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Impulsivity Is Associated with Internet Addiction Through Smartphone Multitasking: The Moderating Role of Resting HF-HRV

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ABSTRACT: Emerging adults are particularly vulnerable to internet addiction, and impulsivity is a well-established risk factor. However, the underlying mechanisms, particularly the mediating role of specific digital behaviors and the moderating role of neurophysiological factors, remain inadequately explored. This study investigated whether smartphone multitasking mediates the relationship between impulsivity and internet addiction, and whether resting high-frequency heart rate variability (HF-HRV) moderates these pathways. A sample of 141 college students completed the Internet Addiction Scale, the Barrett Impulsivity Scale, and the Smartphone Multitasking Scale. The electrocardiogram (ECG) data were collected and resting HF-HRV was computed. The results indicated that smartphone multitasking partially accounted for the association between impulsivity and internet addiction (indirect effect = 0.05, SE = 0.02, 95% [0.005, 0.10]), and that resting HF-HRV moderated the direct association (β = −0.14, SE = 0.07, 95% [−0.28, −0.004]), which was weaker at higher levels of HF-HRV. However, the index of moderated mediation was not significant (index = 0.03, SE = 0.03, 95% CI [−0.01, 0.10]), indicating that the indirect effect did not significantly vary with HF-HRV. These findings suggest a complex pattern of associations in which impulsivity is related to internet addiction both directly and indirectly through smartphone multitasking, while resting HF-HRV, a physiological marker associated with self-regulatory capacity, moderates the direct association. This study provides an integrated perspective, linking personality traits, real-world digital behaviors, and neurophysiological markers to better understand the correlates of internet addiction.

Keywords: Internet addiction; Impulsivity; Smartphone multitasking; High-frequency heart rate variability

1. Introduction

The latest data from the China Internet Network Information Center [1] show that China has 298 million internet users aged 10–29, and almost 99% access the internet via mobile phones. Adolescents and emerging adults are highly susceptible to internet addiction, which denotes an individual's inability to control internet use, resulting in detrimental effects on their academic, professional, and social functioning,

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as well as their physical and mental health [2]. Specifically, smartphone multitasking, a prevalent behavior involving simultaneous engagement with multiple smartphone applications or the use of smartphone applications alongside daily tasks [3,4], has become increasingly common in contemporary society. Critical gaps exist regarding its specific relationship with internet addiction, whether it shares common risk predictors like impulsivity, and how individual neurophysiological factors (e.g., resting HF-HRV) may modulate these complex relationships.

1.1. Impulsivity and Internet Addiction

Impulsivity is a stable, measurable, and predictive psychological trait [5], defined as a behavioral tendency to act prematurely without planning and foresight [6,7]. A growing body of evidence suggests that impulsivity may be a potential vulnerability marker closely related to addictive behaviors [8]. The dual-system theory posits that addiction, including internet addiction, is the result of the developmental mismatch between the reflective system (the cognitive control system) and the impulsive system (the reward system) in the brain [9]. Adolescents and youths face a higher risk of internet addiction due to a developmental disparity: the rapid development of subcortical limbic reward regions and the slower maturation of the prefrontal control system [10].

Studies have shown that impulsivity is closely related to internet addiction [11,12] or other related problems such as excessive internet game use [13], social media addiction, and problematic smartphone use [14]. Longitudinal studies have also confirmed that impulsivity predicts online gaming addiction [15] and the vicious cycle between impulsivity and pathological video game use [16]. Behavioral and neurophysiological results indicate executive control deficits in individuals with internet addiction disorder relative to normal controls [17].

Although impulsivity and impaired executive control have been identified as vulnerability factors for internet addiction, the proximal behavioral processes through which these vulnerabilities may be associated with recurrent digital engagement remain unclear. Dual-system theory explains vulnerability in terms of an imbalance between the impulsive/reward and reflective/control systems, but provides limited specification of the everyday behavioral patterns through which this vulnerability may be associated with addictive internet use. The Interaction of Person-Affect-Cognition-Executive model (I-PACE) [18,19] provides a more process-oriented account, proposing that addictive behaviors develop through interactions between predisposing characteristics, affective and cognitive responses, and executive functions. Impulsivity is conceptualized as a predisposing characteristic, while behavioral decisions are shaped by inhibitory control in earlier stages and may become increasingly habitual through cue-reactivity, craving, and reduced stimulus-specific inhibitory control in later stages. However, the role of observable everyday behavioral patterns within this process remains underexplored. Smartphone multitasking may represent such a proximal behavioral pattern, potentially linking dispositional impulsivity to addictive internet use. It is theoretically valuable because it captures an observable, recurrent behavior at a proximal level, distinct from distal dispositions and outcome-level constructs.

