacity, and is influenced by biological constraints and specific domain learning. In contrast, the explicit system is conscious, operates slowly, sequentially, requires high effort, and has limited capacity, and is reactive to verbal instructions. Inference and decision-making processes may reflect the characteristics of either system, but there is also interaction between systems, with conscious thinking constantly being shaped, guided, and constrained by implicit, pre-attentive systems [50]. The explicit system, such as goal-directed behavior, self-control of personal traits, and executive functions, can improve implicit processes, such as habit formation and emotional experiences [51]. The impact of the explicit system on implicit processes is crucial, and the extent of this impact depends on the strength of habits and emotions as well as the effectiveness of self-regulatory abilities. Although existing research has explored the association between physical activity and smartphone addiction behaviors among college students, the understanding of the specific interactive mechanisms between the two is still insufficient. Therefore, the purpose of this study is to comprehensively analyze how the implicit and explicit factors of smartphone use interactively contribute to smartphone addiction and to attempt to explore whether physical activity can positively influence smartphone addiction by affecting its implicit and explicit variables.On the basis of the previous viewpoints, this study constructed a chain mediation model based on the dual process theory of self-control, the cognitive-behavioral model theory, and the theory of self-control resources, as shown in Fig. 1, and accordingly proposed the following research hypotheses:

Hypothesis 1: physical activity and self-control negatively predict smartphone addiction, and stress perception is a positive predictor of smartphone addiction;



Fig. 1 Chain mediation model diagram for physical activity, self-control, stress perception and smartphone addiction

Hypothesis 2: self-control mediates physical activity and smartphone addiction;

Hypothesis 3: stress perception mediates physical activity and smartphone addiction;

Hypothesis 4: self-control and stress perception play a chain mediating role in physical activity and smartphone addiction.

Materials and Methods

Participants

This study employed a cluster sampling method to select two universities in Province H as the research subjects, with a total of 600 students participating. Data collection was conducted in March 2024. Questionnaires were filled out during the first 15 min of physical education classes, and all students completed the questionnaires within the stipulated time. Criteria for determining the validity of questionnaire data included: missing data on duration or frequency of physical activity, regular answering, response rate below 75%, and omission of questionnaire coding (student ID). Ultimately, this study obtained 559 valid questionnaires. In addition, there were no significant differences in physical activity scores and smartphone addiction scores between the attrition sample and the valid sample(p > 0.05). The age range of the participants was between 18 and 21 years, with an average age of 18.82 years, including 226 males and 333 females. All participants were from two large public universities in the central region of China and were recruited to participate in this study during the compulsory physical education period in the fall semester. Before participating in the study, the students had no direct motivation to participate in this research. To control for social desirability responses, researchers encouraged students to answer questions as truthfully as possible. Participants were assured that they could withdraw from the study at any time, and their decision would not affect their grades. This study was approved by the Institutional Review Committee of Wuhan University of Science and Technology and the leadership of the School of Physical Education, and informed consent was obtained from the participants before the study.

When conducting sample size calculations, according to Cohen's [52] research, both the ideal statistical power and effect size should be greater than 0.8. Using this as a standard, we utilized the G-Power software for estimation, where the parameters that need to be precisely set include effect size, α error, power 1- β , number of groups, number of measurements, intra-class correlation coefficient, and sphericity. Specifically, for correlation analysis, we set p to 0.3 [53]; the α error rate was set to 0.05, and the statistical power 1- β was set to 0.8 [54]; calculations show that a chain mediation model [55] requires at least a sample size of 370 to achieve a statistical validity of 0.80. However, considering the potential subject attrition and invalid questionnaires that may occur during actual surveys, we assumed a non-effect response rate of 15%. Based on this assumption, to ensure that all set effect size conditions are met, the number of questionnaires to be distributed should be 370/(1-0.15) = 435.

Measuring Tools

Physical activity

Physical Activity Rating Scale(PARS-3) Revised by Liang Deqing [56]. The PARS-3 was used to measure the amount of physical activity of participants in the previous month. A total of three items measured exercise intensity, time, and frequency, and each dimension was divided into five levels. Exercise duration levels 1–5 are equivalent to a score of 0–4. Exercise intensity and exercise frequency are equivalent to a score of 1–5. Exercise volume = exercise intensity x exercise duration x exercise frequency. Exercise volume is graded according to the following criteria: \leq 19 points for lesser exercise, 20–42 points for moderate exercise, and \geq 43 points for greater exercise; the higher the score, the greater the exercise volume. The retest reliability of the scale was 0.82 [56].

