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ARTICLE

Longitudinal Impact of Childhood Psychological Abuse on Adolescent Smartphone Addiction: A Moderated Mediation Model

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ABSTRACT: Objectives: Existing research indicates a link between childhood physical abuse (CPA) and adolescent smartphone addiction (SA), yet it primarily relies on cross-sectional data. This leaves the longitudinal developmental pathways, including the mediating role of anxiety and the potential protective role of physical activity (PA), poorly understood and insufficiently examined. This study aimed to examine the longitudinal association between CPA and SA among Chinese middle school students, and to investigate the mediating role of anxiety and the moderating role of PA in this relationship. **Methods:** This study was conducted in two waves of a longitudinal design with an interval of three months from March to June in 2024. A convenience sampling method was used to survey 479 adolescents. After data matching and cleaning, 421 valid samples were obtained. The measurements included CPA, Anxiety, SA, and PA data. Correlation analysis and the construction of the moderated mediation model were conducted using SPSS and the PROCESS plugin. **Results:** CPA (including emotional abuse and emotional neglect) was positively associated with adolescents' subsequent SA (r = 0.297 and 0.113). Anxiety significantly mediated the longitudinal relationship between CPA and SA (CPA → anxiety: $\beta = 0.374$, SE = 0.045, $t = 8.339$, $p < 0.001$; anxiety → SA: $\beta = 0.447$, SE = 0.046, $t = 9.688$, $p < 0.001$), indicating that higher levels of childhood psychological abuse were linked to increased anxiety, which in turn predicted greater risk of SA. In addition, PA was negatively associated with CPA (r = −0.194), anxiety (r = −0.396), and SA (r = −0.265), and moderated the association between CPA and anxiety ($\beta = -0.119$, SE = 0.045, $t = -2.641$, $p < 0.01$), such that higher levels of PA weakened the adverse effect of CPA on anxiety. **Conclusion:** These findings suggest that anxiety plays a key psychological mechanism linking childhood psychological abuse to adolescent SA, while PA may function as a buffering factor that attenuates this risk pathway. From an applied perspective, school-based prevention and early intervention programs that focus on anxiety reduction and the promotion of regular PA may help reduce the likelihood of SA among adolescents exposed to psychological abuse.

KEYWORDS: Childhood psychological abuse; smartphone addiction; physical activity; anxiety; longitudinal study

1 Introduction

Smartphone addiction (SA) refers to a harmful behavioral pattern characterized by excessive smartphone use due to insufficient self-control, leading to addictive tendencies [1–3]. With the advancement of science and technology, adolescents' smartphone usage has been continuously increasing. Statistics show that the number of Chinese teenage internet users aged 7–18 has reached 191 million, with an internet

penetration rate of 96.8% among minors [4]. While smartphones provide adolescents with a favorable platform for learning, communication, and entertainment, those with poor self-regulation may engage in excessive use, which triggers dependency issues and may even deteriorate into SA. Survey results indicate that prolonged smartphone use is associated with emotional instability, impaired concentration, and memory decline [5]. Moreover, addictive behaviors exert the most profound impact on adolescents, who are recognized as the most vulnerable group to addictive risk behaviors [6]. Therefore, exploring the risk factors of adolescent SA holds significant theoretical and practical implications.

Childhood psychological abuse (CPA) refers to persistent and repetitive inappropriate psychological parenting practices imposed on individuals during childhood [7]. Unlike physical or sexual abuse, CPA primarily involves non-physical emotional interactions that undermine children's emotional security, self-worth, and developmental needs [8]. Conceptually, psychological maltreatment is a multidimensional construct that encompasses several caregiving-related dimensions, among which emotional abuse and emotional neglect are considered two core components. Emotional neglect reflects caregivers' chronic failure to provide adequate emotional responsiveness, warmth, and support necessary for children's psychological and social development [9]. In contrast, emotional abuse involves active forms of psychological harm, such as verbal aggression, rejection, humiliation, or intimidation directed at children by caregivers [10]. Although these two dimensions differ in form—one characterized by omission and the other by commission—they often co-occur in dysfunctional caregiving environments and jointly disrupt children's emotional regulation and psychosocial development. In the present study, CPA was operationalized by focusing specifically on these two central dimensions—emotional abuse and emotional neglect—consistent with prior empirical research emphasizing their salience in predicting adolescents' internalizing problems and maladaptive behaviors [11]. Existing studies have shown that adolescents exposed to CPA are more likely to exhibit problematic behavioral outcomes during development, including an elevated risk of SA [12]. One possible explanation is that children who experience emotional abuse or neglect often lack effective emotional regulation and coping strategies. Smartphones may thus serve as an easily accessible means of emotional escape or self-soothing, offering temporary relief from distress through games, short videos, or social media content [13]. Moreover, long-term exposure to emotionally abusive or neglectful caregiving environments may impair the development of secure interpersonal relationships, increasing adolescents' reliance on digital media, such as smartphones and the internet, to seek emotional comfort and perceived social support [14].