1.2. The Mediating Role of Smartphone Multitasking

Smartphone multitasking refers to smartphone use while engaging in other activities and comprises three subtypes: multitasking with nonmedia activities, cross-media multitasking with nonsmartphone media, and single-device multitasking within the smartphone [3]. It is conceptually distinct from other technology-use constructs. Media multitasking broadly refers to the simultaneous use of multiple media or media alongside other activities [20,21]. Smartphone multitasking is smartphone centered and additionally captures multitasking within a single device. It also differs from problematic smartphone use, which refers to dysregulated smartphone use and its associated negative consequences [22], and from general digital

engagement, which primarily reflects the extent or frequency of digital activity. Smartphone multitasking instead describes how digital activities are organized, specifically, a concurrent and fragmented pattern of smartphone use, and does not itself presuppose problematic use. While smartphone multitasking is conceptually more specific than media multitasking, the two constructs share a core feature: the allocation and shifting of attention across concurrent activities. Therefore, findings from the broader media multitasking literature may provide relevant theoretical and empirical insights into the mechanisms underlying smartphone multitasking.

Impulsivity is considered a primary driver of multitasking, motivating individuals through perceived heightened rewards or greater challenge relative to single-task activities [23]. The pleasure derived from switching between different media tasks may increase individuals' preference for this media use pattern [24]. In addition, multitasking may result from an individual's inability to filter out distractions [25]. Previous studies have indicated that impulsivity is significantly positively correlated with media multitasking [26,27], whereas executive control ability is significantly negatively correlated with media multitasking [25,28].

Substantial evidence has revealed that media multitasking is significantly positively correlated with problematic internet use, smartphone use [29], and screen addiction [30]. The link between media multitasking and internet addiction may be explained as follows. First, media multitasking can distort time perception and enhance task enjoyment [31], leading individuals to underestimate the duration of media use and consequently prolong engagement. Second, extensive studies indicate that media multitasking impairs cognitive control. The constant switching between different tasks hinders the maintenance of sustained attention and increases susceptibility to distractions [32]. Conversely, cognitive or attentional control serves as an important protective factor against internet addiction [18].

Taken together, these findings suggest that smartphone multitasking is theoretically relevant as a potential behavioral pathway linking impulsivity to internet addiction. Impulsivity represents a relatively stable vulnerability that may increase responsiveness to immediately salient or rewarding stimuli and promote the tendency to shift rapidly between competing activities. In smartphone-rich environments, such tendencies may be expressed behaviorally through frequent switching between smartphone functions or between smartphone use and other ongoing activities. Smartphone multitasking may therefore represent an observable everyday manifestation of impulsive tendencies in digital contexts, potentially translating a vulnerability into a pattern of recurrent and fragmented digital engagement.

This behavioral positioning also distinguishes smartphone multitasking from alternative mediators commonly examined in research on problematic technology use. These alternative mediators include constructs such as self-control, emotion regulation, and problematic smartphone use, which differ from smartphone multitasking in both their conceptual nature and their proximity to the outcome. Self-control and emotion regulation primarily represent regulatory capacities or psychological processes involved in managing impulses and affective states. Problematic smartphone use is a form of dysregulated technology use and is conceptually closer to the outcome domain of internet addiction. Smartphone multitasking occupies a more proximal behavioral level: it captures an everyday behavioral pattern through which tendencies may be enacted before such behavior necessarily becomes problematic. This conceptualization is consistent with the I-PACE framework, which proposes that relatively stable predispositions interact with affective, cognitive, and executive processes to shape behavioral decisions and, over time, potentially habitual behaviors [18,19]. The updated I-PACE model further proposes that behavioral decisions in earlier stages are influenced by general inhibitory control, whereas later stages increasingly involve habitual responding associated with cue-reactivity, craving, and reduced stimulus-specific inhibitory control [19]. Although the I-PACE model does not explicitly identify smartphone multitasking as a mediating mechanism, it supports the view that dispositional vulnerabilities are expressed through recurring behavioral patterns in digital environments. Smartphone multitasking may thus be conceptualized as one

such pattern, providing a behavioral link between impulsivity and internet addiction. This study advances the I-PACE model by operationalizing smartphone multitasking as a proximal behavioral pathway linking impulsivity to internet addiction.

