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# Anxiety, inhibitory control, physical activity, and internet addiction in Chinese adolescents: a moderated mediation model

Yang Liu<sup>1\*</sup>, Yuan Jin<sup>2</sup>, Jiawei Chen<sup>1,3</sup>, Lianghao Zhu<sup>4</sup>, Yongxiang Xiao<sup>1</sup>, Lei Xu<sup>1,5</sup> and Tiancheng Zhang<sup>1</sup>

## Abstract

**Background** Adolescents may have anxiety due to a series of events such as school work and social interaction. Improper handling of anxiety often leads to some negative consequences, such as Internet addiction. Therefore, this study further explored the relationship between anxiety and Internet addiction, as well as the mediating role of inhibitory control between the two, and also considered the moderating role of physical activity between anxiety and inhibitory control.

**Methods** A total of 1607 adolescents, comprising 664 boys and 943 girls with an average age of 15.86 years ( $SD=0.73$ ), from Shandong, Shanxi, Hebei, and Hunan provinces completed a self-report survey on physical activity, anxiety, inhibitory control, and Internet addiction. Descriptive analysis, correlation analysis, and mediation test were conducted.

**Results** The results revealed a significant positive correlation between anxiety and adolescent internet addiction ( $r=0.413, p<0.001$ ), and a significant negative correlation with inhibitory control ( $r=-0.423, p<0.001$ ). Inhibitory control was found to be significantly positively correlated with physical exercise ( $r=0.143, p<0.001$ ) and significantly negatively correlated with internet addiction ( $r=-0.368, p<0.001$ ). After controlling for demographic variables, anxiety significantly positively predicted Internet addiction ( $\beta=0.311, p<0.001$ ) in adolescents, and it also indirectly predicted Internet addiction through inhibitory control ( $\beta=-0.231, p<0.001$ ). Physical activity significantly weakened the predictive effect of anxiety on inhibitory control ( $\beta=-0.092, p<0.001$ ).

**Conclusions** This study further explored the issue of psychological mechanisms between anxiety and Internet addiction in adolescents, and added that physical activity alleviates the negative effects of anxiety on adolescents. Schools and families are encouraged to promote physical exercise among adolescents to alleviate the influence of negative emotions on their psychological and behavioral health.

**Keywords** Adolescent, Anxiety, Inhibitory control, Internet addiction disorder, Physical activity

\*Correspondence:

Yang Liu  
ldyedu@foxmail.com

<sup>1</sup>School of Sports Science, Jishou University, Jishou, China

<sup>2</sup>School of Sports Science, Shanxi Datong University, Datong, China

<sup>3</sup>School of Automotive Engineering, Hunan Mechanical Electrical Polytechnic, Changsha, China

<sup>4</sup>Key Laboratory of Competitive Sport Psychological and Psychological Regulation, Tianjin University of Sport, Tianjin, China

<sup>5</sup>Institute of Physical Education, Shanxi University of Finance and Economics, Taiyuan, China



## Introduction

In the course of societal development, adolescents often encounter numerous uncertainties and pressures, such as social anxiety [1], academic stress [2], and separation anxiety [3, 4]. Anxiety represents a normal emotional response to real or perceived stimuli or threatening situations [5]. It brings about a range of adverse effects on adolescents, including impairments in memory and attention [6], sleep disorders [7, 8], substance abuse [9, 10] and disruptions in peer relationships [11]. Recent studies have revealed that the prevalence of anxiety among Chinese adolescents reaches as high as 22.34% [12], escalating to 36.7% during the COVID-19 pandemic [13]. Consequently, addressing adolescent anxiety and its array of impacts is a matter of considerable societal concern.