The relationship between CPA and adolescent SA may be explained by multiple internal psychological processes. Among these, anxiety represents a particularly salient and theoretically relevant mediator. Anxiety is a common emotional problem during adolescence and is defined as an unpleasant and complex emotional state characterized by feelings of tension, unease, worry, and irritability when individuals anticipate situations perceived as potentially threatening [15–17]. Adolescence is a developmental period marked by heightened emotional sensitivity and vulnerability to anxiety-related symptoms, making anxiety a central mechanism through which early adverse experiences may exert their influence on later behavioral outcomes. Empirical research has consistently demonstrated a positive association between CPA and adolescent anxiety [18], with adolescents exposed to psychological abuse being more susceptible to anxiety-related difficulties [19]. Early adverse childhood experiences (ACEs), such as psychological abuse, are associated with specific physiological alterations and increased health risks, thereby heightening individuals' vulnerability to anxiety [20]. At the behavioral level, a growing body of adolescent-focused research has identified a significant association between anxiety and SA [21], with anxiety shown to be a robust predictor of problematic smartphone use [22]. Although other internalizing processes—such as depressive symptoms or broader emotion dysregulation—have also been linked to

childhood adversity and problematic technology use [23,24], the present study focuses specifically on anxiety due to its strong empirical support and clear theoretical relevance to self-regulatory failure [25]. Anxiety is known to consume individuals' cognitive resources, leading to executive dysfunction and diminished self-control [26–29], which in turn impairs the ability to regulate smartphone use and increases susceptibility to SA [30]. Accordingly, anxiety was selected as the primary mediating variable to capture a key emotional pathway linking CPA to adolescent SA, while acknowledging that future research should explore additional mediating mechanisms within a more comprehensive framework.

Between CPA and adolescent anxiety, certain protective factors may function as buffers by attenuating emotional distress and, in turn, reducing the likelihood of maladaptive behaviors such as SA. Among these factors, physical activity (PA) has been consistently identified as a salient protective resource for adolescent mental health. Empirical studies have shown that PA plays a crucial role in alleviating emotional problems such as anxiety among adolescents [31,32]. Regular engagement in PA can significantly and negatively predict anxiety symptoms, contributing to improved emotional stability and psychological well-being [33]. From a neurobiological perspective, PA facilitates stress regulation by modulating the hypothalamic–pituitary–adrenal (HPA) axis and regulating neurotransmitter systems associated with emotion and reward processing. Specifically, PA promotes the release of neurotransmitters such as dopamine by upregulating circulating endocannabinoids and anandamide [34], which are known to enhance mood, reduce physiological stress responses, and exert anxiolytic effects [35]. Through these mechanisms, PA may counteract the heightened stress reactivity and emotional dysregulation commonly observed in adolescents exposed to CPA. From a psychosocial perspective, PA also contributes to increased self-esteem, self-efficacy, and perceived coping competence [36]. Participation in physical activities provides adolescents with opportunities for mastery experiences, social interaction, and positive feedback, which may partially offset the negative self-concept and emotional insecurity associated with psychological abuse. These psychosocial benefits may enhance adolescents' capacity to regulate negative emotions and reduce their reliance on maladaptive coping strategies, such as excessive smartphone use, when experiencing anxiety. Consequently, PA may mitigate anxiety induced by CPA, thereby lowering the likelihood of SA in adolescents.

However, despite the growing body of literature linking CPA to adolescent SA, important conceptual and methodological gaps remain. Most notably, existing studies have predominantly relied on cross-sectional designs, which limit the ability to establish temporal ordering and obscure how early adverse experiences translate into later maladaptive technology use. As a result, little is known about the developmental processes through which CPA contributes to the emergence of SA over time. Moreover, although anxiety has been widely identified as a key psychological mechanism linking early maltreatment to addictive behaviors, and PA has been repeatedly shown to function as a protective factor for adolescent mental health, these variables have largely been examined in isolation. Prior research has rarely integrated risk mechanisms and protective factors within a single explanatory framework, particularly one that captures their dynamic interplay across time. Consequently, it remains unclear not only whether anxiety mediates the association between CPA and SA, but also under what conditions this mediating process may be strengthened or attenuated. To address these gaps, the present study adopts a longitudinal design and constructs a moderated mediation model to examine the temporal pathway from CPA to adolescent SA via anxiety, while testing PA as a moderator of the first-stage pathway (Fig. 1). By doing so, this study extends prior work by shifting the focus from static associations to conditional developmental processes, thereby clarifying when the adverse effects of CPA are most pronounced and when they may be buffered. Based on previous theoretical and empirical evidence, we propose the following hypotheses:

Hypothesis 1: *CPA is positively associated with adolescent SA*;

Hypothesis 2: *Anxiety mediates the relationship between CPA and SA*;

Hypothesis 3: *PA moderates the first stage of the pathway "CPA → anxiety → SA".*

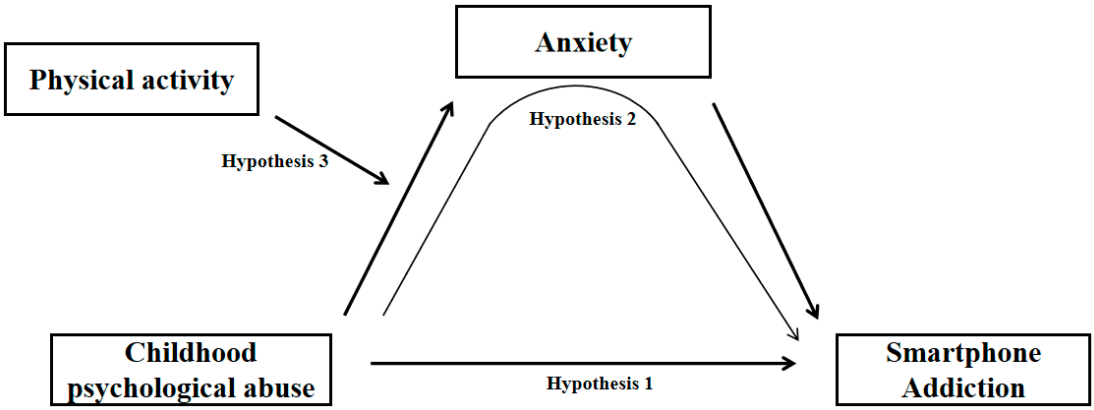

Figure 1: Moderated mediation model.

