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The relationship between physical activity and social network site addiction among adolescents: the chain mediating role of anxiety and ego-depletion

Jiale Wang[1], Ting Xiao[1], Yang Liu[1*], Zhenhua Guo[1] and Zhenxiu Yi[2]

Abstract

Background and objectives Physical activity is associated with social network site addiction in adolescents, yet the mechanisms remain unclear. This study examines whether anxiety and ego-depletion mediate this relationship.

Methods A survey was conducted among 1,174 Chinese adolescents (614 boys, 560 girls; mean age = 12.59, SD = 1.13). Physical activity was assessed with a single item on moderate-to-vigorous exercise in the past 7 days. Social network site addiction, anxiety, and ego-depletion were measured using validated self-report questionnaires. Descriptive statistics, correlation analyses, and a chained mediation model were employed.

Results Physical activity was negatively correlated with social network site addiction (r = -0.165, $p < 0.001$), anxiety (r = -0.121, $p < 0.001$), and ego-depletion (r = -0.119, $p < 0.001$). Anxiety was positively correlated with ego-depletion ($r = 0.574$, $p < 0.001$) and social network site addiction ($r = 0.388$, $p < 0.001$). Ego-depletion was positively associated with social network site addiction ($r = 0.456$, $p < 0.001$). Anxiety and ego-depletion sequentially mediated the relationship between physical activity and social network site addiction.

Conclusion This study clarifies the psychological mechanisms linking physical activity and social network site addiction in adolescents, identifying anxiety and ego-depletion as key mediators. The findings emphasize the need to target these factors for more effective interventions.

Keywords Physical activity, Social network site addiction, Anxiety, Ego-depletion, Adolescents

*Correspondence:
Yang Liu
ldyedu@foxmail.com
[1]School of Sports Science, Jishou University, Jishou, China
[2]School of Sports Training, Chengdu Sport University, Chengdu, China

Introduction

Social network site addiction

With the rapid development of smart electronic devices and social media, social networks have gradually become an integral part of daily life, serving as vital platforms for individuals to access information and enhance social interactions [1]. Recent statistics estimate that approximately 62.3% of the global population uses social networks, with the average daily usage time being 2 h and 23 min [2]. While the widespread use of social networks brings convenience, spending excessive time on these platforms may lead to negative consequences, such as over-reliance and addiction [3]. Research indicates that the internet penetration rate among adolescents in China is 98.5% [4], with a social network usage rate of 95.9% [5]. The adolescent stage emphasizes the formation of social relationships, and developing close interpersonal connections is a key developmental task [6]. The adolescent stage emphasizes the formation of social relationships, and developing close interpersonal connections is a key developmental task [7]. However, if social networks are not used moderately, adolescents are more susceptible to social network site addiction compared to other demographics [8]. The addiction syndrome model [9] posits that social network site addiction is a complex and multifaceted phenomenon, generally believed to arise from distal factors (such as psychosocial influences and underlying vulnerabilities) that contribute to proximal factors (like negative events), leading to excessive use behaviors and ultimately reinforcing addiction [10]. Defined as excessive preoccupation with social networking sites, this form of addiction is characterized by a strong motivation to log in or use these platforms, often at the expense of other social activities, academic/work obligations, interpersonal relationships, and/or psychological well-being. Symptoms include preoccupation with social network activities, tolerance (the need for increased engagement to achieve pleasure), withdrawal (unpleasant feelings upon cessation), persistence despite attempts to reduce usage, escapism (using social networks to evade negative emotions), ongoing engagement despite problems, deception about time spent online, neglecting other activities, and conflicts with others due to social network engagement [11]. Social network site addiction can lead to excessive, compulsive use of these platforms, disrupting daily life and negatively impacting physical, social, and psychological health, contributing to issues such as anxiety, depression, and suicidal behavior [10][12-15]. Recently, social network site addiction has emerged as a pressing mental health issue among adolescents worldwide. There is an urgent need to investigate the factors associated with this addiction to inform preventive and intervention strategies aimed at reducing its prevalence in this population.

The relationship between physical activity and social network site addiction

Numerous studies have demonstrated a close relationship between physical activity and social network site addiction among adolescents [13]. Physical activity is defined as any voluntary bodily movement produced by skeletal muscles that requires energy expenditure, ranging from light activities in daily life to structured exercise, applicable across various intensities and durations [14, 15]. Regular physical activity is crucial for promoting a healthy lifestyle and has positive effects on cardiovascular, respiratory, neurological, and musculoskeletal systems, while also improving mood and reducing the risk of lifestyle-related diseases [16]. Conversely, reduced physical activity combined with increased dependence on internet use exacerbates the negative impacts of a sedentary lifestyle, ultimately harming overall health and quality of life over time [17]. Huang and Chen further established a significant negative correlation between physical activity and social network site addiction [13, 18], noting that physical activity can also alleviate symptoms of social network site addiction [19]. As a comprehensive intervention approach, physical activity can assist adolescents in mitigating their social network site addiction behaviors from physiological, psychological, and social perspectives [20] [16, 17]. A meta-analysis concluded that physical activity interventions can significantly reduce social network site addiction [21]. Therefore, based on this review, this study hypothesizes a negative correlation between physical activity and social network site addiction among adolescents.

