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# Problematic mobile game use and executive function: negative emotions mediation and physical activity moderation

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**Abstract:** This study examined the roles of negative emotions and physical activity in the relationship between problematic mobile game use and executive functioning. A total of 528 participants were included (females = 62.07%; M = 19.24, SD = 1.52). All participants completed the Adapted Internet Addiction Scale, the 21-item Depression Anxiety Stress Scale (DASS-21), the Chinese version of the Adolescent Executive Function Scale, and the Chinese version of the Physical Activity Rating Scale-3 (PARS-3). After controlling for gender, age, school, major, and grade, regression analysis revealed that problematic mobile gaming was significantly associated with impaired executive functioning. Negative emotions mediated this relationship. Physical activity moderated the effect of problematic mobile gaming on executive functioning. Specifically, the protective effect of physical activity was significant only under conditions of low-level problematic mobile gaming, but disappeared when such gaming was at a high level. This study clarifies the emotional mediation mechanism through which problematic mobile gaming impairs executive functioning and delineates the boundary conditions of physical activity as a protective resource, providing a solid empirical foundation for developing tailored intervention strategies.

**Keywords:** problematic mobile game use; executive function; negative emotions; physical activity; college student

## Introduction

The widespread adoption of smartphones has provided a new platform for online gaming. Its portability not only liberates existing online gamers from spatial and temporal constraints but also contributes to the expansion of the gaming population. This phenomenon is particularly evident among university students (Isik Akin et al., 2024). As mobile gaming grows increasingly prevalent, the harms associated with excessive play have gradually drawn researchers' attention. A substantial body of research confirms that Problematic mobile game use (PMG) is accompanied by adverse outcomes, including impairments in both physical and mental health as well as social dysfunction (Shen et al., 2023a). Notably, current research on the relationship between PMG and executive function remains unclear. Executive function constitutes an individual's core cognitive capacity, directly influencing goal attainment and social adaptation (Diamond, 2013; Friedman & Robbins, 2022). More crucially, the potential psychological pathways between the two have received less scholarly focus. University students are in a critical period of cognitive and personality development (Tervo–Clemmens et al., 2023). Clarifying the association between PMG and executive function, along with its underlying mechanisms, is essential for safeguarding their well-being and long-term development. Therefore, this study aims to investigate the relationship between PMG and executive function among university students while elucidating the psychological pathways involved. The research objective is to provide a theoretical foundation and empirical support for developing targeted intervention strategies to mitigate the negative impacts of PMG.

### *Executive function and problematic mobile game use*

Executive function encompasses a suite of higher-order cognitive processes, primarily governed by the prefrontal cortex, that are essential for goal-directed behavior (Diamond, 2013; Friedman & Robbins, 2022). The university years represent a critical period for the maturation of the prefrontal cortex and the refinement of these executive skills (Tervo-Clemmens et al., 2023). As students navigate new challenges—ranging from academic planning and time management to complex social interactions—executive function serves as a foundational pillar. It is not only crucial for resisting distractions and achieving academic goals but also acts as a core cognitive support for acquiring advanced social skills and facilitating future career planning (Ramos-Galarza et al., 2023). Consequently, any factor that impairs executive function has the potential to exert profound and long-lasting effects on an individual's development.

While enjoying greater autonomy and leisure time, university students also face numerous temptations, with online gaming being particularly prominent (Isik Akin et al., 2024). The widespread adoption of mobile internet has led to mobile games dominating the online gaming market. According to the 2021 China Game Industry Report, published by the China Audio-Video and Digital Publishing Association (2021), the number of online game users in China stood at approximately 670 million. Of these, mobile game users reached 656 million, accounting for roughly 98% of all online game users. The high accessibility and fragmented usage patterns associated with smartphones have contributed to the increasing salience of PMG among the university student population.

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PMG is characterized by a loss of control over gaming behaviour and is significantly associated with impairments in physical and mental health, academic decline, and social dysfunction (Shen et al., 2023a).

Of particular concern is the potential negative impact of PMG on executive function. Numerous cross-sectional studies have consistently reported a positive association between PMG and executive function impairments (Choi, 2021; Zhao et al., 2021). However, neuroimaging research reveals a more complex mechanism underlying this relationship. An fMRI study by Shen et al. (2023b) found that, despite no significant differences observed in behavioural tasks (e.g., the Stroop task), individuals with PMG exhibited abnormal hyperactivity in the right dorsolateral prefrontal cortex. This finding suggests that individuals with PMG might recruit additional neural resources to compensate for potential declines in cognitive control efficiency, thereby temporarily maintaining normal behavioural performance on simple tasks. This "neural compensation" phenomenon implies that the relationship between PMG and overt behavioural deficits may not be direct but rather influenced by other internal psychological processes and external protective factors. Consequently, clarifying the key mediating and moderating mechanisms is crucial for a deeper understanding of the relationship between PMG and executive function, yet research in this area remains insufficient.