2 Methods

2.1 Participants

In March 2024, convenience sampling was employed to recruit seventh-grade students from one public middle school in Jishou City, Xiangxi Autonomous Prefecture, Hunan Province. Xiangxi is a relatively underdeveloped mountainous region in central China, characterized by ethnic diversity, comparatively limited educational resources, and greater variability in socioeconomic conditions. The selected school is a typical local public middle school that enrolls students from both urban and surrounding rural areas, making it broadly representative of adolescents in this regional context. The first wave of data collection (T1) was conducted in March 2024, during which 498 questionnaires were distributed, and 479 valid responses were obtained, yielding an effective response rate of 96.19%. The second wave (T2) was conducted 3-months later, in June 2024, with 479 questionnaires distributed and 455 valid responses collected, resulting in an effective response rate of 94.99%. After matching questionnaire codes across waves, questionnaires with substantial missing data or obviously patterned responses were excluded. Only participants who provided complete and valid data at both T1 and T2 were retained for the final analyses, resulting in a final sample of 421 adolescents (92.53%). The final sample consisted of 205 males and 216 females. The mean age of participants was 15.34 years (SD = 0.54). Although the students were enrolled in the same grade level, the relatively higher mean age reflects regional educational characteristics, including delayed school entry and occasional grade repetition, which are more common in economically less developed areas. Importantly, all participants fell within the developmental period of middle adolescence, a stage marked by heightened emotional sensitivity, increased autonomy, and elevated vulnerability to anxiety and problematic technology use. Therefore, the sample remains developmentally appropriate for examining the relationships among CPA, anxiety, PA, and SA, while the age profile should be considered when interpreting the generalizability of the findings to other educational contexts. All participants were minors at the time of the study. Prior to data collection, written informed consent was obtained from parents or legal guardians through the school, and adolescents provided their own assent to participate. Guardians were informed of the study's

purpose, procedures, voluntary nature, and confidentiality assurances, and consent forms were collected and archived by the school in coordination with the research team. The study protocol was reviewed and approved by the Biomedical Ethics Committee of Jishou University (No. JSDX-2024-0086) before the initiation of the project. Informed consent was obtained from the participants and their guardians before the start of the program. The study was conducted in accordance with the Declaration of Helsinki.

The temporal structure of the study was designed to reflect a theoretically informed developmental sequence. CPA, anxiety, and PA were assessed at T1 to capture baseline psychosocial risk and protective factors, whereas SA was assessed at T2 to represent a subsequent behavioral outcome. Anxiety was conceptualized as a proximal psychological mechanism linking earlier adverse experiences to later addictive behaviors, while PA was modeled as a stable protective context influencing anxiety levels. Due to practical constraints related to school-based data collection schedules and the need to minimize participant burden, anxiety was not reassessed at T2. As a result, the temporal ordering specified in the moderated mediation model should be interpreted as theory-driven rather than as evidence of definitive causal direction.

2.2 Measures

2.2.1 Childhood Psychological Abuse (CPA)

At T1, CPA was assessed using the CPA Questionnaire, an independent Chinese instrument developed and validated by Zhao et al. [37]. This questionnaire is conceptually distinct from the widely used Childhood Trauma Questionnaire (CTQ) developed in Western contexts and was specifically designed to capture culturally relevant manifestations of psychological maltreatment within Chinese family environments. The scale retrospectively assesses adolescents' experiences of psychological abuse during childhood and comprises 10 items across two theoretically grounded dimensions: emotional abuse and emotional neglect. Emotional abuse reflects active forms of psychological harm (e.g., verbal hostility and humiliation) and is assessed using a 5-point Likert scale ranging from 1 (never) to 5 (always), with higher scores indicating more frequent experiences of emotional abuse. Emotional neglect reflects the absence of emotional care, responsiveness, and support. These items are rated using the same 5-point Likert scale but are reverse-coded so that higher scores indicate greater levels of emotional neglect. Dimension scores were calculated by summing the item scores within each subscale. The overall CPA score was obtained by summing the emotional abuse and emotional neglect dimension scores, with higher total scores representing greater cumulative exposure to CPA. In the present study, internal consistency reliability was good for both subdimensions and the total scale. Cronbach's α coefficients were 0.839 for emotional abuse, 0.891 for emotional neglect, and 0.876 for the overall CPA scale, supporting the use of both the composite score and the two dimensions as distinct yet related constructs in subsequent analyses.

2.2.2 Anxiety

Anxiety at T1 was measured using the Anxiety subscale of the Depression Anxiety Stress Scale-21 (DASS-21) adapted by Gong et al. [38]. This subscale comprises 7 items scored on a 4-point Likert scale (1 = Strongly disagree to 4 = Strongly agree), with a total score ranging from 7 to 28. Higher scores reflect higher levels of anxiety among adolescents. The Cronbach's α coefficient of this subscale in the current study was 0.885, indicating satisfactory internal reliability.

2.2.3 Physical Activity (PA)

PA at T1 was assessed using the PA Rating Scale-3 (PARS-3) developed by Liang et al. [39]. The scale consists of three items assessing exercise intensity, duration, and frequency, each rated on a 5-point

Likert scale. Following the standard PARS-3 scoring procedure, the three items are combined to generate a composite PA score ranging from 0 to 100, with higher scores indicating higher overall levels of PA among adolescents. In the present study, the Cronbach's α coefficient of the PARS-3 was 0.641. Although this value is relatively modest, it is comparable to prior research using brief behavioral scales. According to methodological guidelines proposed by Hair et al. [40], when a scale consists of fewer than six items, a Cronbach's α coefficient exceeding 0.60 may be considered indicative of acceptable internal reliability. Nevertheless, the limited number of items may still constrain measurement precision, and this factor should be taken into account when interpreting the findings.