Research indicates that anxiety is commonly associated with heightened levels of internet addiction among adolescents. Internet addiction refers to an individual's excessive, problematic, and compulsive engagement in internet-related addictive behaviors [14, 15]. The compensatory Internet use theory posits that individuals often resort to the internet to regulate their emotions, especially when experiencing negative affect [16]. The detection rate of anxiety among adolescents with internet addiction is notably high, with females generally exhibiting higher rates than males [17]. There exists a significant positive correlation between anxiety and adolescent internet addiction [18–21], with anxiety being identified as a critical risk factor for adolescent internet addiction [22]. Furthermore, research has found anxiety to mediate significantly between various factors and adolescent internet addiction [23]. Similarly, longitudinal studies found that anxiety was a significant predictor of adolescent Internet addiction [22, 24, 25]. Based on this evidence, this study hypothesizes that anxiety can significantly predict adolescent internet addiction.

Cognitive activities are often considered in the relationship between emotion and behavior. Studies have found a strong association between internet addiction and inhibitory control [20, 21, 26, 27]. Internet addiction scores are related to lower connectivity in the Default Mode Network (DMN), which is associated with lower inhibitory control [28, 29]. Experimental research has revealed that individuals with internet addiction perform significantly poorer in inhibitory control tasks compared to non-addicted individuals [30]. Therefore, adolescents with lower inhibitory control may exhibit higher levels of internet addiction. Moreover, anxiety may have a negative impact on adolescent inhibitory control levels. Studies have found that individuals with high anxiety exhibit poorer performance in inhibitory control tasks [31, 32], affecting the level of neural recruitment during inhibitory control tasks [32]. Furthermore, based on the strength model of self-control [33], anxiety consumes and depletes

an individual's cognitive resources, potentially leading to failure in inhibiting internet use behaviors as cognitive resources are continuously depleted. Based on this review, we hypothesize that anxiety can predict adolescent inhibitory control, and inhibitory control can predict adolescent internet addiction.

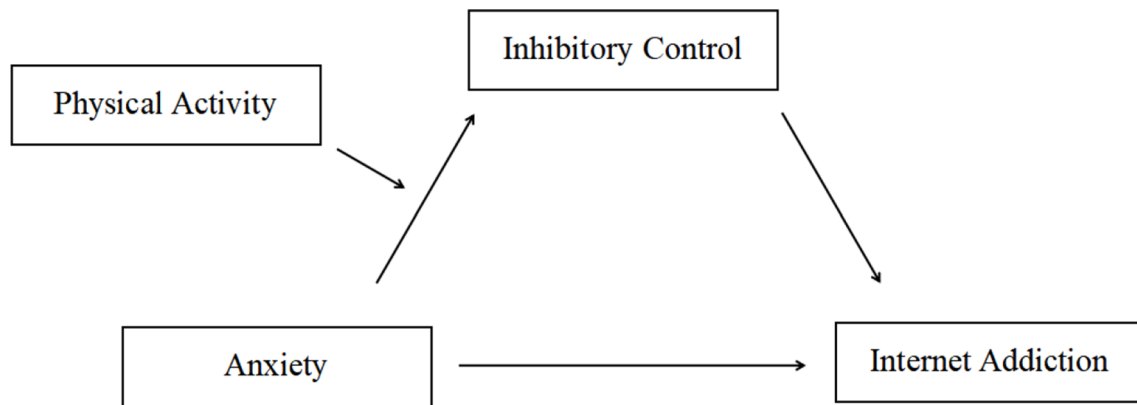
The relationship between anxiety and adolescent inhibitory control may be moderated by other factors. Research suggests that physical activity can reduce anxiety and depression among adolescents [34] and promote hippocampal structural development and serotonin secretion [35], thereby regulating individuals' emotional and cognitive developmental levels [36]. Similarly, physical activity can promote the development of individual inhibitory control [37] and has garnered extensive support from meta-analytic studies [38–42]. Combining the previous review, this study posits that physical activity may weaken the impact of anxiety on adolescent inhibitory control.

Drawing upon the aforementioned review, this study will further explore the relationship between anxiety and adolescent internet addiction through inhibitory control. It also considers the moderating effect of physical activity on anxiety and adolescent inhibitory control. Therefore, this study constructs the hypothesis model as shown in Fig. 1.