### *Mediating role of negative emotions*

The Interaction of Person-Affect-Cognition-Execution (I-PACE) model provides a comprehensive theoretical framework for understanding the dynamic relationships between these variables (Brand et al., 2025). This model posits a positive feedback loop in which addictive behaviours, negative emotions (e.g., depression, anxiety), and executive function deficits mutually reinforce each other. Specifically, an individual might engage in gaming to escape real-life stress (negative reinforcement), a behaviour associated with subsequently intensified negative emotions. This persistent negative emotions, in turn, is linked to the depletion of cognitive resources and a decline in executive function (Brand et al., 2025). Empirical evidence supports these proposed linkages: gaming addiction is correlated with higher levels of negative emotions (Marques et al., 2023; Ahmed et al., 2024), while negative emotionshad a significant detrimental effect on executive function (Lin et al., 2022; Folker et al., 2024; Feng et al., 2021) and weaker inhibitory control (Folker et al., 2024). Based on this, we hypothesize that negative emotions mediates the relationship between PMG and executive function impairments.

### *The moderating role of physical activity*

Beyond clarifying the pathway from PMG to executive function impairments, identifying protective factors capable of buffering this negative impact holds significant practical importance. Physical activity, as an intervenable lifestyle factor, has garnered considerable attention in this context. Its potential protective role can be robustly explained within the theoretical framework of "cognitive reserve." This theory posits that enriching life experiences, such as regular exercise, contribute to the construction of more efficient and resilient neural networks, thereby helping to maintain cognitive function in the face of pathological or physiological challenges (Stern, 2002; Stern, 2003). This theoretical perspective is supported by neurobiological evidence: studies indicate that aerobic exercise builds this neural resilience by enhancing prefrontal cortex function and plasticity, promoting the secretion of brain-derived neurotrophic factor, and optimizing dopaminergic neurotransmission (Wang et al., 2022). Therefore, we propose an integrative hypothesis: regular physical activity, through the mechanisms described above, increases cognitive reserve and may thereby buffer the negative impact of PMG on executive function.

However, existing evidence predominantly stems from strictly controlled laboratory interventions (Li et al., 2020; Wang et al., 2022), and its generalizability to naturalistic settings remains unclear. A critical question is whether an individual's habitual level of physical activity in daily life can practically moderate the relationship between PMG and executive function. More importantly, any protective effect is likely to have its boundaries. We speculate that as the severity of PMG increases, the buffering effect of the cognitive reserve built by physical activity may be depleted; that is, its protective role would diminish or even disappear. Testing for this potential critical threshold is crucial for developing stratified and targeted intervention strategies.

### *The present study and hypotheses*

Integrating the I-PACE model and cognitive reserve theory, the present study proposes and tests a moderated mediation model to systematically investigate the complex relationships between PMG, negative emotions, physical activity, and executive function impairments among university students. Specifically, we posit the following hypotheses:

Hypothesis 1: PMG will be positively associated with executive function impairments.

Hypothesis 2: negative emotions will mediate the association between PMG and executive function impairments.

Hypothesis 3: Physical activity will moderate the direct path between PMG and executive function impairments, such that its buffering effect will be significant at low levels of PMG but non-significant at high levels of PMG.

## Method

### *Participants*

This study included a total of 528 university students recruited from three universities in Henan Province, China (females = 62.07%; M = 19.24 years, SD = 1.52). The distribution by academic year was as follows: 132 first-year students (25.0%), 110 s-year students (20.8%), 144 third-year students (27.3%), and 142 fourth-year students (26.9%). Regarding academic discipline, 269 students (50.9%) were from humanities/social sciences, and 259 students (49.1%) were from science/technology. The screening and enrollment process of the questionnaires is detailed in Figure 1.