2.2.4 Smartphone Addiction (SA)

SA at T2 was measured using a slightly adapted version of the Social Network Usage Scale developed by Wei [41]. In the context of Chinese adolescents, smartphones function as the primary medium through which social networking activities are accessed and maintained. Given this strong behavioral overlap, the term "social network" was replaced with "smartphone" to better reflect adolescents' actual usage patterns and to enhance contextual relevance, while the remaining item content and response format were retained. The adapted scale consists of eight items rated on a 5-point Likert scale (1 = completely inconsistent to 5 = completely consistent), yielding total scores ranging from 8 to 40, with higher scores indicating greater levels of SA. In the present study, the adapted scale demonstrated good internal consistency (Cronbach's $\alpha = 0.869$). Nevertheless, we acknowledge that this adapted measure primarily captures addictive patterns related to smartphone-based social interaction and may not fully encompass other dimensions of SA, such as gaming or information-seeking behaviors. This measurement choice reflects a trade-off between contextual specificity and construct breadth and should be interpreted accordingly.

2.3 Statistical Processing

Analysis and statistics were conducted using SPSS 26.0 software (IBM Corp., Armonk, NY, USA). Firstly, the Harman single-factor test was used to examine the issue of common method bias among the variables in this study. When the percentage of the first factor was below the threshold of 40%, it was considered that there was no significant common method bias problem in this study. Secondly, the mean ± standard deviations (SD) of the main variables in this study were described, and Pearson correlation analysis was conducted. Subsequently, the PROCESS macro for SPSS was used to conduct the mediating model test (Model 4) for CPA (independent variable), anxiety (mediating variable), and SA (dependent variable); in this model, the two sub-dimensions of CPA (emotional abuse and emotional neglect) were also discussed; then, the moderated mediating model test (Model 7) was conducted based on the mediating model, discussing the moderating effect of PA (modifying variable), that is, the first half of the moderated mediating model (the relationship between CPA and anxiety). For model estimation and inference, 5000 bootstrap resamples were employed to generate bias-corrected 95% confidence intervals. Bootstrap-based methods are robust to deviations from normality and are therefore appropriate for handling variables that may exhibit skewed distributions, such as PA. A p-value < 0.05 was considered statistically significant.

3 Results

3.1 Harman's Single-Factor Test

The common method bias was tested by the Harman single-factor test. Among them, the first common factor explains 23.07% of the total variance, which is lower than the critical standard of 40%. In addition,

the collinearity diagnostics revealed that the variance inflation factor (VIF) for all predictor variables was below 5. Therefore, there is no serious common method bias.

3.2 Correlation Analysis

The results of Pearson correlation analysis (Table 1) revealed strong associations among CPA, anxiety, PA, and SA across T1 and T2. Specifically, T1 CPA (including emotional abuse and emotional neglect) was positively correlated with T1 anxiety (r = 0.401) and T2 SA (r = 0.229), while negatively correlated with T1 PA (r = −0.194). T1 anxiety was negatively correlated with T1 PA (r = −0.396) and positively correlated with T2 SA (r = 0.500). Additionally, T2 SA was negatively correlated with T1 PA (r = −0.265). All correlation coefficients were statistically significant at the level of $p < 0.001$.

Table 1: Correlation coefficients of study variables (N = 421).

Variable	Mean ± SD	1	2	3	4	5
1 T1 Childhood psychological abuse	19.03 ± 7.31	-				
2 T1 Emotional abuse	8.24 ± 3.84	0.813***	-			
3 T1 Emotional neglect	10.79 ± 4.75	0.883***	0.445***	-		
4 T1 Anxiety	13.48 ± 5.05	0.401***	0.417***	0.281***	-	
5 T1 Physical activity	21.24 ± 23.71	−0.194***	−0.158***	−0.171***	−0.396***	-
6 T2 Smartphone addiction	19.37 ± 7.26	0.229***	0.297***	0.113***	0.500***	−0.265***

Note: ***$p < 0.001$.

3.3 Testing for Mediating Effects

After controlling for demographic variables (gender, age, only-child status, left-behind status, and parental educational level), Model 4 in the SPSS PROCESS macro was used to test the mediating effect, with T1 CPA, emotional abuse, and emotional neglect as independent variables, T1 anxiety as the mediating variable, and T2 SA as the dependent variable. The results (Tables 2 and 3) showed that T1 CPA and emotional abuse were all positively associated with adolescents' T1 anxiety levels ($\beta = 0.374$, $\beta = 0.395$, $\beta = 0.255$) and positively associated with T2 SA (all $p < 0.001$). After T1 anxiety was included in the model, the associations between T1 CPA, emotional abuse, and emotional neglect and T2 SA were no longer statistically significant (all $p > 0.05$), whereas T1 anxiety remained positively associated with T2 SA ($\beta = 0.447$, $\beta = 0.418$, $\beta = 0.463$; all $p < 0.001$). Regarding model explanatory power, the inclusion of anxiety substantially increased the variance explained in SA. As shown in Table 2, the final model explained 29.8% of the variance in T2 SA ($R^2 = 0.298$), indicating that the combination of CPA and anxiety accounts for a meaningful proportion of variability in adolescents' SA, while acknowledging that other psychological and contextual factors also contribute. Within the tested prospective model over a 3-month period, the indirect pathway from T1 CPA to T2 SA via T1 anxiety was statistically significant, and the direct effects became nonsignificant after anxiety was included. To further evaluate the practical significance of this pathway, we calculated the ratio of the indirect effect to the total effect. As shown in Table 3, the indirect effect (Effect = 0.167) accounted for approximately 93.8% of the total effect (0.178). These findings suggest that anxiety plays a central psychological role in linking CPA to subsequent SA within the constraints of the study design, rather than establishing a definitive causal mechanism. The mediating effect model is illustrated in Fig. 2.