Self-control

The self-control Scale for College Students was adopted from the revised self-control Scale for College Students by Tan Shuhua et al. [57]. This scale has 19 items and five dimensions. The five dimensions are impulse control, resisting temptation, focusing on work or study, abstaining from entertainment and healthy habits. The scale is a 5-point scale with 1 point for "completely disagree", 2 points for "mostly disagree", 3 points for "not sure", 4 points for "mostly agree", and 4 points for "mostly agree". "The scale includes 15 inverse scales. At the same time, the scale consists of 15 reverse scoring items. The higher the sum of the scores of all the items, the higher the students' self-control ability. The Cronbach's alpha coefficient was 0.871, which showed high reliability.

Stress perception

Stress perception was measured using the Chinese version of the Stress Perception Scale developed by Li Yajie et al. [58]. It assess 3 types of stressful situations, namely, daily chores, major events, and changes in stressors. The CPSS consists of 14 items, which 4, 5, 6, 7, 9, 10, and 13 are reverse scored on a 5-point scale from 1 (never) to 5 (a lot), with the total score ranging from 0 to 56, with higher scores indicating higher levels of stress perception.Cronbach's alpha coefficient is 0.878, which indicates a higher reliability.

Smartphone addiction

The short version of the Smartphone Addiction Scale (SAS) was used in this study, which consists of the 10 items from the SAS that are most closely related to smartphone addiction. Revised by Xiang Mingqiang et al. et al. [59]. The scale has 6 levels of scoring, one dimension, and the scores are "not at all consistent", "mostly not consistent", "somewhat not consistent", " somewhat meets somewhat does not meet," "somewhat meets," and "mostly meets." The total score is the result of adding up the scores of each question, and boys are considered addicted if their total score is higher than 31, and girls are considered addicted if their total score is higher than 33. The Cronbach's alpha coefficient is 0.848, which shows a high level of reliability.

Statistical analysis

In this study, we used the latest version of statistical software SPSS 27.0 and SPSS process plug-in for in-depth analysis and processing of the data collected from the questionnaire. These software tools provide us with powerful functions to perform various complex statistical analysis tasks. First of all, we performed a descriptive analysis of the collected data. Through this analysis, we obtained statistical indicators such as the mean, standard deviation, maximum value and minimum value of each variable, so as to have a comprehensive understanding of the results of the questionnaire survey. At the same time, we also conducted a correlation analysis to reveal the interrelationships among the variables. In further analysis, we also conducted a regression analysis. Through this analysis, we could determine which variables significantly influenced the dependent variable, thus exploring the relationship between them in depth. In addition, we conducted a reliability analysis to ensure that the results of our questionnaire were reliable and consistent.

Results

Common method deviation test and normality evaluation

After the Harman's one-way method test, the results of the non-rotated principal component factor analysis of all the question items showed the existence of 11 factors with initial eigenvalues exceeding 1. Of these, the first factor explained 24.61% of the variance, which was below the critical threshold of 40%. Based on the above data, it can be inferred that the present study did not suffer from significant common method bias problems in the methodology.

We subsequently conducted a normality assessment of the data, and the results are shown in Table 1.Typically, lests of normality revealed that the study variables showed no significant deviation from normality (ie, Skewness < 3.0and Kurtosis < /10.0l) [60].

Descriptive statistics and correlation analysis

Table 2 shows that there is a significant negative correlation between physical activity and stress perception and smartphone addiction, with correlation coefficients of -0.247 and -0.275, respectively, and these relationships are statistically significant (p < 0.01). Meanwhile, there was a significant positive correlation between physical activity and self-control with a correlation coefficient of 0.220, which was also statistically significant (p < 0.01). There were also significant negative correlations between self-control and stress perception and smartphone addiction, with correlation coefficients of -0.591 and -0.581, respectively, and again these relationships were statistically significant (p < 0.01). Notably, there was a significant positive correlation between stress perception and smartphone addiction with a correlation coefficient of 0.488, which was also statistically significant (p < 0.01). These results support our hypothesis 1. To ensure the accuracy of the follow-up study, we also considered the effects of covariates such as gender, grade, student domicile, and class, and excluded them as control variables.