The mediating effect of anxiety

In the relationship between physical activity and social network site addiction among adolescents, anxiety may serve as a significant mediating factor [22]. According to the Global Burden of Disease Study, anxiety disorders are the most prevalent mental disorders worldwide [23]. Since anxiety typically manifests in early adolescence and young adulthood [24], and the majority of affected adolescents do not receive appropriate mental health treatment [25], anxiety has become a pressing public health challenge among this demographic [26]. As a high-risk psychological disorder in adolescents, anxiety is characterized by excessive fear or worry about specific situations (such as panic attacks or social interactions), difficulty concentrating, and challenges in decision-making [27]. Moreover, anxiety disorders increase the risk of behavioral dependence [18-233] and substance use disorders, as well as suicidal thoughts and behaviors [28]. Research indicates that physical activity is an effective method for regulating mental health issues among adolescents [29], and active participation in physical activity is negatively correlated with the risk of experiencing

anxiety symptoms [30–32]. Specifically, individuals with higher levels of physical activity are 21% less likely to develop anxiety compared to those with lower levels [33]. Additional meta-analyses have also found a strong association between low physical activity and increased anxiety risk, revealing that low cardiorespiratory fitness (CRF)—a marker of insufficient physical activity—correlates with a higher risk of anxiety compared to high CRF [34]. Previous studies have demonstrated that physical activity (primarily through exercise) exerts anxiolytic effects through various biological and psychosocial pathways. Physical activity induces multiple interdependent changes in the brain that create an environment conducive to anxiety prevention. For example, it stimulates neurotrophic factors, triggering downstream cellular processes or activating the neuroendocrine system [35], leading to lasting structural changes in the brain that enhance the functioning of regions associated with anxiety [36]. Several psychosocial factors, including self-esteem, self-efficacy, and social support, accompany these biological changes and may interact with them, mediating the effects of physical activity on anxiety [36]. Prior research has also confirmed that physical activity can moderate the relationship between various variables and anxiety [37, 38].

Furthermore, increasing evidence supports the significant role of anxiety in the development of social network site addiction [39–43]. The mood enhancement hypothesis posits that individuals experiencing unpleasant emotions are more likely to engage in leisure activities, including social networking, as a means of stress relief [44]. In this context, adolescents with anxiety may seek to alleviate their emotional symptoms by spending more time on social networks and other recreational activities [45]. Although anxious adolescents crave social interaction to fulfill their feelings of loneliness and emotional needs, they often avoid real-life interpersonal interactions due to fear of negative evaluation [46]. The threatening stimuli that induce anxiety (such as visual and verbal responses from others) are significantly limited on social networks [47]. Consequently, individuals with anxiety can more easily present themselves online [48]. In face-to-face interactions, anxious individuals anticipate negative evaluations and rejection from others, which can lead them to immerse themselves in social networks to avoid these situations [49, 50]. Studies have found that adolescents with psychosocial issues (such as anxiety and depression) prefer online socializing over face-to-face interactions, as social networks compensate for their social skill deficits [51, 52][24]. This preference for online social connections may lead to compulsive engagement with social networks, ultimately resulting in social network site addiction [53]. The I-PACE model also identifies anxiety as a crucial potential factor in social network site addiction [54]. Research has revealed a direct correlation between anxiety and the severity of social network site addiction [55, 56], with anxiety increasing the risk of social network site addiction among Chinese adolescents [41, 57]. Meta-analyses have further confirmed that anxiety is positively correlated with social network site addiction, indicating that anxious adolescents are at a higher risk for this addiction [58]. Based on this review, the current study hypothesizes that anxiety mediates the relationship between physical activity and social network site addiction among adolescents.

The intermediary role of ego-depletion

In addition to anxiety, ego-depletion may also serve as a critical mediating factor between physical activity and social network site addiction among adolescents. Ego-depletion refers to the consumption of self-control or willpower, which utilizes conscious mental resources (libido). When these resources are continuously used without respite, they may become exhausted (the term "self" is used here in a psychoanalytical context rather than colloquially) [59]. When mental energy is low, self-control is often impaired, which is considered a state of ego-depletion. Specifically, experiencing ego-depletion compromises one's ability to exert control in the future [60]. The exercise of self-control enables individuals to align their responses with certain standards, such as ideals, values, morals, and societal expectations, while supporting the pursuit of long-term goals. Conversely, various behavioral problems, such as non-substance addiction [25-27], eating disorders, and domestic violence, are associated with a lack of self-control [61]. According to the strength model of self-control, self-control capacity comprises baseline ability and the ability to withstand depletion [62]. Previous studies have shown that physical activity can enhance resistance to ego-depletion [63]. Participants engaged in physical activity demonstrated significant improvements in their ability to withstand depletion [64], with 6 months of high-intensity aerobic exercise improving baseline self-control in women [65]. Aerobic exercise has also been shown to enhance cognitive executive control in elderly individuals, children, and certain clinical populations [66].