Therefore, to address the unexamined interconnectedness among these three constructs, this study investigates the mediating role of smartphone multitasking in the relationship between impulsivity and internet addiction.

1.3. The Moderating Role of Resting HF-HRV

High-frequency heart rate variability (HF-HRV) is widely used as a nonintrusive measure that reflects dynamic interactions between cardiac autonomic control and respiratory activity [33,34]. Within the Neurovisceral Integration Model [35], resting HF-HRV is viewed as a physiological marker of the central autonomic network's capacity for inhibitory control, which supports self-regulation and adaptive behavior. Higher levels of resting HF-HRV are generally associated with greater self-regulation and adaptive social functioning, whereas lower levels are linked to regulatory difficulties [36,37].

Research has shown that resting HF-HRV is negatively correlated with problematic internet use [38], internet gaming addiction [39,40], substance use, depression, and anxiety [41,42]. In addition to the main effect of resting HF-HRV, researchers have also discovered its moderating effect. Resting HF-HRV was found to moderate the impact of parental marital conflict on internet addiction among college students [43]. Other studies have also indicated that higher resting HF-HRV levels can buffer the negative effects of adverse environments on children's development [44], while children and adolescents with lower resting HF-HRV show susceptibility or vulnerability to adverse environments [37,45].

However, whether high resting HF-HRV, which may serve a protective role, would buffer the negative association of impulsivity with internet addiction and smartphone multitasking remains unexplored. Therefore, the second objective of this study is to examine whether resting HF-HRV interacts with impulsivity to predict both smartphone multitasking and internet addiction.

1.4. The Present Study

In summary, we predict that impulsivity is positively associated with smartphone multitasking and internet addiction, and that smartphone multitasking may mediate the association between impulsivity and internet addiction. Higher resting HF-HRV may weaken the associations between impulsivity and both smartphone multitasking and internet addiction.

2. Method

2.1. Participants

The required number of participants was calculated using G*Power software (version 3.1.9.7). In the regression model of internet addiction in this study, up to seven predictor variables were involved (*i.e.*, smartphone multitasking, impulsivity, resting HF-HRV, the interaction between resting HF-HRV and impulsivity, as well as gender, age, and parental education level). With a medium effect size of $f^2 = 0.15$, $\alpha = 0.05$, and Power = 0.80, 103 participants were needed. The participants were 141 undergraduate students aged 16–26 years $M_{age} = 18.94$, $SD = 1.21$, including 97 females and 44 males). The educational attainment of participants' parents was as follows: 28% of the fathers and 24% of the mothers had a bachelor's degree or above, 22% of the fathers and 16% of the mothers had a high school education, 38% of the fathers and 31% of the mothers had a junior high school education, 12% of the fathers and 29% of the mothers had a primary school education or below. The study protocol was approved by the Ethics Committee of the corresponding author's institution, and written informed consent was obtained from participants prior to the study.

2.2. Procedure

Participants were scheduled for their experimental sessions via phone. They were instructed not to consume alcohol, coffee, nicotine, or other drugs two hours before the experiment. Data collection for female participants was scheduled outside of the menstrual period. After participants arrived at the laboratory, the experimenter explained the experimental procedures and precautions to them. The experiment commenced with the collection of the participants' physiological data (resting HF-HRV), after which the participants completed the questionnaires.

3. Measures

3.1. Chen Internet Addiction Scale

Internet addiction was measured using the Chen Internet Addiction Scale (CIAS) [46]. This scale consists of 26 items that assess symptoms of internet addiction across five dimensions: compulsive internet use, withdrawal, reduced tolerance, interpersonal and health problems, and time management issues. Participants rated each item on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree). Higher scores represent a higher level of internet addiction. In this study, Cronbach's alpha for the scale was 0.92.