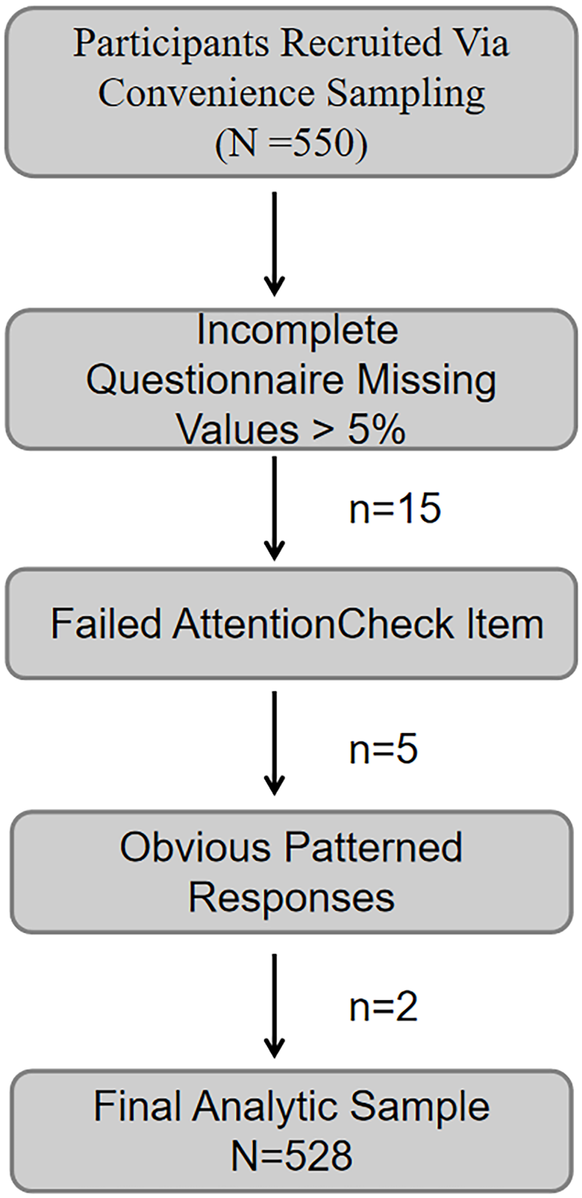


**Figure 1.** Participant flow diagram. The "N" denotes the total sample size at each stage, and the "n" represents the number of participants excluded for each specific criterion

***Measures***

*The adapted internet addiction test*

The Internet Addiction Test developed by Young and Rogers (1998) was the first instrument confirmed to be effective in screening individuals with internet addiction disorder (Widyanto et al., 2010). Research across multiple countries has further demonstrated the good reliability of this questionnaire in screening various subtypes of internet addiction. Accordingly, in the present study, the term "internet use" in the original questionnaire was adapted to "mobile gaming" to measure individuals' problematic mobile game use (Wang et al., 2017; Lee et al., 2018). This scale consists of 20 items (e.g., "Do you find that you spend more time playing mobile games than you initially intended?"). All items are rated on a 5-point Likert scale ranging from "rarely" to "always," with higher total scores indicating more severe problematic mobile gaming behavior. In this study, the Cronbach's α coefficient for this scale was 0.88.

*The depression anxiety stress scale*

Negative emotions were assessed using the simplified Chinese version of the Depression Anxiety Stress Scale (DASS-21), originally developed by Lovibond and Lovibond (1995) and later revised by Gong et al. (2010). The scale consists of 21 items covering three dimensions: depression (e.g., "I felt that I had lost interest in everything"), anxiety (e.g., "I experienced dryness of the mouth"), and stress (e.g., "I found it difficult to relax"). All items were rated on a 4-point Likert scale ranging from "did not apply to me at all" to "applied to me very much or most of the time." Higher scores indicate more severe levels of negative emotions. In this study, the internal consistency reliability of the three subscales was good, with Cronbach's $\alpha$ coefficients of 0.85 for depression, 0.81 for anxiety, and 0.83 for stress.

*The adolescent executive function scale*

Executive function was assessed using the Adolescent Executive Function Scale developed by Huang et al. (2014), which was constructed based on Miyake's three-factor model of executive function. The scale consists of 21 items covering three dimensions: inhibitory control (e.g., "I am impulsive"), working memory (e.g., "I often forget what I was doing in the middle of a task"), and cognitive flexibility (e.g., "I get upset when plans change"). All items were rated on a 5-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Higher total scores indicate poorer executive functioning. In this study, the internal consistency reliability of the three subscales was good, with Cronbach's $\alpha$ coefficients of 0.85 for inhibitory control, 0.86 for working memory, and 0.84 for cognitive flexibility.

*The physical activity rating scale-3*

Physical activity was assessed using the Physical Activity Rating Scale (PARS-3) revised by Liang (1994). The scale consists of three items (e.g., "What types of physical activities do you usually engage in?") designed to evaluate the intensity, duration, and frequency of physical activity. Participants were asked to rate each item on a scale from 1 to 5 points. The total physical activity score was calculated using the formula: intensity × (duration − 1) × frequency, with higher scores indicating a higher level of physical activity. In this study, the internal consistency of the PARS-3 scores was $\alpha = 0.72$.

***Data analysis***

Data analysis was performed using IBM SPSS Statistics 27.0 and the PROCESS macro. The specific procedures were as follows:

First, Harman's single-factor test was conducted to assess common method bias. The results indicated that serious common method bias was not present.

Second, independent samples $t$-tests and one-way analysis of variance (ANOVA) were employed to examine differences in the main study variables across demographic characteristics such as gender and major. Variables showing significant differences were included as control variables in subsequent analyses.

Next, Pearson correlation analysis was used to examine the relationships between the four core variables: PMG, executive function impairments, negative emotions, and physical activity. This provided preliminary evidence for constructing the subsequent model.