Moreover, increasing evidence supports the significant role of ego-depletion in the development of social network site addiction among adolescents. Ego-depletion is a key risk factor for social adaptation and mental health [67]. When individuals experience ego-depletion, they may become psychologically fatigued, leading to unconscious or automatic behaviors, such as internet addiction and alcohol dependence [68]. Low self-control capacity has been identified as one of the primary causes of social network site addiction among adolescents [69], and low self-control is a predominant state of ego-depletion [60].

Previous research has confirmed that low ego-depletion acts as a protective factor against social network site addiction [70]. As described in ego-depletion theory, when an individual's self-control resources are exhausted, they enter a state of ego-depletion, making it difficult to suppress undesirable behaviors, thereby leading to social network site addiction [71, 72]. Empirical studies have also found that ego-depletion can promote approach tendencies and reward-seeking behaviors [73]. Given the multifunctionality of social networks, which can be utilized for various activities, individuals experiencing ego-depletion may be particularly drawn to these platforms and prone to excessive use. This could ultimately result in addiction to social networks. Therefore, based on this review, we hypothesize that ego-depletion mediates the relationship between physical activity and social network site addiction.

Chained mediating role of anxiety and ego-depletion

Increasing evidence supports the significant role of anxiety in the development of ego-depletion. Research has shown that anxiety, as a negative emotion, can lead to increased levels of ego-depletion [74] and diminish self-control abilities. According to the Conservation of Resources Theory, anxiety compels individuals to prioritize resource conservation, resulting in reduced investment in self-control among adolescents [75]. Anxiety drives them to focus their resources on coping with perceived threats, thereby diminishing attention to other self-control tasks and accelerating ego-depletion. Moreover, individuals experiencing anxiety tend to concentrate on their internal feelings, which heightens psychological burdens and depletes mental resources, ultimately contributing to ego-depletion [72]. Studies indicate that anxiety can prompt individuals to ruminate, immersing them in negative emotional states that further diminish self-control [76]. Neurobiological research has also provided evidence that anxiety increases ego-depletion; for example, one study found that anxiety signaling pathways negatively impact the structure and function of the prefrontal cortex, a critical region for self-control and decision-making [77]. Based on this review, we hypothesize that anxiety and ego-depletion play a chain-mediated role in the relationship between physical activity and social network site addiction among adolescents.

In summary, previous studies have explored the relationship and predictive effects between physical activity and social network site addiction; however, little is known about the underlying mechanisms connecting the two. To further enrich research in this area and investigate the internal psychological mechanisms, this study introduces anxiety and ego-depletion as mediating variables. Consequently, we have developed a hypothetical path model (Fig. 1).

Methods

Participants

In March 2024, the research team conducted a cross-sectional survey among adolescents from three middle schools in Hunan Province, selected through convenience sampling based on their willingness to participate. Before the survey, the research team provided class teachers with detailed information, including the purpose and content of the study. With consent, the electronic questionnaire link was shared in class group chats by the teachers. An informed consent form for both participants and their guardians was included on the first page of the questionnaire. Only those who clicked "Agree" could proceed to complete the survey, while those who selected "Decline" were automatically exited from the page, ensuring voluntary participation and adherence to informed consent principles. The survey was anonymous to protect participants' privacy and reduce social desirability bias. Participation was entirely voluntary, and respondents could withdraw at any time without providing a reason. The estimated time to complete the questionnaire was approximately 20 min. Ethical approval for this study was obtained from the medical ethics committee of the authors' affiliated institution, and all procedures followed ethical guidelines. Invalid questionnaires, such as those with patterned responses or abnormal completion times, were excluded. A total of 1,288

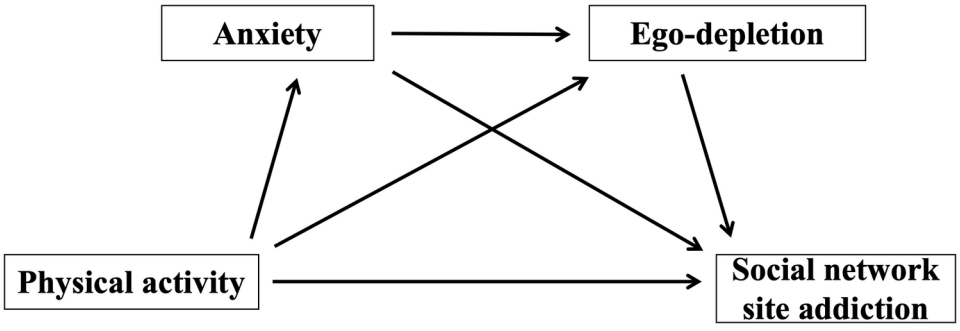

Fig. 1 Hypothesized a mediation model

questionnaires were collected, and 1,174 valid responses were retained (614 boys, 560 girls), with a mean age of 12.59 years (SD = 1.13).