Table 1 Normality evaluation of data

	physical activities	smartphone addiction	self-control	Stress perception
Skewness	2.903	-0.283	0.273	-0.075
Kurtosi	8.915	-0.371	0.238	0.596

variable	M	SD	I	2	3	4	5	6	/	8
1.Gender	1.600	0.491	1							
2. Age	18.820	0.850	0.374**	1						
3. Only child	1.610	0.487	0.007	-0.014	1					
4. Domicile	1.530	0.503	0.069	0014	-0.341**	1				
5. smartphone addiction	3.439	0.963	0.129**	0.055	0.024	-0.080	1			
6. self-control	3.243	0.608	-0.157**	-0.020	-0.032	0.085*	-0.581**	1		
7. Stress perception	2.916	0.640	0.046	-0.043	0.048	-0.081	0.488**	-0.591**	1	
8. physical activities	5.800	6.742	-0.079	.0007	0.036	-0.013	-0.275**	0.220**	-0.247**	1

Table 2 Statistics of Pearson Correlation Coefficient

** p < 0.01

Variable	Model 1	Model 2	Model 3	Model 4
Gender	.127	.104	.015	.091
Age	.010	.018	.044	.043
An only child	004	.006	.001	014
Place of domicile	089	087	030	052
Physical activity		264***		
self-control			585***	
Stress perception				.480***
R	.152	.304	.594	.500
F	3.286	11.190	60.120	36.803
ΔR^2	.023	.092	.353	.250

**** p < 0.001

Regression analysis

From Table 3, we can see that the effects of physical activity, self-control and stress perception on smartphone addiction are gradually revealed in the four models. In Model 1, only control variables such as gender, age, only child and household location were considered, and it was found that these variables had a small effect on smartphone addiction. In Model 2, the variable of physical activity was added, and the results showed that physical activity had a significant negative effect on smartphone addiction ($\beta = -0.264$, p < 0.001), suggesting that students who were less involved in physical activity were more likely to be addicted to smartphones.

The variable of self-control was added to Model 3, and its results showed that self-control had a significant negative effect on smartphone addiction ($\beta = -0.585$, p < 0.001), indicating that students with poorer self-control are more likely to be addicted to smartphones. This result supports our hypothesis 2 that self-control is a significant influence on smartphone addiction.

In Model 4, we simultaneously considered the effects of three variables, physical activity, self-control and stress perception, on smartphone addiction. The results show that physical activity and self-control still have a significant effect on smartphone addiction, while stress perception has a significant positive effect on smartphone addiction ($\beta = 0.480, p < 0.001$), indicating that students who feel more stress are more likely to be addicted to smartphones. This result supports our hypothesis 3 that stress perception is a significant influence on smartphone addiction.

In addition, the R-squared value of the model shows that the explanatory strength of the model gradually increases with the addition of variables. The R-squared value of Model 4 is 0.500, indicating that the three variables of physical activity, self-control, and stress perception together explain 50% of the variance in smartphone addiction. As for the F-values of the models, all of them have F-values greater than 10, indicating that they are all statistically significant.

In summary, through regression analysis we found that physical activity, self-control and stress perception are important influencing factors of smartphone addiction. In order to reduce the incidence of smartphone addiction among college students, schools and families should encourage students to participate more in physical activities, improve self-control, and reduce academic and life stress.

Mediating effects test for physical activity, self-control, tress perception, and smartphone addiction

After controlling for variables such as gender, grade level, whether an only child, and location of household registration, this study explored the chain mediating effects of self-control and stress perception between physical activity and smartphone addiction. The research findings (see Table 4) indicate that physical activity has a significant negative predictive effect on smartphone addiction ($\beta = -0.264$, t = -6.468, p < 0.01), suggesting that the higher the frequency of an individual's participation in physical activities, the lower the likelihood of smartphone addiction. Additionally, physical activity has a significant