Finally, to test the mediating role of negative emotions and the moderating role of physical activity on the direct path, we utilized the Bootstrap method (with 5000 resamples) proposed by Hayes (2013) to estimate Model 4 and Model 5 in PROCESS. In this model, PMG was the independent variable, executive function was the dependent variable, negative emotions was the mediator, and physical activity was the moderator. Gender, age, discipline, university, and academic year were included as statistical control variables. All continuous predictor variables were standardized prior to creating the product terms. The significance of the effects was evaluated using 95% bias-corrected confidence intervals; effects were deemed statistically significant if the interval did not contain zero. The significance level for all statistical analyses was set at $\alpha = 0.05$.

## Results

### *Common method biases analyses*

All data in this study were collected via participant self-report. To assess potential common method bias, Harman's single-factor test was conducted. This test evaluates the severity of common method bias by examining whether the first factor extracted before rotation accounts for the majority of the variance. The results indicated that the first factor explained 17.34% of the variance, which is below the critical threshold of 40%. According to Podsakoff et al. (2003), this suggests that common method bias does not pose a serious problem in this study.

### *Analysis of demographic differences in main variables*

Comparative analyses were conducted to examine the main study variables across different demographic characteristics among the university students. Regarding gender, male students scored significantly higher than female students on both PMG (males: 39.01 ± 15.11; females: 31.12 ± 12.04; $t = 6.62$, $p < 0.001$) and physical activity (males; 22.15 ± 15.47; females; 13.70 ± 13.21; $t = 6.64$, $p < 0.001$). No significant gender differences were observed in negative emotions or executive function scores ($p > 0.05$). Concerning academic discipline, students majoring in sciences had significantly higher physical activity scores than those in arts/humanities (sciences; 20.24 ± 22.19; liberal arts; 11.38 ± 14.59; $t = -4.63$, $p < 0.001$). No other significant differences in PMG, total negative emotions, executive function, or physical activity scores were found for other demographic variables (e.g., academic year) ($p > 0.05$). Detailed results are presented in Table 1.

### *Correlation analysis of main variables*

Pearson correlation analyses (see Table 2) revealed that PMG scores were significantly and positively correlated with both executive function difficulties ($r = 0.47$, $p < 0.01$) and negative emotionsscores ($r = 0.51$, $p < 0.01$). However, PMG scores were not significantly correlated with physical activity scores ($p > 0.05$). Executive function scores showed a significant positive correlation with negative emotionsscores ($r = 0.63$, $p < 0.01$) and a significant negative correlation with physical activity scores ($r = -0.09$, $p < 0.05$). Finally, no significant correlation was found between negative emotionsscores and physical activity scores ($p > 0.05$).

### *The mediating role of negative emotions*

After controlling for covariates including gender, age, discipline, university, and academic year, PMG significantly and positively predicted executive function difficulties ($\beta = 0.64$, $t = 13.16$, $p < 0.01$). It is crucial to note that higher scores on the executive function scale used in this study indicate greater impairment. Therefore, this result signifies that a higher degree of PMG is associated with more severe executive function impairments. Thus, Hypothesis H1 was supported.

Further mediation analysis revealed that PMG not only positively predicted negative emotions ($\beta = 0.88$, $t = 13.82$, $p < 0.01$), but negative emotions also positively predicted executive function difficulties (i.e., higher negative emotions was associated with more severe executive function impairment; $\beta = 0.39$, $t = 13.31$, $p < 0.001$). Notably, after accounting for the mediating effect of negative emotions, the direct predictive effect of PMG on executive function difficulties remained significant ($\beta = 0.30$, $t = 6.12$, $p < 0.001$). These results confirm that negative emotions plays a partial mediating role in the relationship between PMG and executive function. The indirect effect was 0.34, with a 95% bias-corrected confidence interval of [0.27, 0.42]. Using the method proposed by Wen and Ye (2014), the ratio of the indirect effect to the total effect was calculated as 53.13%, highlighting the substantial role of negative emotions as a mediator in this relationship. Consequently, Hypothesis H2 was supported. The mediation model is depicted in Figure 2, and the corresponding regression coefficients are detailed in Table 3.

### *Analysis of the moderating effect of physical activity*

After controlling for demographic variables (gender, age, and discipline), the results (see Table 4) showed that PMG significantly and positively predicted executive function difficulties ($\beta = 0.29$, $t = 5.92$, $p < 0.001$), providing further support for H1. Physical activity significantly and negatively predicted executive function difficulties ($\beta = -0.05$, $t = -1.71$, $p < 0.001$), indicating that higher levels of physical activity were associated with less severe executive function impairment. Most importantly, the interaction term between PMG and physical activity was a significant predictor of executive function difficulties ($\beta = 0.01$, $t = 2.24$, $p < 0.05$), confirming the moderating role of physical activity in the relationship between PMG and executive function (see Figure 3 for details).