Measures

Physical activity

Physical activity was assessed with a single item: "In the past 7 days, how many times did you engage in exercise or at least 20 minutes of physical activity that made you sweat or breathe hard?" Response options ranged from 0 days to 7 days [78]. This tool has been utilized in previous research [79][26].

Social network site addiction

The questionnaire used to assess social network site addiction was adapted and validated by Wei Qi, based on the scale developed by Elphinston et al. [80, 81]. This scale consists of 8 items that evaluate aspects such as feelings and frequency of social network usage, impacts on daily life (including study, social interactions, and sleep), and the presence of withdrawal symptoms. Each item is rated on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The total score across items represents the severity of social network site addiction among adolescents, with scores ranging from 8 to 40; higher scores indicate greater addiction severity. The Cronbach's α for this sample was 0.867.

Anxiety

Anxiety levels in adolescents were assessed using the anxiety subscale from the Depression-Anxiety-Stress Scale-21, developed by Lovibond et al. [82] and revised by Gong et al. [83]. The anxiety subscale includes 7 items, rated on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree). The total score indicates the level of anxiety, with scores ranging from 7 to 28; higher scores reflect greater anxiety. The Cronbach's α for this sample was 0.828.

Ego-depletion

Ego-depletion was measured using a scale developed by Lin and Johnson [84], based on research by Twenge et al. [85]. This scale comprises 5 items and employs a 5-point Likert scale, where 1 indicates strong disagreement and 5 indicates strong agreement. This measurement tool has been validated and widely used in previous studies [86–88]. The Cronbach's α for this sample was 0.857.

Data processing and analysis

Statistical analyses were conducted using SPSS 26.0. Initially, a common method bias test was performed, with a threshold of less than 40% indicating no significant common method bias in the study [89]. Subsequently, descriptive statistics and correlation analyses were conducted for the demographic characteristics of the participants and the main variables. Prior to further analysis, data for the main variables were standardized. To test our hypotheses, we employed the PROCESS plugin (Model 6) in SPSS to examine the relationship between physical activity and social network site addiction, exploring the mediating roles of anxiety and ego-depletion [90]. This analysis involved 5,000 bootstrap resampling iterations to assess model fit and estimate 95% confidence intervals (95% CI), enhancing the robustness of our data analysis [91]. Throughout the analysis, gender and grade level were controlled as covariates, with a significance level set at 0.05.

Results

Common method bias test

The common method bias test for this study revealed three factors with eigenvalues greater than 1. The first factor accounted for 30.24% of the total variance, which is below the threshold of 40%, indicating that there is no significant risk of common method bias in this study.

Descriptive analysis

As shown in Table 1, significant differences were found in physical activity ($t = 8.72$, $p < 0.001$), ego-depletion ($t = -5.80$, $p < 0.001$), and social network site addiction ($t = -4.48$, $p < 0.001$) based on gender. Specifically, male adolescents scored higher in physical activity, while girls scored higher in anxiety, ego-depletion, and social network site addiction. Additionally, there was a significant

Table 1 Describes the analysis

Variables	Physical activity		Anxiety		Ego-depletion		Social network site addiction	
	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
Boys	4.11	2.11	12.88	4.78	12.16	4.81	16.08	6.85
Girls	3.07	1.99	13.85	5.05	13.89	5.32	17.98	7.57
t	8.72***		−3.38**		−5.80***		−4.48***	
Only child	3.42	2.06	13.61	4.86	11.96	5.00	16.47	7.22
Non-Only child	3.67	2.13	13.27	4.92	13.28	5.14	17.14	7.27
t	−1.73		0.10		−3.71***		−1.32	

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

Table 2 Correlation analysis

Variables	1	2	3	4
1 Age	-			
2 Physical activity	0.161***	-		
3 Anxiety	0.089**	−0.121***	-	
4 Ego-depletion	0.204***	−0.119***	0.574***	-
5 Social network site addiction	0.152***	−0.165***	0.388***	0.456***

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

difference in ego-depletion (t = -3.02, $p<0.001$) based on whether the adolescents were only children. Only children scored lower in ego-depletion compared to non-only children.

Correlation analysis

Table 2 shows that physical activity was significantly negatively correlated with anxiety (r = -0.121, $p<0.001$), ego-depletion (r = -0.119, $p<0.001$), and social network site addiction (r = -0.165, $p<0.001$) among adolescents. Anxiety was positively correlated with both ego-depletion ($r=0.574$, $p<0.001$) and social network site addiction ($r=0.388$, $p<0.001$). Furthermore, ego-depletion showed a significant positive correlation with social network site addiction ($r=0.456$, $p<0.001$). These findings suggest that these psychological and behavioral variables are interrelated within the adolescent sample.