## Methods

### Participants

Between February and March 2024, a convenience sampling method was employed to survey middle school students from 6 secondary schools across Shandong, Hebei, Shanxi, and Hunan provinces. Utilizing Kendall's formula and considering the number of items in our study survey, a preliminary estimate of the required sample size was calculated to be 5–10 times the number of study variables [43]. To account for the potential loss of online questionnaire responses, an additional 30% of the sample size was added. Consequently, the formula for calculating the sample size in this study was:  $n = 10 \times \text{number of variables} / (1 - 30\%)$ . This resulted in a minimum sample size of 315. To respect the academic pressures faced by senior high school students, no surveys were conducted among those in their final year of high school. Ethical approval was obtained from the institutional medical ethics committee prior to the study's commencement (JSDX-2023-0034), and the research was conducted in accordance with the Declaration of Helsinki. During participants' vacation when they returned home, the study provided electronic questionnaire links to the guardians of the participants through the class teacher to the class group chat. Once the guardians clicked on the link and read the instructions and introduction on the first page of the questionnaire, they could consent to the survey being



**Fig. 1** Hypothetical model of moderating mediation

presented to the participants. The instructions and introduction clearly explained the research objectives, data anonymity, confidentiality, and the purpose of data use. The first page of the questionnaire also included an online informed consent form. Participants and their guardians could proceed with the survey upon agreement; those who chose to opt out could simply close the online questionnaire page. The questionnaire was designed to be completed by participants in approximately 15 min. It is important to emphasize that a small-scale pre-survey was conducted prior to the formal survey. As a result, in the formal survey, samples with extremely short or long response times were identified and excluded. Additionally, the questionnaire contained irrelevant questions designed to flag patterned responses. These flagged samples were considered invalid and were not included in the final analysis. Data collection online ceased either when participants returned from vacation or after a five-day period. The raw data were securely stored in the account of the electronic questionnaire website. After data collection, a total of 1,977 participants completed the survey. Samples with abnormal response times or overly regular response patterns were excluded, leading to a final analysis sample of 1,607 participants, including 664 boys and 943 girls, with a mean age of 15.86 years ( $SD=0.73$ ).

### Measurement tools

#### *Physical activity*

Physical activity levels of adolescents were assessed using a single-item question: “During the past 7 days, on how many days did you exercise or engage in physical activities for at least 20 minutes that made you sweat or breathe hard?” The response options ranged from 0 to 7 days [44]. This measurement tool for physical activity has been previously utilized [45].

#### *Internet addiction*

The level of internet addiction among adolescents was assessed using the revised and validated Internet

Addiction Scale by Wei [46]. This scale consists of 8 items rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The sum of scores from all items represents the severity of internet addiction, with scores ranging from 8 to 40. Higher scores indicate a higher level of internet addiction. The Cronbach’s  $\alpha$  for the sample in this study was 0.884.

#### *Anxiety*

Adolescent anxiety levels were assessed using the anxiety subscale of the revised and validated Depression-Anxiety-Stress Scale by Gong et al. [47]. The anxiety subscale consists of 7 items rated on a 4-point Likert scale ranging from 1 (not at all) to 4 (completely). The sum of scores from all items represents the level of anxiety, with scores ranging from 7 to 28. Higher scores indicate a higher level of anxiety. The Cronbach’s  $\alpha$  for the sample in this study was 0.869.

#### *Inhibitory control*

The inhibitory control subscale of the Executive Function Scale developed by Huang et al. was used to measure inhibitory control [48]. This subscale comprises 6 items rated on a scale from 1 (never) to 3 (often). The sum of scores from all items represents the inhibitory control score, ranging from 6 to 18. Higher scores indicate higher levels of inhibitory control. To ensure consistency with the general expectation, scores on this scale were reverse-scored, where higher scores indicate higher levels of inhibitory control. The Cronbach’s  $\alpha$  for the sample in this study was 0.844.