3.2. Barratt Impulsiveness Scale

Impulsivity was measured using the Chinese version of the Barratt Impulsiveness Scale [47]. The scale contains 30 items that measure attentional impulsivity, motor impulsivity, and non-planning impulsivity. Participants rated each item on a 4-point Likert scale from 1 (never) to 4 (always). Higher scores represent higher impulsivity. In this study, Cronbach's alpha for the scale was 0.90.

3.3. The Smartphone Multitasking Scale

Smartphone multitasking was measured by assessing the extent to which participants combined mobile phone use with nonmedia activities or other media activities, or switched between different activities on the phone [3]. Participants responded to a 7-point scale ranging from 1 (never) to 7 (always) for each described situation. Nonmedia multitasking included combining mobile phone use with six nonmedia activities: traveling, studying or attending classes, eating, walking, exercising, and socializing. Multitasking with other media activities included watching TV, using a computer, using a tablet, reading books or newspapers, *etc.* Switching between different activities on the phone included listening to music, watching videos, playing games, browsing the web, and using social media. In this study, Cronbach's alpha for the scale was 0.92.

3.4. Physiological Data

Upon arrival, participants rested quietly for 10 min to acclimatize to the standard laboratory environment. Subsequently, they sat quietly for a 5-min resting HF-HRV recording while viewing a neutral picture (selected from the International Affective Picture System) presented on a computer screen. Participants were instructed to relax and focus on the picture on the screen. All measurements were performed in a quiet, well-lit laboratory designed for standard psychology behavioral testing. Physiological data were recorded using a portable physiological measurement device SOMNOtouch™ RESP (SOMNOmedics GmbH, Randersacker, Germany, http://www.somnomedics.de (accessed on 6 October 2026)). The device included a SOMNOtouch™ RESP main unit, a strap, and a 3-electrode electrocardiogram lead. Three Ag-AgCl electrodes were attached to the left and right clavicles and the left rib of the participant. The SOMNOtouch™ RESP main unit was strapped to the participant's sternum, and the electrocardiogram lead was connected to the main unit. Notably, respiratory rate and tidal volume were

not recorded concurrently during the resting HF-HRV assessment. The recorded data were converted and analyzed using DOMINO 1.4.0 software (SOMNOmedics GmbH, Randersacker, Germany). Artifacts were automatically detected by the software and excluded from analysis. Resting HF-HRV was computed as the average HF-HRV value during the 5-min resting period. The software obtained high-frequency heart rate variability (HF-HRV, 0.15–0.4 Hz) through spectral analysis using Fast Fourier transform and used the natural logarithm of HF-HRV in subsequent analysis.

4. Results

4.1. Test of Common Method Bias

Common method bias was assessed using Harman's single-factor test. Factor analysis yielded 22 factors with eigenvalues greater than 1, and the unrotated first factor accounted for 18% of the total variance, well below the critical threshold of 40%. This suggests that common method bias was unlikely to be a serious concern in this study.

4.2. Descriptive Statistics and Bivariate Correlations

The inclusion of control variables (participant gender, age, and parental education level) revealed no significant associations with the primary variables of interest, nor did theses variables affect the regression outcomes. Therefore, the analyses presented below do not include these controls.

The results of the correlation analysis (Table 1) indicated that impulsivity was significantly positively correlated with internet addiction and smartphone multitasking, and smartphone multitasking was significantly positively correlated with internet addiction. The correlations between resting HF-HRV and the measured variables were not significant. Additional analyses showed no significant gender differences in any of the main study variables (all $p > 0.05$).

Table 1. Descriptive statistics and bivariate correlations for all variables.