Mediation model testing

After controlling for demographic variables, the results presented in Table 3; Fig. 2 indicate a significant negative association between physical activity and adolescent social network site addiction (β = -0.170, $p<0.001$). Even after introducing the mediating variables, the direct association remained significant (β = -0.110, $p<0.001$). Moreover, in the mediation model, physical activity was significantly and negatively associated with anxiety (β = -0.118, $p<0.001$), and anxiety was significantly and

Table 3 Mediation model test

Outcome variables	Predictor variables	β	SE	t	R^2	F
Social network site addiction	Physical activity	−0.170	0.029	−5.759***	0.070	22.108***
	Gender	0.104	0.029	3.557***		
	Age	0.187	0.029	6.459***		
	Only child	0.001	0.029	0.398		
Anxiety	Physical activity	−0.118	0.030	−3.931***	0.035	10.540***
	Gender	0.083	0.030	2.796		
	Age	0.123	0.029	4.165***		
	Only child	−0.048	0.029	−1.633		
Ego-depletion	Physical activity	−0.057	0.024	−2.373*	0.381	143.686***
	Anxiety	0.545	0.023	23.265***		
	Gender	0.107	0.024	4.474***		
	Age	0.160	0.024	6.729***		
	Only child	0.095	0.023	4.035***		
Social network site addiction	Physical activity	−0.110	0.027	−4.121***	0.251	65.219***
	Anxiety	0.183	0.031	5.867***		
	Ego-depletion	0.312	0.032	9.698***		
	Gender	0.041	0.027	1.547		
	Age	0.094	0.027	3.504***		
	Only child	−0.001	0.026	−0.049		

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

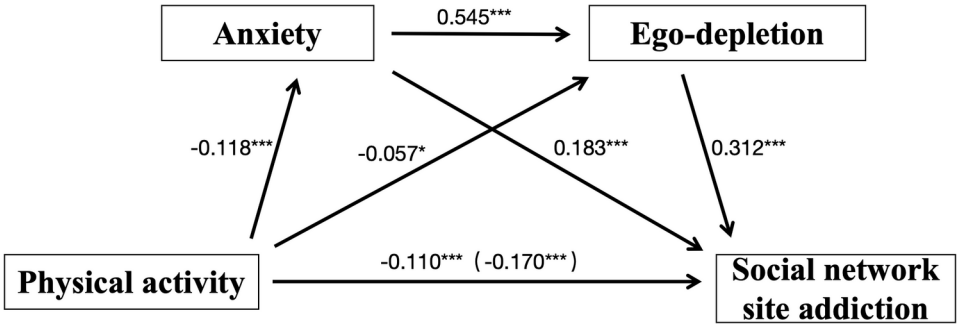

Fig. 2 Chain mediation model diagram

Table 4 Mediation model path analysis

Intermediate path	Effect size	SE	Bootstrap 95% CI	Proportion of mediating effect
Total effect	−0.170	0.029	−0.227,−0.112	100%
Total direct effect	−0.110	0.027	−0.162,−0.058	67.50%
Total indirect effect	−0.060	0.013	−0.087,−0.009	35.29%
Physical activity→Anxiety→Social network site addiction	−0.022	0.007	−0.038,−0.009	12.94%
Physical activity→Ego-depletion→Social network site addiction	−0.018	0.008	−0.034,−0.003	10.56%
Physical activity→Anxiety→Ego-depletion→Social network site addiction	−0.020	0.006	−0.033,−0.009	11.76%

positively associated with social network site addiction (β = 0.183, $p < 0.001$). Physical activity was also significantly and negatively related to ego-depletion (β = -0.057, $p < 0.05$), and ego-depletion showed a significant positive association with social network site addiction (β = 0.312, $p < 0.001$). Additionally, a significant chained association was observed from physical activity to social network site addiction via both anxiety and ego-depletion (β = 0.545, $p < 0.001$). The specific proportions of each indirect path are summarized in Table 4.

Table 4 shows that the confidence intervals for the direct association between physical activity and social network site addiction, as well as for the indirect associations through anxiety and ego-depletion, do not include zero. This indicates that physical activity is significantly associated with lower levels of social network site addiction, both directly and indirectly via anxiety and ego-depletion. The total direct effect (-0.110) has a 95% confidence interval of [-0.162, -0.058], and the total indirect effect (-0.060) has a 95% confidence interval of [-0.087, -0.009]. Specifically, the indirect path through anxiety (-0.022) has a 95% confidence interval of [-0.038, -0.009], the path through ego-depletion (-0.018) has a 95% confidence interval of [-0.034, -0.003], and the chain mediation effect via both anxiety and ego-depletion (-0.020) has a 95% confidence interval of [-0.033, -0.009]. These effects respectively account for 67.50%, 35.29%, 12.94%, 10.56%, and 11.76% of the total effect (-0.170; 95% CI = [-0.227, -0.112]). These results suggest that anxiety and ego-depletion may be important psychological pathways in the association between physical activity and social network site addiction. A detailed path model is presented in Fig. 2. However, given the cross-sectional nature of the study, these results should be interpreted as associations rather than causal effects.