Table 2: Mediation model test of anxiety (N = 421).

Outcome Variable	Predictive Variable	β (95%CI)	SE	*t*	R^2	F
T1 Anxiety	T1 Childhood psychological abuse	0.374 (0.286, 0.462)	0.045	8.339***	0.201	14.872
T2 Smartphone addiction	T1 Childhood psychological abuse	0.178 (0.087, 0.270)	0.047	3.830***	0.138	9.461
T2 Smartphone addiction	T1 Childhood psychological abuse	0.011 (−0.078, 0.100)	0.045	0.244	0.298	21.872
	T1 Anxiety	0.447 (0.357, 0.538)	0.046	9.688***		
T1 Anxiety	T1 Emotional abuse	0.395 (0.307, 0.483)	0.045	8.859***	0.216	16.242
T2 Smartphone addiction	T1 Emotional abuse	0.249 (0.158, 0.339)	0.046	5.407***	0.167	11.793
T2 Smartphone addiction	T1 Emotional abuse	0.084 (−0.007, 0.174)	0.046	1.818	0.304	22.450
	T1 Anxiety	0.418 (0.327, 0.509)	0.046	9.003***		
T1 Anxiety	T1 Emotional neglect	0.255 (0.164, 0.346)	0.046	5.496***	0.130	8.850
T2 Smartphone addiction	T1 Emotional neglect	0.074 (−0.018, 0.166)	0.047	1.587	0.113	7.515
T2 Smartphone addiction	T1 Emotional neglect	−0.044 (−0.129, 0.041)	0.043	−1.015	0.300	22.045
	T1 Anxiety	0.463 (0.377, 0.550)	0.044	10.483***		

Note: ***$p < 0.001$.

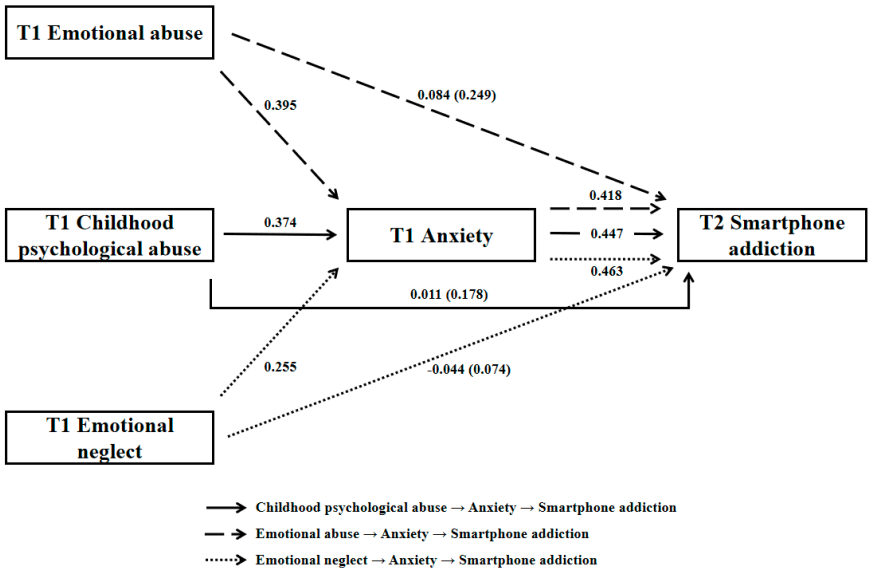

Figure 2: Mediating effect diagram.

3.4 Mediated Moderation Effect Test

After controlling for demographic variables (gender, age, only-child status, left-behind status, and parental educational level), Model 7 in the SPSS PROCESS macro was employed to test the moderated mediating effect. Here, T1 CPA, emotional abuse, and emotional neglect served as independent variables, T1 anxiety as the mediating variable, T1 PA as the moderating variable, and T2 SA as the dependent variable. The results (Table 4) showed that when PA was incorporated as a moderating variable, higher levels of PA were significantly associated with lower anxiety levels (β = −0.346, β = −0.341, β = −0.355; all $p < 0.001$). Meanwhile, the interaction effects between T1 CPA (including emotional abuse and emotional neglect) and T1 PA significantly attenuated adolescents' anxiety levels (β = −0.119, β = −0.105, β = −0.093; all $p < 0.05$). The simple slope analysis plots for these moderating effects are presented in Fig. 3.

Table 3: Analysis of the mediating effect of anxiety (N = 421).

Type of Effect	Effect Value	SE	95%CI
T1 Childhood psychological abuse → T1 Anxiety → T2 Smartphone addiction			
Total Effect	0.178	0.047	0.087, 0.270
Direct Effect	0.011	0.045	−0.078, 0.100
Indirect Effect	0.167	0.031	0.112, 0.231
T1 Emotional abuse → T1 Anxiety → T2 Smartphone addiction			
Total Effect	0.249	0.046	0.158, 0.339
Direct Effect	0.084	0.046	−0.007, 0.174
Indirect Effect	0.165	0.031	0.111, 0.231
T1 Emotional neglect → T1 Anxiety → T2 Smartphone addiction			
Total Effect	0.074	0.047	−0.018, 0.166
Direct Effect	−0.044	0.043	−0.129, 0.041
Indirect Effect	0.118	0.027	0.068, 0.177

Table 4: Tests of mediation and moderation effects (N = 421).