Simple slope analysis was conducted to probe this interaction. For individuals with a low level of PMG (M – 1 SD), those with high physical activity had significantly lower executive function difficulty scores (i.e., less

**Table 1.** Descriptive statistics and group differences for study variables by demographic characteristics

| Variable | N | PMG | Negative emotions | Executive function | Physical activity |
|---|---|---|---|---|---|
| **Gender** | | | | | |
| Male | 200 | 39.01 ± 15.11 | 20.81 ± 21.72 | 44.48 ± 16.92 | 22.15 ± 15.47 |
| Female | 328 | 31.12 ± 12.04 | 18.81 ± 21.38 | 47.01 ± 16.12 | 13.70 ± 13.21 |
| *t* | | 6.62*** | 1.04 | −1.72 | 6.64*** |
| **Age** | | | | | |
| 17–19 | 258 | 33.80 ± 13.40 | 19.04 ± 21.63 | 45.71 ± 16.62 | 15.40 ± 17.53 |
| 20–22 | 270 | 33.61 ± 13.86 | 19.87 ± 21.39 | 46.63 ± 16.23 | 14.47 ± 18.97 |
| *t* | | 0.16 | −0.45 | −0.64 | 0.59 |
| **Major** | | | | | |
| Liberal arts | 269 | 33.11 ± 13.38 | 20.24 ± 22.19 | 46.88 ± 16.17 | 11.38 ± 14.59 |
| Science | 259 | 34.32 ± 13.88 | 18.66 ± 20.75 | 45.46 ± 16.65 | 20.24 ± 22.19 |
| *t* | | −1.02 | 0.84 | 0.99 | −4.63*** |
| **School** | | | | | |
| A | 188 | 35.29 ± 13.25 | 18.03 ± 20.14 | 45.78 ± 15.78 | 14.33 ± 20.14 |
| B | 149 | 33.47 ± 12.94 | 21.76 ± 23.29 | 47.21 ± 16.40 | 15.35 ± 14.37 |
| C | 191 | 32.32 ± 14.40 | 19.09 ± 21.27 | 45.77 ± 17.06 | 14.37 ± 18.29 |
| *F* | | 2.29 | 1.3 | 0.41 | 0.17 |
| **Grade** | | | | | |
| Freshman | 132 | 35.19 ± 15.58 | 19.36 ± 19.67 | 46.28 ± 15.58 | 15.65 ± 17.77 |
| Sophomore | 110 | 32.53 ± 13.04 | 18.24 ± 23.27 | 43.42 ± 17.74 | 14.16 ± 18.55 |
| Junior | 144 | 33.48 ± 12.37 | 21.26 ± 23.61 | 46.04 ± 16.02 | 15.31 ± 18.82 |
| Senior | 142 | 33.46 ± 13.37 | 18.69 ± 19.43 | 48.37 ± 16.32 | 14.44 ± 18.12 |
| *F* | | 0.823 | 0.517 | 1.899 | 0.188 |

*Note*. Data are presented as mean ± standard deviation. ***$p < 0.001$.

**Table 2.** Correlation analysis

| Variable | Mean | SD | PMG | Executive function | Negative emotions | Physical activity |
|---|---|---|---|---|---|---|
| PMG | 33.70 | 13.63 | 1 | | | |
| Executive function | 46.18 | 16.41 | 0.47** | 1 | | |
| Negative emotions | 19.47 | 21.49 | 0.51** | 0.63** | 1 | |
| Physical activity | 14.92 | 18.27 | 0.05 | −0.09* | −0.01 | 1 |

*Note*. *$p < 0.05$, **$p < 0.01$.

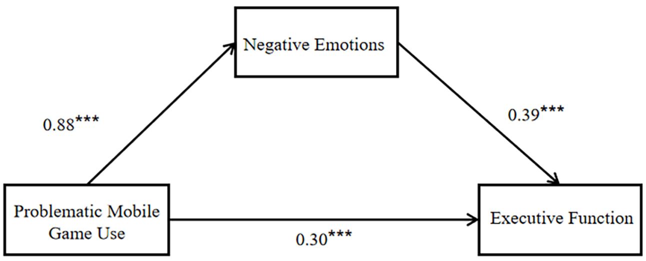


**Figure 2.** A simple mediation model showing the effects of PMG on executive function via negative emotions. *Note*. ***$p < 0.001$.

impairment) than those with low physical activity (Effect = 0.24, SE = 0.06, $t = 4.23$, $p < 0.001$, 95%CI = [0.13, 0.35]). Given that higher executive function scores indicate greater impairment, this negative simple slope demonstrates that within the low-PMG subgroup, higher physical activity was associated with a lower level of executive function impairment, indicating a protective effect of physical activity. Conversely, for individuals with a high level of PMG (M + 1 SD), there was no significant difference in executive function difficulty scores between those with high and low physical activity levels ($p > 0.05$). This suggests that the protective effect of physical activity disappears when the degree of problematic use is severe.