Discussion

This study explores the interrelationships among physical activity, social network site addiction, anxiety, and ego-depletion in adolescents. Additionally, we discuss the mediating roles of anxiety and ego-depletion in detail. Our findings indicate significant negative correlations between physical activity and both social network site addiction and anxiety, while anxiety is positively correlated with both ego-depletion and social network site addiction, all achieving statistical significance. After controlling for demographic variables, both anxiety and ego-depletion were found to mediate the relationship between physical activity and social network site addiction, with these two factors functioning as sequential mediators, thereby validating our initial hypothesis.

This study demonstrates that physical activity is significantly negatively associated with social network site addiction, a finding corroborated by other related research [13, 37, 92]. The mechanisms through which physical activity affects social network site addiction are complex and may involve a range of neurobiological and psychosocial processes. Neurobiological mechanisms could include neuroplasticity and gut microbiota, where disruptions in neuroplastic pathways may underlie the pathophysiology of social network site addiction [93]. Physical activity may enhance neuroplasticity by promoting neurogenesis [94] and increasing synaptic plasticity [95]. Furthermore, dysfunction in the gut microbiota-gut-brain axis is considered a fundamental basis for substance addiction [96], with physical activity potentially alleviating social network site addiction by reducing the abundance of Betaproteobacteria and Sutterellaceae and altering lipopolysaccharide secretion levels [97]. Prior studies have also indicated that physical activity aligns with the explanatory principles of authoritative models of social network site addiction and can serve as an effective preventive and intervention strategy [98]. The psychosocial mechanisms by which physical activity mitigates social network site addiction can be interpreted through cognitive-behavioral models. These models suggest that significant impairments in specific cognitive domains may exacerbate symptoms of social network site addiction [99]. Research has established a moderate positive correlation between physical activity and cognitive functioning [100]. When physical activity involves cognitively demanding coordination, it can enhance cognitive performance, which is critical for various cognitive operations [101]. Collectively, this evidence supports our hypothesis that physical activity is significantly negatively correlated with social network site addiction in adolescents.

Our study reveals that anxiety mediates the relationship between physical activity and social network site addiction, aligning with our initial hypothesis. Previous

research has found a strong negative correlation between physical activity and anxiety in adolescents [102, 103]. The relationship between anxiety and social network site addiction has also been robustly demonstrated [104, 105], including studies within the Chinese context [106]. This relationship between physical activity and anxiety can be explained through several mechanisms. Individuals with anxiety often have lower self-esteem, and the relationship between self-esteem and anxiety can be cyclical; poor self-esteem can amplify anxiety symptoms [107]. The exercise and self-esteem model [108] emphasizes that increases in self-esteem are crucial for the mood-enhancing effects of physical activity, and structural equation modeling has indicated that self-esteem or body self-concept mediates the relationship between physical activity and anxiety [109]. Low self-efficacy can create a vicious cycle where individuals do not pursue achievable goals or tasks, leading to feelings of frustration and lower self-efficacy, which may exacerbate anxiety symptoms [110]. Physical activity can enhance self-efficacy, which may translate to other areas and mitigate anxiety symptoms [30]. Recent systematic reviews in neurobiology suggest that physical activity may reduce the risk of anxiety by increasing hippocampal plasticity, facilitating serotonin metabolism, and enhancing synaptic plasticity [111], as well as increasing the circulation of various neurotrophic factors [112].

Additionally, anxiety is often characterized by negative emotions, and many adolescents with anxiety tend to be more introverted and less willing to engage in peer communication. These individuals may be more inclined to turn to social networks as a means of emotional relief, which is associated with increased dependence on internet use [113]. According to the social compensation theory [114], individuals experiencing emotional distress may be more likely to seek support through online interactions and use social networks to alleviate negative feelings or cope with difficulties in their offline lives. Such coping behaviors are associated with higher levels of social network use, which may in turn coincide with further stress and anxiety. This cycle of emotional distress and compensatory online behavior may be related to elevated social network site addiction. Importantly, the current study's cross-sectional design does not allow for causal conclusions; the observed associations are consistent with prior findings from both cross-sectional and longitudinal research in addiction psychology [115, 116], but should be interpreted cautiously as correlational patterns rather than evidence of directional effects.