#### *Statistical analysis*

In this study, we utilized SPSS version 26.0 for statistical analysis. Prior to the analysis of the primary variables, the normality of the data was assessed using the Shapiro-Wilk test. Data were considered approximately normally distributed if the absolute value of skewness was less than 2 and the absolute value of kurtosis was less than

**Table 1** Descriptive results

Variables	Total		Boys		Girls		Boys vs. Girls t
	Mean	Sd	Mean	Sd	Mean	Sd	
Anxiety	13.40	4.86	12.88	4.62	13.77	5.00	-3.67***
Physical activity	1.92	1.93	2.29	3.04	1.65	1.80	6.47***
Inhibitory control	14.24	2.61	14.49	2.65	14.07	2.56	3.24**
Internet addiction	19.28	6.71	18.72	6.90	19.67	6.54	-2.79**

\*\* $p < 0.01$ ; \*\*\* $p < 0.001$

**Table 2** Correlation analysis

Variables	1	2	3
1 Anxiety	-		
2 Physical activity	-0.160***	-	
3 Inhibitory control	-0.423***	0.143***	-
4 Internet addiction	0.413***	-0.124***	-0.368***

\*\*\* $p < 0.001$

7 [49]. Our analysis revealed that the primary variables conformed to a normal distribution, allowing the use of parametric tests in subsequent analyses. Initially, Harman's single-factor test was conducted to detect common method bias. A threshold below 40% for this test would suggest that no significant common method bias was present in the study [50]. Following this, we employed Student's t-test to analyze the differences in the main variables between genders, and Pearson correlation analysis ( $r$ ) was used to assess the relationships between variables. Lastly, to test our hypotheses, the PROCESS macro plugin in SPSS (Models 4 and 7) was utilized to investigate the mediating effect of inhibitory control on the relationship between anxiety and adolescent internet addiction, as well as the moderating effect of physical activity on the relationship between anxiety and inhibitory control [51]. Prior to model testing, the data were standardized. This PROCESS macro plugin incorporated 5000 bootstrap resamples to test and estimate the model within a 95% confidence interval (CI). A relationship was deemed statistically significant if the 95% CI did not encompass zero. To evaluate the effect size of the mediation and moderation, we reported the standardized

regression coefficients ( $\beta$ ) for the paths implicated in these processes. Additionally, the analysis controlled for gender and age, with statistical significance set at  $\alpha = 0.05$ .

## Results

### Descriptive results

The common method bias test revealed two factors with eigenvalues greater than 1. The first factor accounted for 29.95% of the total variance, below the threshold of 40%, indicating no significant risk of common method bias in this study.

Table 1 presents the results indicating gender differences in anxiety ( $t = -3.67$ ,  $p < 0.001$ ), physical activity ( $t = 6.47$ ,  $p < 0.001$ ), inhibitory control ( $t = 3.24$ ,  $p < 0.01$ ), and internet addiction ( $t = -2.79$ ,  $p < 0.01$ ), all reaching statistical significance.

### Correlation analysis

Table 2 shows significant negative correlations between adolescent anxiety and physical activity ( $r = -0.160$ ,  $p < 0.001$ ), and inhibitory control ( $r = -0.423$ ,  $p < 0.001$ ), and a significant positive correlation with internet addiction ( $r = 0.413$ ,  $p < 0.001$ ). Inhibitory control was positively correlated with physical activity ( $r = 0.143$ ,  $p < 0.001$ ) and negatively correlated with internet addiction ( $r = -0.368$ ,  $p < 0.001$ ).