Dependent variable	Independent variable	R	R ²	F	β	t	Р
smartphone addiction		0.304	0.092	11.190			
	Age				0.018	0.400	0.690
	Gender				0.104	2.347	0.019
	An only child				0.006	0.130	0.897
	Domicile				-0.087	-2.000	0.046
	Physical activity				-0.264	-6.468	0.000
self-control		0.295	0.087	10.530			
	Age				0.052	1.187	0.236
	Gender				-0.171	-3.866	0.000
	An only child				-0.000	-0.009	0.993
	domicile				0.099	2.270	0.024
	Physical activity				0.222	5.443	0.000
Stress perception		0.613	0.376	55.184			
	Age				-0.032	-0.887	0.375
	Gender				-0.046	-1.238	0.216
	An only child				0.030	0.834	0.405
	domicile				-0.019	-0.533	0.594
	Physical activity				-0.112	-3.239	0.001
	self-control				-0.578	-16.389	0.000
smartphone addiction		0.628	0.394	51.007			
	Age				0.052	1.461	0.145
	Gender				0.018	0.481	0.631
	An only child				-0.000	-0.008	0.994
	domicile				-0.029	-0.799	0.425
	Physical activity				-0.119	-3.448	0.000
	Self-control				-0.444	-10.455	0.000
	Stress perception				0.190	4.515	0.000

Table 4 Regression analysis of the multiple mediation model

positive predictive effect on the enhancement of selfcontrol abilities (β =0.222, t=5.443, p<0.01), meaning that engaging in physical activities helps to strengthen an individual's self-control abilities. Furthermore, selfcontrol also has a significant negative predictive effect on smartphone addiction (β =-0.578, t=-16.389, p<0.01), implying that the stronger the self-control, the less likely an individual is to develop smartphone addiction. Self-control plays a mediating role between physical activity and smartphone addiction (effect size=-0.014, BootCI=[-0.021, -0.008]), with its effect size accounting for 38.85%.

Stress perception also exhibits a mediating effect between physical activity and smartphone addiction (effect size = -0.003, BootCI = [-0.006, -0.001]), with its effect size accounting for 7.89%. Stress perception has a significant positive predictive effect on smartphone addiction (β = 0.613, t = 55.184, p < 0.01), indicating that the greater the perceived stress, the higher the likelihood of smartphone addiction. At the same time, physical activity has a significant negative predictive effect on stress perception ($\beta = -0.112$, t = -3.239, p < 0.01), suggesting that participating in physical activities helps to reduce an individual's stress perception.

To further validate this chain mediation effect, we conducted a Bootstrap mediation effect test (see Table 5). The results showed that the indirect effect of physical activity on smartphone addiction through self-control and stress perception was significant (Effect value = -0.021, BootCI = [-0.030, -0.013]) and accounted for 55.27% of the total effect. This result further supports our hypothesis that self-control plays an important mediating role between physical activity and smartphone addiction, and that this mediating role is achieved by reducing stress perception.

In summary, the results of this study suggest that physical activity reduces the likelihood of smartphone addiction by improving self-control and reducing stress perception. This finding has important implications for the prevention and treatment of smartphone addiction. Future research can further explore how physical activity and other interventions can effectively prevent and treat

		Boot	BootCl	BootCl	
Effect path	Effect value	Standard error	Lower limit	Upper limit	Effect percentage
Total effect	-0.038	0.006	-0.050	-0.026	100.00%
Direct effect	-0.017	0.005	-0.027	-0.007	44.73%
Total mediating effect	-0.021	0.004	-0.030	-0.013	55.27%
PA-SC-SMA (Ind1)	-0.014	0.003	-0.021	-0.008	38.85%
PA-SP-SMA (Ind2)	-0.003	0.001	-0.006	-0.001	7.89%
PA-SC-SP-SMA (Ind3)	-0.004	0.001	-0.006	-0.002	10.53%
C1(Ind1 minus Ind2)	-0.011	0.003	-0.018	-0.004	
C2(Ind1 minus Ind3)	-0.011	0.003	-0.017	-0.006	
C3 (Ind2 minus Ind3)	0.000	0.001	-0.002	0.003	

Table 5 Test results of Bootstrap mediation effect

PA Physical activity, SC self-control, SP stress perception, SMA smartphone addiction

smartphone addiction by improving individuals' self-control and reducing stress perception.