In summary, the buffering effect of physical activity on executive function depends on the level of PMG: its protective role is evident only under conditions of low PMG but dissipates under conditions of high PMG. These results support Hypothesis H3. The pattern of the moderating effect is illustrated in Figure 4.

## Discussion

This study investigated the complex relationships between PMG, executive function, negative emotions, and physical activity among Chinese university students. The main findings confirmed our hypotheses: PMG was directly associated with executive function impairments, negative emotions partially mediated this relationship, and physical activity moderated the direct path, with its protective effect being significant only at low levels of PMG.

Consistent with previous research (Ahmed et al., 2024), male students reported significantly higher levels of PMG than females, a difference potentially attributable to males' heightened sensitivity to reward cues in gaming

**Table 3.** Mediation model test

| Outcome variable | Predictor variable | β | SE | *t* | 95% CI |
|---|---|---|---|---|---|
| Negative emotions | PMG | 0.88 | 0.06 | 13.82*** | [0.76, 1.01] |
| | Gender | 4.11 | 1.95 | 2.11* | [0.28, 7.94] |
| | Age | 0.36 | 1.62 | 0.22 | [−2.82, 3.54] |
| | School | 0.88 | 1.09 | 0.81 | [−1.25, 3.02] |
| | Major | −0.32 | 1.90 | −0.17 | [−4.05, 3.41] |
| | Grade | 0.36 | 0.71 | 0.51 | [−1.03, 1.75] |
| Executive function | PMG | 0.30 | 0.05 | 6.12*** | [0.21, 0.40] |
| | Negative emotions | 0.39 | 0.03 | 13.31*** | [0.33, 0.45] |
| | Gender | 6.19 | 1.30 | 4.76*** | [3.63, 8.74] |
| | Age | 0.01 | 1.08 | 0.01 | [−2.11, 2.12] |
| | School | −0.38 | 0.72 | −0.52 | [−1.80, 1.04] |
| | Major | 0.80 | 1.26 | 0.63 | [−1.68, 3.28] |
| | Grade | 0.89 | 0.47 | 1.89 | [−0.04, 1.81] |

*Note*. *$p < 0.05$, ***$p < 0.001$.

**Table 4.** Test of moderated mediating effect

| Variable | Eq. (1) (outcome: negative emotions) | | | | Eq. (2) (outcome: executive function) | | | |
|---|---|---|---|---|---|---|---|---|
| | SE | β | *t* | 95% CI | SE | β | *t* | 95% CI |
| PMG | 0.06 | 0.88 | 13.82*** | [0.76, 1.01] | 0.05 | 0.29 | 5.92*** | [0.20, 0.39] |
| Gender | 1.95 | 4.11 | 2.11* | [0.28, 7.94] | 1.35 | 5.57 | 4.1362*** | [2.92, 8.21] |
| Age | 1.62 | 0.36 | 0.22 | [−2.82, 3.54] | 1.07 | −0.04 | −0.03 | [−2.14, 2.07] |
| School | 1.09 | 0.88 | 0.81 | [−1.25, 3.02] | 1.72 | −0.37 | −0.51 | [−1.71, 1.05] |
| Major | 1.90 | −0.32 | −0.17 | [−4.05, 3.41] | 1.26 | 0.98 | 0.78 | [−1.49, 3.45] |
| Grade | 0.71 | 0.36 | 0.51 | [−1.03, 1.75] | 0.47 | 0.8969 | 1.92 | [−0.02, 1.81] |
| Negative Emotions | – | – | – | – | 0.03 | 0.3841 | 13.24*** | [0.33, 0.44] |
| Physical Activity | – | – | – | – | 0.0310 | −0.0532 | −1.71 | [−0.11, 0.01] |
| PMG × Physical Activity | – | – | – | – | 0.0016 | 0.0036 | 2.24* | [0.01, 0.03] |
| $R^2$ | – | – | – | 0.28 | – | – | – | 0.46 |
| *F* | – | – | – | 28.81*** | – | – | – | 44.74*** |

*Note*. *$p < 0.05$, ***$p < 0.001$.

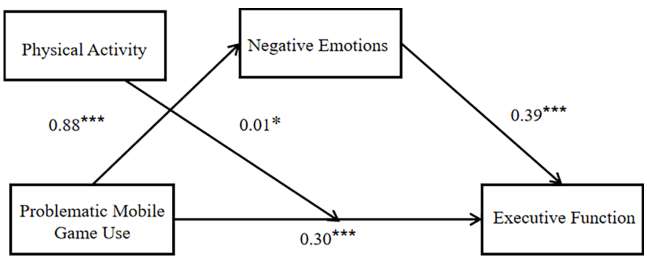


**Figure 3.** Results of the moderated mediation model analysis. *Note*. *$p < 0.05$, ***$p < 0.001$.

contexts (Sayeed et al., 2021). Notably, despite exhibiting higher PMG, males did not show significantly different executive function scores. This seemingly counterintuitive finding can be interpreted through the lens of physical activity's moderating role. In simple between-group comparisons, the generally higher level of physical activity among males might have masked the underlying negative association between PMG and executive function. Our subsequent moderated mediation analysis, which explicitly modeled this effect, successfully uncovered this more complex relationship. The finding that science majors reported higher physical activity levels than arts/humanities majors likely reflects the known gender segregation across academic disciplines in Chinese higher education (Xu et al., 2023).