### Mediation model testing

After controlling for gender and age, the results shown in Table 3 indicate that anxiety significantly and positively predicted adolescent internet addiction directly

**Table 3** Mediation model test

Outcome variables	Predictor variables	$\beta$	SE	t	$R^2$	F
Internet addiction	Gender	0.068	0.046	1.477	0.177	114.974***
	Age	0.101	0.031	3.252**		
	Anxiety	0.408	0.023	17.907***		
Inhibitory control	Gender	-0.088	0.046	-1.900	0.182	118.771***
	Age	-0.048	0.031	-1.547		
	Anxiety	-0.418	0.023	-18.411***		
Internet addiction	Gender	0.048	0.045	1.066	0.221	113.418***
	Age	0.090	0.030	2.972**		
	Anxiety	0.311	0.024	12.757***		
	Inhibitory control	-0.231	0.024	-9.470***		

\*\* $p < 0.01$ ; \*\*\* $p < 0.001$

**Table 4** Mediation model path analysis

Paths	Effect size	SE	Bootstarp 95% CI	Proportion of mediating effect
Total effect size	0.408	0.023	0.363, 0.452	
Direct effect size	0.311	0.024	0.263, 0.359	
Indirect effect size	0.097	0.012	0.073, 0.121	23.77%

( $\beta=0.408$ ,  $SE=0.023$ ,  $p<0.001$ ). Even after adding inhibitory control as a mediator, anxiety remained a significant positive predictor of adolescent internet addiction ( $\beta=0.311$ ,  $SE=0.024$ ,  $p<0.001$ ). Furthermore, mediation testing revealed that anxiety significantly negatively predicted adolescent inhibitory control ( $\beta= -0.418$ ,  $SE=0.023$ ,  $p<0.001$ ), while inhibitory control also significantly negatively predicted adolescent internet addiction ( $\beta= -0.231$ ,  $SE=0.024$ ,  $p<0.001$ ). The proportions of the mediation paths are shown in Table 4.

#### Moderated mediation model testing

Table 5 displays the results of the moderated mediation model testing. After controlling for demographic variables, anxiety continued to significantly negatively predict adolescent inhibitory control even with the inclusion of physical activity ( $\beta= -0.410$ ,  $SE=0.023$ ,  $p<0.001$ ). Physical activity significantly positively predicted adolescent

inhibitory control ( $\beta=0.064$ ,  $SE=0.023$ ,  $p<0.01$ ), and it significantly attenuated the predictive effect of anxiety on adolescent inhibitory control ( $\beta= -0.092$ ,  $SE=0.022$ ,  $p<0.001$ ). Refer to Figs. 2 and 3 for further details.

#### Discussion

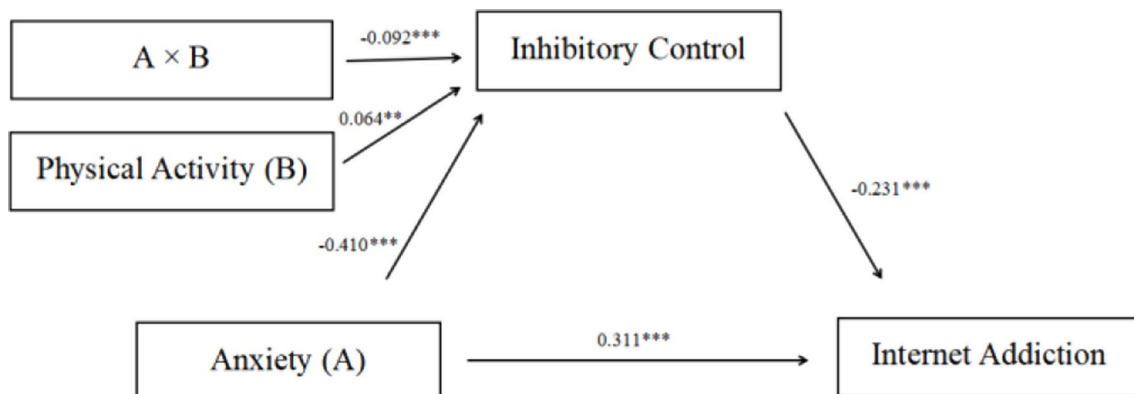
This study explores the relationship between anxiety and adolescent internet addiction, as well as the mediating role of inhibitory control between them. Additionally, physical activity moderates the relationship between anxiety and inhibitory control. The research discovered a significant positive correlation between anxiety and adolescent internet addiction, and a significant negative correlation with adolescent inhibitory control. Physical activity exhibited a significant positive correlation with adolescent inhibitory control. Inhibitory control plays a mediating role between anxiety and adolescent internet addiction. Lastly, physical activity moderated the relationship between anxiety and inhibitory control in adolescents.