Discussion

The direct role of physical activity on smartphone addiction in college students

This study primarily found that college students' physical activities have a significantly negative predictive effect on their smartphone addiction. This also verifies Hypothesis 1, which is consistent with previous research findings [61]. According to the theory of network use and satisfaction, individuals' psychological needs, such as social interaction and entertainment and recreation, are satisfied to varying degrees when they use the network. This satisfaction motivates individuals to use network devices such as smartphones more frequently. However, long-term over-reliance on smartphones and other network devices may trigger smartphone addiction problems, which can negatively affect an individual's physical and mental health. Adolescents with severe smartphone addiction tend to habitually ignore their surroundings and real-world interpersonal interactions, and are prone to become addicted to the virtual online world mediated by smartphones, leading to an increase in static screen behaviors, which in turn affects their level of participation in, and experience of, daily school physical activity [62]. The value of physical activity, as one of the effective ways to improve physical health, lies not only in strengthening the body, but also in promoting mental health and interpersonal skills. Increased physical activity, especially leisure-related exercise, prompts the pituitary gland to secrete endorphins, which compete for receptors with addictive substances in the central nervous system, thereby inducing a sense of pleasure, and thus inhibiting addiction [63]. Therefore, we believe that physical activity can reduce the time individuals spend on smartphones and dependence on social networks [64] and effectively control Internet addiction, which is an important way to correct Internet addiction in adolescents [65].

The mediating role of self-control in physical activity on college students' smartphone addiction

Based on Hypothesis 2, this study indicates that self-control plays a mediating role in the impact of physical activity on college students' smartphone addiction. This is consistent with previous research [66]. The Self-Control Theory [67] emphasizes the crucial role of self-control in the effective management of one's own behavior. Physical activity has a significant impact on enhancing self-control. Participating in physical activities not only allows individuals to exercise their bodies but also hones their willpower and improves their ability for self-restraint and self-discipline through practice. Physical activities typically require participants to act according to certain rules, strategies, and goals, which helps cultivate individual self-control [68]. During sports, individuals need to continuously overcome various difficulties and challenges, an experience that can strengthen their determination and perseverance, enabling them to adhere to goals and principles in daily life and resist various temptations. For instance, long-distance runners need to overcome physical fatigue and mental weariness during competitions, which can enhance their self-control when facing other life challenges. Similarly, basketball players need to make quick decisions and execute tactics during games, and this ability can also be transferred to daily life, helping them better manage their time and tasks. For those addicted to smartphones, their self-control is usually weak and they are easily distracted and tempted by their phones. smartphone addicts often find it difficult to control the time and frequency of their phone use, easily falling into uncontrolled swiping, gaming, or social media browsing. Participating in physical activities can help them gradually strengthen their self-control, thereby reducing excessive dependence and usage of their phones. Through

physical activities, individuals can shift their attention away from their phones and invested in more meaningful and constructive activities. In addition, physical activities can provide a healthy alternative behavior, helping individuals to achieve physical and psychological satisfaction while reducing their phone usage [69].

The mediating role of stress perception in physical activity on smartphone addiction in college students

Based on Hypothesis 3, this study found that perceived stress plays a mediating role in the impact of physical activity on college students' smartphone addiction, which is consistent with the results of previous studies [70]. Further, it reveals the importance of perceived stress in behavioral regulation. According to the stress coping theory, individuals will adopt a series of coping strategies to deal with stressors when facing stress, thereby alleviating the negative impact of stress. However, different coping strategies may produce entirely different outcomes. When college students face stress, they may choose smartphone addiction as a way to cope with stress, for example, by overusing social media, games, or videos to escape from the stressors in reality. Thus, alleviating the negative impact of stress. When college students face stress, they may choose to use their smartphones as a way to cope with stress, such as by overusing social media, games, or videos to escape from the stressors in reality [71]. Studies have shown that smartphone addiction can cause stress for college students [72]. Even those behaviors of excessive smartphone use that do not reach the level of addiction can make college students feel greater stress, because excessive use of smartphones occupies a lot of time and energy, resulting in individuals being unable to effectively complete learning tasks or deal with other matters in life, thereby generating more anxiety and stress [73]. This means that excessive use of smartphones cannot effectively alleviate stress, but may instead increase the individual's sense of stress and anxiety. Physical activity, as a positive stress coping strategy, can help individuals manage and alleviate stress more effectively. By participating in physical activities, individuals can effectively release stress, alleviate tension, and thereby promote physical and mental health. Physical activity can promote the release of endorphins and other "happy hormones" in the brain, thereby improving mood states and reducing levels of anxiety and depression [74, 75].