The findings of this study support the hypothesis that ego-depletion mediates the relationship between physical activity and social network site addiction in adolescents. Numerous studies have identified a positive correlation between physical activity and self-control in adolescents [117], with declines in self-control considered indicative of ego-depletion. One study found that five weeks of aerobic exercise enhanced self-control following ego-depletion [63]. These results confirm that physical activity can serve as a potentially effective intervention for enhancing self-control among adolescents experiencing ego-depletion.The relationship between physical activity and ego-depletion may be explained through several mechanisms: (1) The glucose hypothesis of ego-depletion posits that self-control relies on brain energy, primarily sourced from glucose [118]. During ego-depletion, glucose levels in the brain decrease, impairing cognitive function and self-control. Although some studies have raised doubts about this hypothesis, recent experiments have demonstrated that simply tasting (but not swallowing or consuming) sugary beverages can reverse the effects of resource depletion [119]. Physical activity effectively enhances the body's glucose utilization efficiency and restores brain energy levels through increased metabolism [120]. Thus, we hypothesize that regular physical activity may help adolescents recover more quickly after tasks that deplete willpower by maintaining stable glucose levels, thereby reducing the effects of ego-depletion. (2) Prior research has identified heart rate variability (HRV) as a marker of ego-depletion and an indicator of self-control prior to task engagement [121]. A lack of physical activity is associated with reduced resting HRV, while athletes typically exhibit higher HRV [122]. Physical activity may enhance control over HRV [123]. (3) Engaging in physical activity increases dopamine release in the brain, aiding impulse regulation and enhancing motivation and self-control in adolescents [124]. Regular physical activity may also strengthen sensitivity to dopamine receptors over the long term, improving adolescents' ability to control immediate rewards and reduce ego-depletion [125]. (4) Long-term physical activity may enhance connections between neurons in the prefrontal cortex, thereby improving cognitive control and planning abilities in adolescents, which can mitigate the depletion of self-control and enhance self-regulation when facing challenges and temptations [126]. (5) Participation in physical activities, particularly team sports, can bolster adolescents' social support networks and sense of belonging [127]. These positive social relationships provide emotional support and role modeling, which can help adolescents cope with stress and impulses by offering additional psychological resources. The presence of social support contributes to lowering psychological burdens, reducing ego-depletion, and enhancing the capacity to resist external temptations [128].

Furthermore, the positive correlation found between ego-depletion and social network site addiction in this study aligns with previous research [129, 130]. Risk factors for social network site addiction among adolescents

include interpersonal difficulties [131], lack of social support [132], depression, and attention-deficit/hyperactivity disorder (ADHD) [133]. Ego-depletion can exacerbate these risk factors. Interpersonal interactions require substantial self-regulation and control, including impulse control, emotion management, and understanding others' feelings and intentions. These processes depend on individuals' self-control resources [134]. When individuals experience ego-depletion, their self-control resources are diminished, making effective social interaction challenging and potentially increasing the risk of social network site addiction. In summary, the evidence supports our hypothesis that ego-depletion serves as a mediator in the relationship between physical activity and social network site addiction among adolescents.

Additionally, our results indicate a positive correlation between anxiety and ego-depletion, suggesting that both anxiety and ego-depletion function as chain mediators between physical activity and social network site addiction in adolescents. Physical activity not only directly influences social network site addiction but also exerts an indirect effect through anxiety and ego-depletion. Prior studies have similarly demonstrated a positive correlation between anxiety and ego-depletion [74, 135]. When individuals encounter negative emotions, they may deplete their limited self-control resources to manage these feelings [136]. This implies that anxiety-induced negative emotions and cognitions consume individuals' limited psychological energy or self-control resources, leading to ego-depletion [137]. Anxiety can lead adolescents to exhibit withdrawal behavior in social situations [138]. Anxious individuals often feel a sense of pressure or threat during interactions with others, prompting them to reduce social activities. This lack of social interaction means they miss a crucial pathway for resource restoration, as social support systems are vital for emotional regulation and replenishing self-control resources [139]. As anxious adolescents gradually isolate themselves from society, their self-control resources are further depleted, making it difficult to obtain support from others. Moreover, previous neurobiological studies have indicated that anxiety triggers stress responses by activating the hypothalamic-pituitary-adrenal (HPA) axis, resulting in the release of stress hormones such as cortisol [140]. Prolonged elevated cortisol levels can damage neural structures in the brain, including the hippocampus and prefrontal cortex, impairing functions related to self-control and emotional regulation [141]. The stress responses triggered by anxiety continuously deplete self-control resources, making adolescents more susceptible to states of ego-depletion. In summary, we confirm the existence of a chain mediation effect of anxiety and ego-depletion in the relationship between physical activity and social network site addiction among adolescents, supporting our final hypothesis.