Outcome Variable	Predictive Variable	β (95%CI)	SE	*t*	R^2	F
T1 Anxiety	T1 Childhood psychological abuse	0.315 (0.230, 0.399)	0.043	7.299***	0.293	18.892
	T1 Physical activity	−0.346 (−0.439, −0.252)	0.048	−7.282***		
	T1 Childhood psychological abuse × T1 Physical activity	−0.119 (−0.208, −0.031)	0.045	−2.641**		
	T1 Emotional abuse	0.346 (0.262, 0.430)	0.043	8.106***	0.311	20.633
	T1 Physical activity	−0.341 (−0.430, −0.252)	0.045	−7.527***		
	T1 Emotional abuse × T1 Physical activity	−0.105 (−0.191, −0.019)	0.044	−2.340*		
	T1 Emotional neglect	0.201 (0.114, 0.289)	0.045	4.527***	0.229	13.531
	T1 Physical activity	−0.355 (−0.452, −0.258)	0.049	−7.219***		
	T1 Emotional neglect × T1 Physical activity	−0.093 (−0.186, −0.001)	0.047	−1.974*		

Note: *p < 0.05, **p < 0.01, ***p < 0.001.

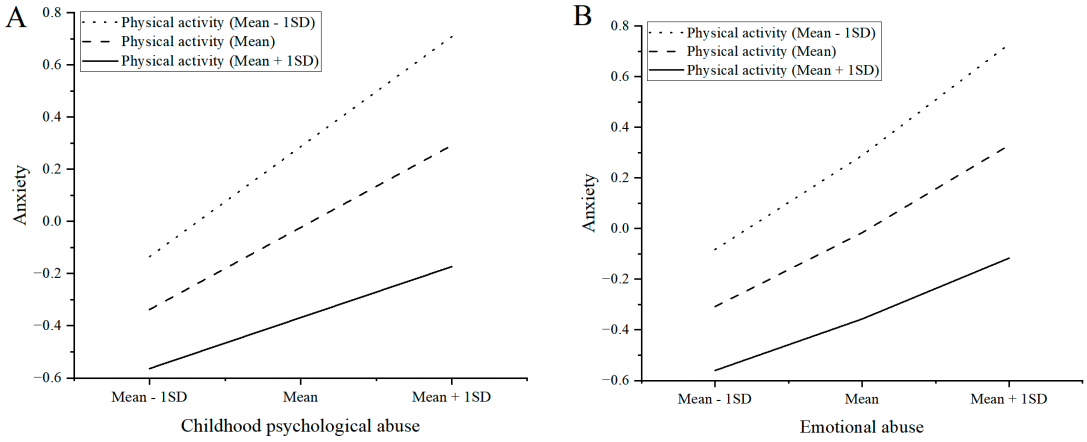

Figure 3: *Cont.*

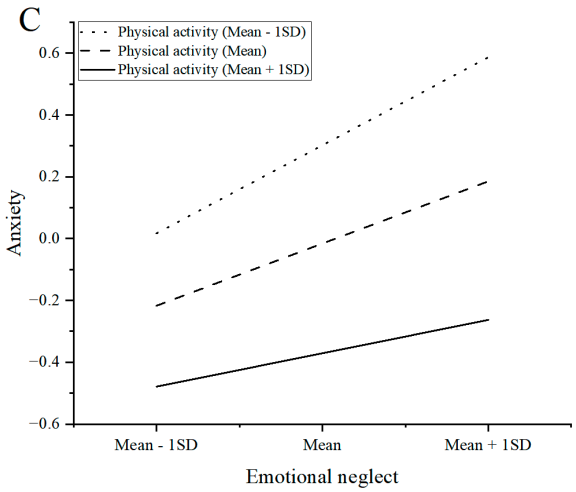

Figure 3: Moderating effect of physical activity. (**A**) Childhood psychological abuse; (**B**) Emotional neglect; (**C**) Emotional abuse.

4 Discussion

Using a 3-month longitudinal research design, the present study found that retrospective reports of CPA, emotional abuse, and emotional neglect not only directly predicted adolescent SA but also indirectly influenced SA through the full mediating effect of anxiety. Furthermore, PA partially mitigated the negative impact of CPA, emotional abuse, and emotional neglect on anxiety, thereby alleviating adolescent SA behaviors.

4.1 Childhood Psychological Abuse and Smartphone Addiction

The present study found that CPA (including emotional abuse and emotional neglect) was positively associated with adolescent SA, supporting Hypothesis 1. Importantly, the magnitude of this association was moderate (r = 0.229), suggesting that while CPA constitutes a meaningful risk factor, it represents one of several contributors to adolescent SA rather than a dominant or deterministic influence. This effect size is comparable to those reported in previous studies examining the links between adverse childhood experiences and digital addictive behaviors, where correlations typically range from small to moderate, depending on the type of maltreatment and behavioral outcome assessed [42]. Together, these findings suggest that psychological abuse exerts a lasting influence on adolescents' behavioral regulation while acting in concert with other psychological and contextual factors. Attachment theory suggests that early emotional interactions with caregivers play a foundational role in shaping individuals' expectations of interpersonal relationships and emotion regulation strategies [43]. Abusive or neglectful parenting practices may disrupt the development of secure attachment, leading to insecure attachment patterns characterized by heightened attachment anxiety or emotional withdrawal [44].