Our study provides crucial behavioral evidence of a direct association between PMG and self-reported executive dysfunction. While previous research has established correlations between problematic gaming and cognition, this study extends the literature by systematically uncovering an underlying mechanism—the mediating role of negative emotions—and a critical boundary condition—the moderating role of physical activity. The positive predictive effect of PMG on executive function impairments aligns with the prefrontal compensation theory (Shen et al., 2023b). Based on the existing literature and the findings of this study, our results may indicate that the

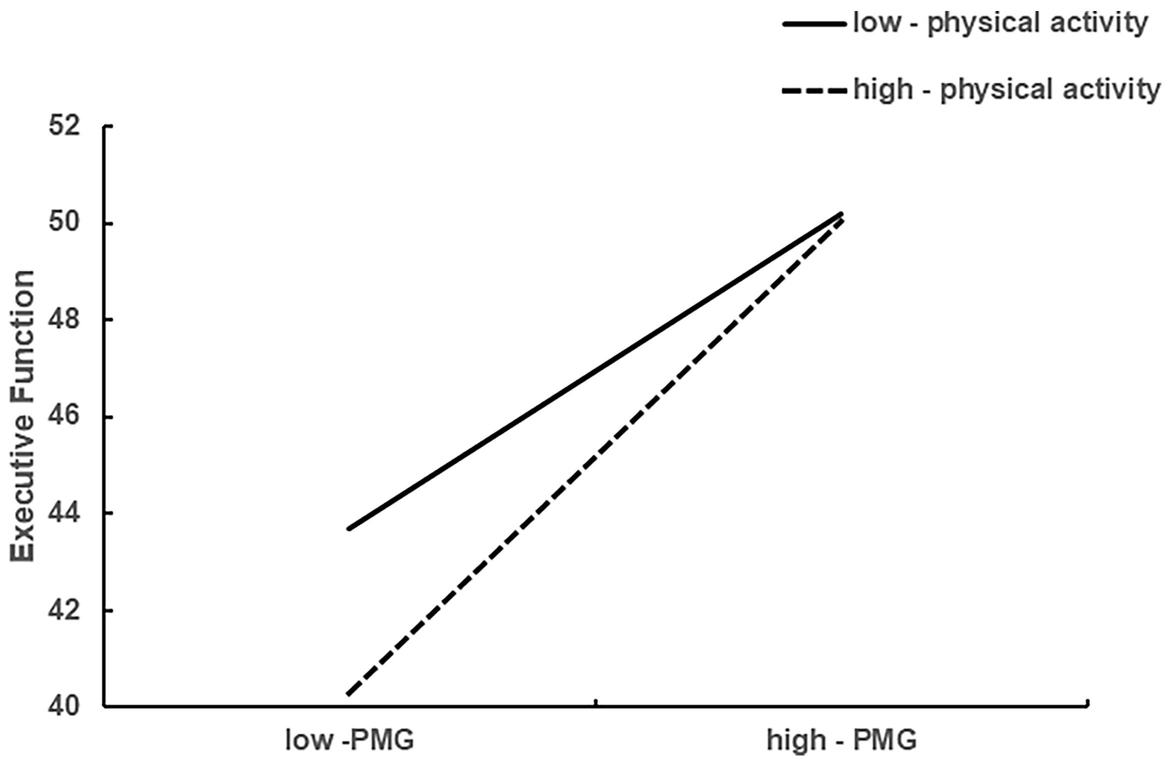


**Figure 4.** Moderating effect of physical activity

neural compensatory mechanisms (e.g., overactivation in the dorsolateral prefrontal cortex [DLPFC]) observed in fMRI research may translate into subjective experiences of cognitive stress and behavioral deficits in daily life.

A central contribution of this study is the identification of a significant mediating pathway through negative emotions. This finding provides a mechanistic explanation consistent with the I-PACE model (Brand et al., 2025). The identified mediation pathway supports a theoretically plausible model wherein PMG may contribute to executive dysfunction via the exacerbation of negative emotions. This model fits a potential 'vicious cycle': individuals might engage in mobile gaming as a maladaptive coping strategy for reality escape; however, this behavior could subsequently intensify negative emotions due to the accumulation of unresolved real-life problems. These heightened negative emotions, in turn, impair cognitive resources, leading to executive dysfunction. It is important to note that our cross-sectional model tested the pathways in one direction of this cycle. The relationships between variables are likely bidirectional and mutually reinforcing, a dynamic that should be examined in future longitudinal research.