This study enriches the existing literature by delving deeper into the relationship between physical activity and social network site addiction among adolescents, an area of increasing concern in the digital age. By incorporating anxiety and ego-depletion as sequential mediators, the research sheds light on the internal emotional and cognitive mechanisms through which physical activity may influence adolescents' engagement in problematic online behaviors. These mediating factors—though recognized in broader psychological literature—have been relatively underexplored in the context of technology-related addictions, especially within adolescent populations. Although the cross-sectional design of the study limits the ability to establish definitive causal relationships between variables, the findings still provide valuable insights. They contribute to a more nuanced understanding of the potential pathways linking physical health behaviors with psychological well-being and digital media use. Specifically, the introduction of a chain mediation model represents a theoretical advancement by illustrating how emotional distress (anxiety) and diminished self-regulatory resources (ego-depletion) can interactively mediate the association between physical activity and social network site addiction. This model not only extends the application of ego-depletion theory and emotion regulation theory to the field of adolescent behavioral addictions, but also underscores the multifaceted nature of such addictions, which are shaped by both psychological vulnerabilities and behavioral habits. Moreover, the study's findings offer practical implications for health education, psychological counseling, and school-based intervention programs. While the observed effect sizes—particularly for physical activity—were relatively modest, they highlight the potential of exercise as a low-cost, accessible, and non-stigmatizing strategy to support adolescents' mental health and reduce excessive reliance on social media. Rather than viewing physical activity as a standalone solution, the results suggest it should be integrated into a broader framework of protective factors, including emotional support, cognitive training, and environmental adjustments. Schools and families should pay close attention to adolescents who have experienced adverse life events [28-32], such as childhood maltreatment, bullying victimization, and family conflict, as these experiences may not only increase the risk of technology addiction but also negatively impact sleep quality and raise the likelihood of emotional regulation difficulties such as alexithymia. Given the cumulative effects of these risk factors, targeted protective interventions are urgently needed. These could include offering stable family support to foster a sense of security and emotional belonging [33], encouraging physical activity to promote

both physical and mental well-being and enhance emotion regulation [34, 5], and strengthening cognitive training programs to improve adolescents' abilities to cope with negative emotions and stress. Taken together, this research provides both theoretical enrichment and practical guidance for stakeholders aiming to mitigate the growing issue of social network site addiction among adolescents. It encourages interdisciplinary approaches that bridge physical health promotion with mental health and digital literacy education, paving the way for more holistic and effective intervention strategies.

However, this study has several limitations. First, physical activity—being a key variable in the model—was assessed using a single self-reported item. Although such measures are convenient and often used in large-scale surveys, they may suffer from limited reliability and construct validity. This simplification fails to capture the multidimensional nature of physical activity (e.g., intensity, frequency, and duration), which may affect the accuracy of the findings. Second, the reliance on self-reported survey data may compromise accuracy due to subjective bias, memory errors, or insufficient self-awareness, thereby potentially impacting the objectivity and validity of the data. Third, the use of convenience sampling may limit the representativeness of the sample, as the surveyed participants may not fully reflect the diversity of the adolescent population, reducing the generalizability and external validity of the results. Fourth, the cross-sectional design restricts the ability to draw causal conclusions. Future studies should consider employing longitudinal designs to examine the dynamic relationships among variables over time. Fifth, although this study controlled for demographic variables such as gender and age, other potentially influential unmeasured factors—such as family environment, academic stress, and patterns of screen time use—may also play a role in shaping adolescents' psychological states and behavioral tendencies. These variables should be included in future research to strengthen the explanatory power of the model and provide a more nuanced understanding of the mechanisms at play. Lastly, when investigating the relationship between internet use and physical activity, future research should expand the scope beyond social network site addiction to include other common digital behaviors such as online gaming or short video consumption, in order to gain a more comprehensive understanding of adolescent technology use and its psychological correlates [142].

Conclusion

This study examined the relationships among physical activity, social network site addiction, anxiety, and ego-depletion, and constructed a chain mediation model in which anxiety and ego-depletion sequentially link physical activity to social network site addiction. While the statistical associations were significant, the effect sizes—particularly those involving physical activity—were relatively modest. Therefore, the practical implications of these findings should be interpreted with appropriate caution. Physical activity may play a supportive but not dominant role in mitigating social network site addiction, and should be considered as part of a broader, multifaceted approach. Individuals, families, schools, and society should remain aware of the potential psychological and behavioral impacts of social network site addiction and consider incorporating stratified screening and tailored interventions. Future research is encouraged to adopt longitudinal designs to clarify causal relationships and to explore whether sustained physical activity can yield long-term benefits for reducing social network site addiction. Additionally, experimental studies should further assess the efficacy of specific intervention programs aimed at alleviating anxiety and ego-depletion. These findings also provide meaningful guidance for policymakers, educators, and public health stakeholders. While physical activity initiatives may serve as one helpful strategy, greater emphasis should be placed on integrated mental health efforts—including anxiety reduction and the development of self-regulation skills—as potentially more impactful components in supporting adolescent well-being and reducing problematic social media use.

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Author contributions

Jiale Wang12456, Ting Xiao12356, Yang Liu123456, Zhenhua Guo156, Zhenxiu Yi1256. 1 Conceptualization; 2 Methodology; 3 Data curation; 4 Writing - Original Draft; 5 Writing - Review & Editing; 6 Funding acquisition.

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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

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Competing interests

The authors declare no competing interests.

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