	1	2	3	4
1 internet addiction				
2 smartphone multitasking	0.33 **			
3 impulsivity	0.56 **	0.21 *		
4 resting HF-HRV	0.11	0.13	0.02	
M	58.44	94.96	76.93	7.10
SD	10.33	22.51	11.81	1.08

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

4.3. Mediation Analysis

The mediating role of smartphone multitasking was examined using SPSS MACRO PROCESS (Model 4). The significance of the mediating effect was tested using the bootstrap method with 5000 samples. Three regression equations were established to test the direct effect of impulsivity on internet addiction and smartphone multitasking, as well as the predictive effect of smartphone multitasking on internet addiction after adding impulsivity. Diagnostic analyses were conducted prior to interpreting the regression results. There was no serious multicollinearity problem (VIF = 1.05; tolerance = 0.96; largest condition index = 1.24). The histogram and normal P-P plot of standardized residuals indicated approximate normality, and the residual-versus-fitted plot showed no systematic pattern, supporting linearity and homoscedasticity. Cook's distance (max = 0.11), leverage, and Mahalanobis distance revealed a few relatively high-leverage cases, but their Cook's distances were well below 1, and excluding them did not alter the substantive conclusions. All cases were therefore retained in the main analysis.

The results (Table 2) showed that the positive association between impulsivity and internet addiction was significant. Smartphone multitasking mediated the association between impulsivity and internet addiction. Specifically, impulsivity was positively associated with smartphone multitasking, and smartphone multitasking was positively associated with internet addiction. Impulsivity accounted for 32% of the variance in internet addiction and 5% of the variance in smartphone multitasking. The indirect effect of impulsivity on internet addiction through smartphone multitasking was significant (*ab* = 0.05, *SE* = 0.02, 95% CI [0.005, 0.10]), though small in magnitude, accounting for 9% of the total effect (*ab*/*c*). The direct effect was substantially larger than the indirect effect.

Table 2. Smartphone multitasking mediates the effect of impulsivity on internet addiction.

Variables	Internet Addiction			Smartphone Multitasking			Internet Addiction				
	β	SE	95% CI	β	SE	95% CI	β	SE	95% CI	Tolerance	VIF
impulsivity	0.56 ***	0.07	[0.42, 0.70]	0.21 *	0.08	[0.05, 0.38]	0.52 ***	0.07	[0.38, 0.65]	0.96	1.05
Smartphone multitasking	—	—	—	—	—	—	0.22 **	0.07	[0.08, 0.35]	0.96	1.05
R^2	0.32 ***			0.05 *			0.36 ***				

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

4.4. Moderating Effect of Resting HF-HRV

Impulsivity and resting HF-HRV were standardized, and the moderating effect of resting HF-HRV on the mediating model was analyzed using SPSS MACRO PROCESS (Model 8). The significance of the mediating effect was tested using the bootstrap method with 5000 samples. Diagnostic analyses were conducted prior to interpreting the regression results. There was no serious multicollinearity problem (VIF = 1.00–1.09; tolerance = 0.92–1.00; largest condition index = 1.39). The histogram and normal P-P plot of standardized residuals indicated approximate normality, and the residual-versus-fitted plot showed no systematic pattern, supporting linearity and homoscedasticity. Cook's distance (max = 0.068), leverage, and Mahalanobis distance revealed a few relatively high-leverage cases, but their Cook's distances were well below 1, and excluding them did not alter the substantive conclusions. All cases were therefore retained in the main analysis.

The results are presented in Table 3. Resting HF-HRV moderated the direct association between impulsivity and internet addiction, but the interaction between resting HF-HRV and impulsivity did not significantly predict smartphone multitasking. The index of moderated mediation was 0.03 (*SE* = 0.03, 95% CI [−0.01, 0.10]). The 95% CI included zero, indicating that the moderated mediating effect was not significant.

Table 3. Results of the moderated mediation model with resting HF-HRV as the moderator.

Variables	Smartphone Multitasking					Internet Addiction				
	β	SE	95% CI	Tolerance	VIF	β	SE	95% CI	Tolerance	VIF
Impulsivity	0.23 **	0.08	[0.07, 0.40]	0.98	1.03	0.49 ***	0.07	[0.35, 0.63]	0.92	1.08
Smartphone multitasking	—	—	—	—	—	0.23 **	0.07	[0.09, 0.37]	0.92	1.09
Resting HF-HRV	0.13	0.08	[−0.03, 0.30]	1.00	1.00	0.06	0.07	[−0.07, 0.20]	0.98	1.02
Impulsivity × Resting HF-HRV	0.15	0.08	[−0.02, 0.32]	0.98	1.03	−0.14 *	0.07	[−0.28, −0.004]	0.95	1.05
R^2	0.08					0.38				
F	F (3, 137) = 4.16 **					F (4, 136) = 21.13 ***				