Perhaps the most novel finding is the demonstration that the protective effect of physical activity is not universal but is contingent upon the severity of addictive behavior. The significant interaction effect, followed by simple slope analysis, revealed that physical activity significantly buffered executive function impairments only for individuals with low levels of PMG. This is consistent with neurobiological evidence that exercise enhances prefrontal cortex function and dopaminergic signaling (Wang et al., 2022). However, when PMG reaches high levels, the resulting neurocognitive deficits (e.g., potential grey matter alterations or profound neural circuit dysregulation) may exceed a critical threshold beyond which the beneficial effects of routine physical activity are no longer sufficient to confer protection. This finding crucially refines the I-PACE model by indicating that the effectiveness of a resource-based protective factor, like physical activity, is constrained by the severity of addiction. For intervention practitioners, this implies the necessity for risk stratification: promoting physical activity represents a viable primary prevention strategy for at-risk individuals, but for those with severe PMG, more intensive, multi-faceted interventions are likely required.

***Research contributions and future research directions***

On a theoretical level, this study provides important empirical support and extension for the I-PACE model. Firstly, the results validate the core mediating pathway of "problematic use → negative emotions → executive function impairments," highlighting the critical role of emotional factors in addiction-related cognitive decline. More importantly, this study innovatively reveals the "efficacy boundary" of the protective factor, physical activity, demonstrating that its protective effect is significant only during the mild stage of problematic use. This finding adds a crucial "boundary condition for resource-based protective factors" to the I-PACE model, clarifying that protective factors are not universally effective and that their efficacy is constrained by the severity of addictive behavior, thereby refining the dynamic framework of behavioral addiction.

On a practical level, this study provides instructive evidence for prevention and intervention efforts. For the broader student population and educators, the findings underscore the potential of promoting physical activity as a low-cost, accessible cognitive protection strategy. Specifically, educational institutions and public health initiatives can advocate for regular physical activity as a "primary prevention" measure to prevent the escalation of mild gaming use. However, for individuals already entrenched in severe PMG, the results of this study serve as a clear warning: physical activity alone may be insufficient to reverse their cognitive impairments. This necessitates that clinical and psychological practitioners implement risk stratification in their practice. For high-risk individuals, it is crucial to develop and implement integrated intervention packages that combine neuromodulation, cognitive-behavioral therapy, and family support, rather than relying solely on exercise prescriptions.

### *Limitations and future research directions*

This study has several limitations, which also point to valuable directions for future research. First, the cross-sectional design precludes the establishment of causal relationships between variables. The relationships between problematic use, negative emotions, and executive function are likely bidirectional and dynamic. Future research should employ longitudinal designs to clarify the temporal sequencing among these core variables. Second, all data were derived from self-report measures, which may introduce common method bias and social desirability effects. Although statistical tests indicated that common method bias was not severe in this dataset, future studies would benefit from incorporating objective measures to enhance the validity and robustness of the findings. Examples include: monitoring gaming behavior via logged screen time on mobile devices, assessing physical activity using accelerometers, and evaluating executive function with computerized neuropsychological tasks. Third, the generalizability of the findings is limited by the sample (a convenience sample from universities within a single Chinese province). Future research is necessary to replicate and validate the proposed model in more diverse, nationally representative samples encompassing different geographical and cultural contexts to examine its stability and boundary conditions.

Regarding research content, we propose two promising future directions. On one hand, neurobiological investigations utilizing techniques such as functional magnetic resonance imaging (fMRI) or event-related potentials (ERP) could directly examine how physical activity modulates functional connectivity and activation patterns within the prefrontal-striatal circuits in individuals characterized by problematic gaming use. This would provide mechanistic neural evidence for our behavioral findings. On the other hand, intervention studies are needed to develop and evaluate targeted physical activity protocols. Future work should determine the effective "dose" (e.g., intensity, frequency, type) of activity for different risk groups and explore the effects of integrated intervention models that combine physical activity with cognitive training or mindfulness practice.

## Conclusion

In summary, PMG serves as a significant predictor of executive function among university students. Negative emotions played a mediating role in the relationship between PMG and executive function. Physical activity moderated the direct path through which PMG affects executive function. Specifically, the protective effect of physical activity was significant only under conditions of low-level problematic mobile gaming but disappeared when such gaming was at a high level.

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**Availability of Data and Materials:** The data are available upon request from the corresponding author.

**Ethics Approval and Informed Consent:** The study was conducted in compliance with the Declaration of Helsinki and received approval from the Academic Ethics Committee of Henan University (Approval Number: 20250309006). All participants provided informed consent individually, with assurances of anonymity and confidentiality. To protect participants' privacy, all data were de-identified, and analyses were conducted on aggregated data.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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