Chained mediating roles of self-control and Stress perception in physical activity on college students' smartphone Addiction

Based on Hypothesis 4, we verified the research hypothesis that physical activity exerts a chain mediating effect on smartphone addiction through self-control and stress perception. We also supported the dual-process theory that aligns with long-term beneficial behavioral decision-making. In the impact of physical activity on smartphone addiction, the impulsive system may drive individuals to over-rely on their phones, seeking immediate entertainment and satisfaction, whereas the control system suppresses smartphone addiction by enhancing self-control abilities and reducing stress perception. Physical activity promotes the enhancement of individual self-control abilities, strengthening the function of the control system, enabling individuals to adhere to principles and resist impulses when faced with temptations like smartphones. At the same time, physical activity also further weakens the role of the impulsive system by reducing individual stress perception. Stress is one of the important factors leading to individual dependence on smartphones; when individuals are under high-pressure situations, they are more likely to use smartphones to escape reality or seek temporary relaxation. However, physical activity, as an effective way to alleviate stress, can help individuals regulate their emotions and reduce the need for dependence on smartphones. Through this dual mechanism-enhancing self-control abilities and reducing stress perception-physical activity plays a balancing role between the impulsive system and the control system, thereby effectively suppressing smartphone addiction behavior.

Implications

The results of this study have important implications for the prevention and treatment of smartphone addiction in college students. First, colleges and universities should pay attention to the development of sports activities, encourage students to actively participate in all kinds of sports activities, improve physical fitness and self-control ability, and reduce the feeling of pressure, so as to effectively prevent the occurrence of smartphone addiction. Secondly, colleges and universities should strengthen mental health education to help students recognize the harm of smartphone addiction, improve their self-control ability, and avoid excessive dependence on smartphones. In addition, colleges and universities can provide psychological counseling services, pay attention to the stress situation of college students, and provide necessary psychological support and interventions to help them effectively deal with stress and avoid excessive reliance on smartphones as a means of coping with stress.

Limitations and future research

Although this study achieved some meaningful conclusions, it still has some shortcomings. First, this study primarily utilized a cross-sectional research design, which did not allow for the identification of causal relationships. Future studies could adopt a longitudinal research design

or experimental research methods to more accurately explore the causal relationship between physical activity, self-control, stress perception, and smartphone addiction. Second, the sample of this study was mainly from college students in two college, which may have the problem of underrepresentation of the sample. Future studies can expand the sample to include college students from different geographic regions, different schools, and different age levels to improve the generalizability and applicability of the study. The next step is that we will collect questionnaires for the subjects of this study for the second and third time in the tenth and sixteenth weeks of this semester, respectively, and in the process of collecting questionnaires for the second and third time, we will pay special attention to the trend of the change of the situation of college students' smartphone addiction. Through the analysis of the potential growth model, we will reveal the inner pattern of smartphone addiction over time and try to identify the key factors involved. We expect to gain new insights from this and provide a stronger scientific basis for solving the problem of college students' smartphone addiction. Finally, we hope that through this study, we can provide useful suggestions for the prevention and intervention of college students' smartphone addiction problems.

Conclusions

- Physical activity and self-control negatively predicted smartphone addiction, and stress perception was a positive predictor of smartphone addiction;
- 2. self-control mediates physical activity and smartphone addiction;
- 3. Stress perception mediates physical activity and smartphone addiction;
- 4. self-control and stress perception play a chain mediating role in physical activity and smartphone addiction.

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Authors' contributions

Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Writing—original draft,Zicong Ye;T Zhang; Formal analysis, Supervision, Ying Peng, Wei Rao and Peng Jia. All authors have read and agreed to the published version of the manuscript.

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Data availability

The raw data supporting the conclusions of this article can be made available by the authors Zicong Ye(286505361@qq.com), without undue reservation.

Declarations

Ethics approval and consent to participate

All methods were performed in accordance with the relevant guidelines and regulations. The study protocol was approved by the ethics committee of Wuhan University of Science and Technology School of Physical Education and Sport. Before formal investigation and testing, the researchers received the informed consent of the subjects involved in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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