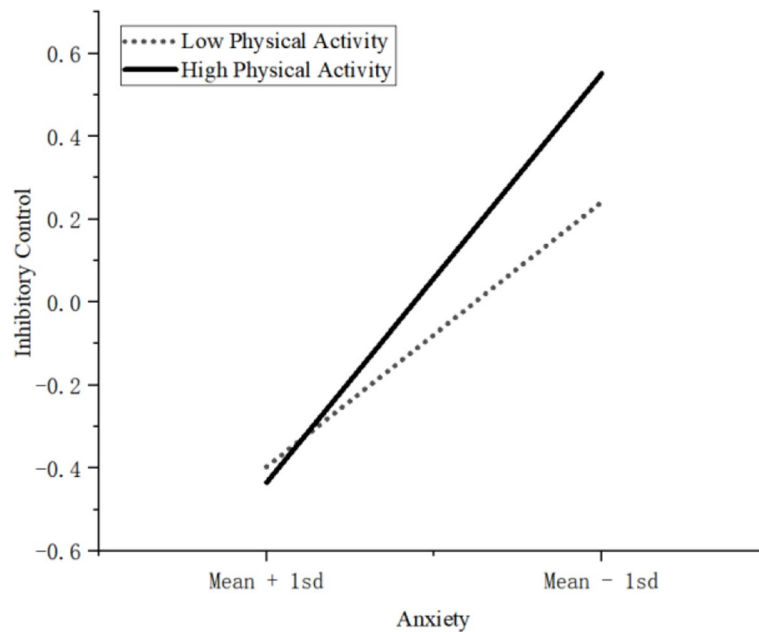
The study reveals that high levels of anxiety predict higher levels of internet addiction in adolescents, similar to previous studies [19, 24]. Anxiety is commonly a risk factor for internet addiction [52, 53], as adolescents often face various anxieties [3] and seek entertainment activities to alleviate this emotional pressure. Our study aligns

**Table 5** Moderated mediation model test

Outcome variables	Predictor variables	$\beta$	SE	t	$R^2$	F
Inhibitory control	Gender	-0.070	0.046	-1.505	0.196	77.888***
	Age	-0.052	0.031	-1.699		
	Anxiety	-0.410	0.023	-18.006***		
	Physical activity	0.064	0.023	2.760**		
	Anxiety $\times$ Physical activity	-0.092	0.022	-4.175***		
Internet addiction	Gender	0.048	0.045	1.066	0.221	113.418***
	Age	0.090	0.030	2.972**		
	Anxiety	0.311	0.024	12.757***		
	Inhibitory control	-0.231	0.024	-9.470***		

\*:  $p<0.05$ ; \*\*:  $p<0.01$ ; \*\*\*:  $p<0.001$

**Fig. 2** Moderated mediation model (\*\*:  $p<0.01$ ; \*\*\*:  $p<0.001$ )



**Fig. 3** Simple slope chart

with the mood enhancement hypothesis [54] as adolescents with high anxiety levels are more inclined towards internet behaviors due to the anonymity and convenience of the internet [55]. This exacerbates their involvement in internet activities, leading to internet addiction. Thus, based on the evidence, we hypothesize that anxiety predicts adolescent internet addiction.