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

Finally, simple slope tests were conducted for the direct effect of impulsivity on internet addiction at the average level of resting HF-HRV and at HF-HRV ± 1 *SD* levels. The results (see Figure 1) showed that when the resting HF-HRV level was 1 *SD* below the average, $b = 0.63$ ($SE = 0.09$), $p < 0.001$; when the resting HF-HRV was at the average level, $b = 0.49$ ($SE = 0.07$), $p < 0.001$; when the resting HF-HRV level was 1 *SD* above the average, $b = 0.35$ ($SE = 0.11$), $p = 0.002$. As the resting HF-HRV level increased, the association between impulsivity and internet addiction became weaker. The region of significance test further indicated that when the resting HF-HRV was higher than 1.51 *SD* above the average, the predictive effect of impulsivity on internet addiction was not significant.

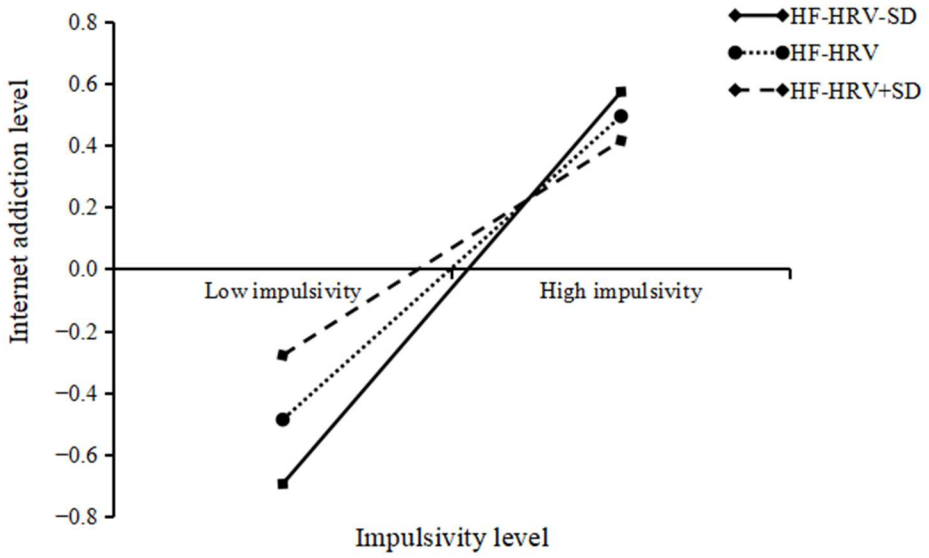


Figure 1. Impulsivity interacted with resting HF-HRV to predict internet addiction.

5. Discussion

This study employed a combination of questionnaire and physiological measures to examine the mediating role of smartphone multitasking in the relationship between impulsivity traits and internet addiction among college students, as well as the moderating effect of resting HF-HRV. The results indicated that smartphone multitasking partially accounted for the association between impulsivity and internet addiction, and resting HF-HRV moderated the direct association between impulsivity and internet addiction in the mediation model. However, resting HF-HRV did not significantly moderate the association between impulsivity and smartphone multitasking, and the moderated mediation index was not statistically significant. Overall, the findings partially supported the hypothesized model.

5.1. Impulsivity and Internet Addiction: The Mediating Role of Smartphone Multitasking

Consistent with previous research, this study identified impulsivity as a significant risk factor for internet addiction. This finding can be interpreted through the dual-system theory of addiction, which posits that addictive behaviors stem from an imbalance between an overactive, reflexive impulsive system and a weakened, conscious reflective system [48]. The impulsive system is rooted in the amygdala-striatal circuit, which mediates motivational and reward processing, while the reflective system is primarily governed by the prefrontal cortex, which supports cognitive control [49]. High impulsivity, a core marker of addiction [50], reflects this imbalance—manifesting as low self-control and poor inhibitory function. Indeed, individuals with internet addiction consistently demonstrate elevated trait impulsivity and share behavioral (e.g., reward seeking, impaired inhibitory control) and neurocircuitry characteristics with substance use disorders [51].