In this context, adolescents exposed to emotional abuse may become hypersensitive to negative evaluation and rejection, whereas those experiencing emotional neglect may develop chronic feelings of emotional deprivation. Although both pathways are linked to increased SA, they may reflect distinct psychological needs that smartphones temporarily fulfill [45]. Smartphones provide immediate access to social feedback, distraction, and perceived interpersonal connection, which may function as compensatory mechanisms for adolescents who lack emotional support in their offline environments. For emotionally abused adolescents, excessive smartphone use may serve as a means of regulating distress and counteracting

negative self-perceptions. For emotionally neglected adolescents, smartphones may offer a readily available substitute for unmet emotional needs, providing stimulation and a sense of connection that is otherwise absent. In this sense, SA may represent not only a maladaptive behavior but also a coping response to early relational adversity. Moreover, traumatic experiences of CPA can impair emotional regulation and cognitive functioning by disrupting neurodevelopmental processes [46]. Such impairments may increase adolescents' reliance on externally driven regulation strategies, including excessive smartphone use, particularly in emotionally demanding situations. This mechanism helps explain why psychological abuse, even in the absence of overt physical harm, can exert long-lasting effects on behavioral outcomes during adolescence. Taken together, these findings suggest that the association between CPA and SA reflects a complex interplay between early emotional adversity, attachment-related vulnerabilities, and maladaptive coping strategies. The moderate effect size underscores the importance of viewing SA not as a direct consequence of early abuse, but as an outcome embedded within broader developmental, emotional, and contextual processes shaped by childhood experiences.

4.2 The Mediating Role of Anxiety

T1 CPA (including emotional abuse and emotional neglect) was significantly associated with adolescents' T1 anxiety levels, which is consistent with previous research [47]. Prior studies have similarly indicated that adolescents exposed to psychologically abusive family environments are more vulnerable to anxiety-related difficulties during development [48]. Exposure to higher levels of psychological abuse has also been linked to increased avoidance tendencies and maladaptive emotional outcomes, including heightened anxiety [49]. Taken together, these findings suggest that CPA represents a salient emotional stressor that is closely associated with elevated anxiety during adolescence. Beyond replicating this well-established association, the present study provides further insight into the role of anxiety as a psychological pathway linking CPA to adolescent SA. Anxiety is typically characterized by persistent worry, heightened threat sensitivity, and difficulties in emotional regulation. Adolescents who grow up in emotionally abusive or neglectful environments may internalize chronic feelings of insecurity and hypervigilance, which are reflected in elevated anxiety levels. Such emotional states may, in turn, increase reliance on external coping strategies. Consistent with this interpretation, the current findings showed that anxiety was positively associated with adolescent SA, in line with prior research [22].

Importantly, anxiety should be understood as one of multiple potential internalizing mechanisms through which CPA may influence maladaptive technology use. Previous studies have suggested that broader emotion dysregulation, repetitive negative thinking such as rumination, and depressive symptoms also play important mediating roles in the links between adverse childhood experiences and problematic digital behaviors [50,51]. These mechanisms may coexist with anxiety or operate through partially overlapping pathways, reflecting the complex psychological sequelae of early emotional maltreatment. The present study focused specifically on anxiety due to its salience during adolescence and its theoretical relevance to coping-motivated smartphone use; however, future research would benefit from examining more comprehensive models that integrate multiple emotional and cognitive mediators. Importantly, these results should be interpreted with appropriate caution. CPA and anxiety were measured concurrently at T1, whereas SA was assessed prospectively at T2. Thus, while the model supports a prospective association in which baseline anxiety statistically accounts for the link between CPA and subsequent SA over a 3-month period, it does not constitute a fully longitudinal test of mediation. Rather than establishing definitive causal ordering, the findings are best understood as supporting a theoretically informed, prospective mediation framework in which anxiety functions as a proximal psychological correlate linking early

adverse experiences to later maladaptive technology use. Accordingly, Hypothesis 2 is supported within the constraints of the study design.

4.3 The Moderating Effect of Physical Activity

In this study, T1 PA functioned as a moderator in the first segment of the pathway connecting T1 CPA and adolescent T2 SA. It significantly and negatively predicted adolescents' T1 anxiety and notably weakened the predictive impact of T1 CPA on adolescents' T1 anxiety levels. Therefore, Hypothesis 3 has been verified. This outcome aligns with prior studies, which have shown that psychological abuse experienced in childhood can elicit diverse negative emotions (like anxiety and depression) in later development [52]. Physical exercise plays a critical role in sustaining the normal operation of the HPA axis in individuals. It can reduce or alleviate stress and tension levels, decrease negative emotions, and improve emotional states through various physiological and biochemical mechanisms. Additionally, engaging in PA can help individuals shift negative emotions, enhance self-esteem and self-efficacy, and promote the secretion of beneficial neurotransmitters [53]. Research also indicates that the type, amount, and frequency of exercise impact adolescents' participation in PA and their psychological health outcomes. Engaging in moderate to high-intensity aerobic physical activities over the long term can improve adolescents' mood and alleviate symptoms of anxiety. This type of exercise helps release beneficial chemicals such as endorphins and dopamine in the body, enhancing mood, boosting self-perception, and reducing anxiety levels. Therefore, encouraging adolescents to actively participate in appropriate types and intensities of PA is crucial for their psychological well-being [54]. Importantly, however, the moderation effect observed in the present study should be interpreted with appropriate caution. Although the interaction between PA and CPA in predicting anxiety was statistically significant, the interaction coefficients (ranging from −0.093 to −0.119) indicate a relatively modest effect size. This suggests that while PA may serve as a meaningful buffering factor, it is unlikely to fully offset the adverse emotional consequences associated with severe or persistent psychological abuse. Rather than functioning as a comprehensive protective mechanism, PA appears to operate as one contributory factor within a broader constellation of individual, familial, and social resources. Future intervention studies—particularly randomized controlled trials and longitudinal experimental designs—are needed to directly test whether structured PA programs can effectively reduce anxiety and, in turn, lower the risk of SA among adolescents exposed to CPA. Accordingly, PA should be viewed as a promising but complementary target within broader, multifaceted prevention and intervention frameworks.