Apart from predicting adolescent internet addiction, anxiety also indirectly impacts adolescent internet addiction by negatively affecting inhibitory control levels in adolescents. The study found that individuals with high anxiety levels experience a significant negative impact on their inhibitory control [31, 56, 57], consistent with previous theories [58]. The extent of anxiety's impact on adolescent inhibitory control is not always constant. This study reveals that physical activity can mitigate the negative impact of anxiety on adolescent inhibitory control. This is attributed to the impact of physical activity on anxiety [34, 35, 59–61], as well as brain regions involved in emotional regulation [36], and its promotion of inhibitory control [37, 38, 40–42, 62, 63]. Therefore, physical activity weakens anxiety's impact on adolescent inhibitory control.

This study's findings underscore the pivotal role of anxiety and inhibitory control in adolescent internet addiction, with physical activity as a key moderating factor. The significant correlation between anxiety and internet addiction supports the mood enhancement hypothesis, where the internet acts as an escape for anxious adolescents. Our results also indicate that anxiety negatively affects inhibitory control, a critical component in self-regulation and a potential pathway to addiction. The

moderation effect of physical activity introduces a significant variable that could mitigate the adverse effects of anxiety on inhibitory control. This aligns with the broader understanding of physical activity's benefits on cognitive functions, including attention and emotional regulation. The implications are clear: promoting physical activity among adolescents could be an effective strategy to reduce anxiety and support inhibitory control, thereby lowering the risk of internet addiction. Furthermore, these findings suggest the importance of integrating physical education and stress management into school curricula and community programs. This approach could provide adolescents with the tools to manage their emotions and improve self-control, contributing to healthier online habits. In summary, by examining the interplay between anxiety, inhibitory control, and physical activity, this study provides a nuanced view of the factors contributing to adolescent internet addiction. The results highlight the potential of physical activity as a protective factor and point to evidence-based strategies for prevention and intervention.

This study makes a significant contribution by delving into the connection between anxiety and adolescent internet addiction, analyzing the mediating role of inhibitory control in this relationship, and examining the moderating effect of physical activity on the relationship between anxiety and inhibitory control. However, the study has several limitations. Firstly, it is based on cross-sectional data, which restricts the ability to interpret causal relationships among variables. Secondly, key variables are measured through self-report surveys, which are susceptible to bias and may lack objectivity. Lastly,

the sample primarily originates from certain regions in China, limiting the generalizability of the results to other cultural contexts.

## Conclusion

The results demonstrate that anxiety significantly positively predicts adolescent internet addiction, partially explained by the mediating effect of inhibitory control. Furthermore, the impact of anxiety on adolescent inhibitory control can be moderated by physical activity. Therefore, it is recommended that schools and families pay attention to the emotional states of adolescents, avoiding adding untimely academic tasks to reduce the development of adolescent anxiety. Additionally, schools and families should encourage adolescents to engage in physical activities to alleviate the negative effects of anxiety.

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12887-024-05139-6>.

Supplementary Material 1

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Zirui Zhou, Shiju Zhu, Guilin Hu, Shuzhen You and Yumeng Zhang.

## Author contributions

Yang Liu: Conceptualization, Methodology, Data curation, Writing - Original Draft, Writing - Review & Editing. Yuan Jin: Conceptualization, Data curation, Writing - Review & Editing. Jiawei Chen: Conceptualization, Data curation, Writing - Review & Editing. Lianghao Zhu: Conceptualization, Data curation, Writing - Review & Editing. Yongxiang Xiao: Conceptualization, Data curation, Writing - Review & Editing. Lei Xu: Conceptualization, Writing - Review & Editing, Funding acquisition. Tiancheng Zhang: Conceptualization, Writing - Review & Editing, Funding acquisition.

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Not applicable.

## Data availability

The datasets generated and/or analysed during the current study are not publicly available due [our experimental team's policy] but are available from the corresponding author on reasonable request.

## Declarations

### Ethics approval and consent to participate

The study was approved by the Biomedicine Ethics Committee of Jishou University before the initiation of the project (Grant number: JSDX-2024-0086). And informed consent was obtained from the participants and their guardians before starting the program. We confirm that all the experiment is in accordance with the relevant guidelines and regulations such as the declaration of Helsinki.

### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

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