In the hypothetical model of the present study, T1 CPA was positively associated with adolescents' T1 anxiety levels, which in turn positively predicted T2 SA behaviors. Within the tested longitudinal model over a 3-month period, T1 anxiety exhibited a full mediating effect in the association between T1 CPA and T2 SA. This finding should be interpreted as a statistically supported pathway within the specified model rather than as evidence of a definitive causal mechanism. As a moderating variable, T1 PA attenuated the association between T1 CPA and T1 anxiety, thereby weakening the indirect pathway from CPA to subsequent SA through anxiety. This result suggests that PA may function as a protective or buffering factor in the emotional processes linking psychological abuse to maladaptive behavioral outcomes. However, given the observational nature of the study, the mitigating role of PA should be interpreted with caution. Although prior research suggests that PA may help reduce anxiety and improve emotional well-being by enhancing mood and alleviating stress, the present findings do not establish PA as a causal intervention. Rather, they provide preliminary evidence that supports future intervention-based and experimental research to

examine whether promoting PA in school settings could help reduce anxiety and lower the risk of SA among adolescents exposed to CPA.

Despite the successful construction of a prospective moderated mediation model, several limitations of the present study should be acknowledged. First, the sample size was relatively modest and drawn from a single public middle school in Hunan Province using convenience sampling. Although China is often treated as a culturally homogeneous context, substantial regional differences exist in economic development, educational environments, and family structures. These contextual variations may influence adolescents' exposure to CPA as well as their patterns of smartphone use. Consequently, the generalizability of the findings is limited. Future research should employ larger samples and multi-site, cross-regional designs to better capture heterogeneity within the Chinese adolescent population. Second, the study relied exclusively on self-report questionnaires, which may be subject to recall bias and shared method variance. This concern is particularly relevant for retrospective assessments of CPA and self-evaluations of emotional states and behavioral tendencies. Future studies would benefit from incorporating multi-informant approaches, such as reports from parents, teachers, or peers, as well as objective or observational indicators, to enhance measurement validity. Third, several measurement-related limitations warrant consideration. SA was assessed using an adapted version of the Social Network Usage Scale rather than a standardized SA instrument. Although this adaptation was intended to enhance contextual relevance for Chinese adolescents—whose smartphone use is largely centered on social networking—it may not fully capture the multidimensional nature of SA, thereby constraining construct validity. In addition, the internal consistency of the PA Rating Scale–3 (PARS-3) was relatively modest. While such reliability is often considered acceptable for brief behavioral measures, limited internal consistency may have attenuated the observed effects involving PA, particularly interaction effects. Accordingly, findings related to PA should be interpreted with caution, and future research is encouraged to employ more robust and objective assessments, such as accelerometer-based measures. Fourth, an important limitation concerns the temporal structure of the mediation model. Although SA was assessed prospectively at T2, CPA, anxiety, and PA were all measured concurrently at T1. As a result, the mediating role of anxiety and the moderating role of PA cannot be considered fully longitudinal. Alternative directional pathways—such as anxiety influencing PA levels or current emotional states shaping retrospective reports of abuse—cannot be ruled out. Therefore, the proposed pathways should be interpreted as theoretically informed rather than as evidence of definitive causal sequencing. Future research should adopt multi-wave designs with repeated measurements of all key variables to more rigorously test developmental trajectories. Fifth, the present study focused on the overall model and did not conduct subgroup or stratified analyses. Although several demographic variables were statistically controlled, potential differences across gender, socioeconomic status, or family structure were not explicitly examined. It is plausible that the impact of CPA on anxiety, or the buffering effect of PA, varies across these subgroups. Future studies should explore such heterogeneity to identify particularly vulnerable populations. Finally, from a model-level perspective, although the final model explained 29.8% of the variance in SA, a substantial proportion of variance remained unexplained. This suggests that other factors—such as peer influence, academic stress, personality traits, or broader family dynamics—likely play important roles in shaping adolescents' smartphone use behaviors. In addition, while several demographic covariates were included, other potential confounding factors (e.g., household income, parental occupation, or more nuanced indicators of family socioeconomic status) were not assessed, raising the possibility of residual confounding. Future research incorporating a broader range of contextual variables would help clarify the robustness and boundary conditions of the proposed moderated mediation model.

5 Conclusions

Using a two-wave prospective design, this study examined the associations among CPA, anxiety, PA, and adolescent SA. The findings indicate that CPA is positively associated with SA, with anxiety serving as a key psychological correlate linking early adverse experiences to later problematic smartphone use. In addition, PA appears to buffer the association between CPA and anxiety. Although the proposed pathways are theory-driven rather than fully causal, the results highlight the importance of emotional processes and health behaviors in adolescent digital use. Interventions that address anxiety and promote PA may help reduce the risk of SA among vulnerable adolescents.

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