This study also confirmed previous related research, indicating a significant positive correlation between impulsivity and smartphone multitasking [52]. Impulsivity is associated with poorer executive function and behavioral inhibition [53,54], and frequent media multitasking is linked to executive function deficits [55,56]. Therefore, individuals with high impulsivity, due to their diminished ability to filter distractions and focus on primary tasks, are more prone to engaging in multiple media tasks simultaneously. Moreover, compared to those with low impulsivity, individuals with high impulsivity are more inclined to pursue potential rewards and immediate gratification while being less sensitive to possible risks or costs [23,57]. The media environment is replete with potential rewards (new messages, likes, updated content, *etc.*), and for individuals with high impulsivity, the novelty and surprise of frequently switching between media tasks may themselves be a form of reward.

A key finding of this study is that smartphone multitasking partially accounted for the association between impulsivity and internet addiction. Although the indirect effect was modest, accounting for 9% of the total effect, examining this mediating pathway is still theoretically informative because it can be understood through interconnected cognitive, behavioral, and neurobiological mechanisms. First, from a motivational perspective, impulsivity amplifies an individual's sensitivity to rewards while diminishing sensitivity to potential costs [58]. This disposition is associated with a heightened pursuit of the immediate gratifications offered by the dynamic media environment, such as new messages and updated content, making frequent task-switching itself a rewarding behavior. Consequently, the pleasure derived from smartphone multitasking can prolong overall media engagement, a known behavioral precursor to internet addiction [59]. Second, from a cognitive standpoint, the diminished capacity for sustained attention and inhibitory control characteristic of high impulsivity predisposes individuals to engage in more media multitasking, which in turn may exacerbate cognitive load and further erode self-regulatory capacity [23], creating a vicious cycle that facilitates addictive internet use patterns. Third, these behavioral phenomena may be supported by shared neural substrates. Effective multitasking often involves the automation of tasks, a process associated with a shift from prefrontal cortical control to striatal-based automatic processing [60], a transition that mirrors the neuroadaptations seen in addiction, where reward-related striatal activity is enhanced alongside a weakening of prefrontal cognitive control circuits [51]. Thus, smartphone multitasking may serve as a modest behavioral conduit through which impulsivity is related to internet addiction, although other mechanisms likely play a larger role. This modest effect should be interpreted in light of the multifactorial etiology of internet addiction. Twin studies have shown that genetic factors alone explain 48–66% of the variance in problematic internet use [61,62]. Thus, any single behavioral mediator likely accounts for only a limited proportion of the total effect. The observed indirect effect of 9% is therefore not trivial. Furthermore, unlike stable dispositions such as impulsivity, smartphone multitasking is an observable and modifiable everyday behavior, making it a feasible intervention target despite its limited mediating effect. Reducing task-switching or promoting sustained attention may be more actionable than attempts to alter trait-level impulsivity. Thus, the 9% indirect effect carries practical value because it points to a concrete, changeable behavior rather than a fixed predisposition. Given the cross-sectional design, these mechanisms should be interpreted as theoretical possibilities rather than established causal pathways. These possibilities warrant further investigation.

5.2. The Moderating Role of Resting HF-HRV

Another important finding of this study is that resting HF-HRV can moderate the direct association between impulsivity and internet addiction after controlling for smartphone multitasking. Specifically, a high level of resting HF-HRV can buffer the adverse association between impulsivity and internet addiction, supporting the protective role of high resting HF-HRV. Previous studies have shown that high resting HF-HRV is associated with children's behavioral, cognitive, and emotional regulation abilities [63], and high resting HF-HRV is usually associated with children's adaptive development, while lower resting HF-HRV

is often associated with children's maladaptive outcomes such as anxiety, depression, or aggression [64]. The protective role of resting HF-HRV may reflect stronger self-regulatory capacities. Recent evidence indicates that higher vagally mediated HRV is associated with better executive functioning, particularly cognitive inhibition and cognitive flexibility [65,66]. Moreover, resting HF-HRV has been considered a potential physiological indicator of general emotion regulation, and improvements in working memory have been positively associated with increases in resting HF-HRV [67]. Thus, higher resting HF-HRV may indicate greater executive and emotion-regulatory capacities, enabling individuals to better regulate impulsive tendencies and thereby reducing their translation into problematic internet use. This interpretation is also consistent with Zeng et al. [68], who suggested that higher resting vagally mediated HRV may be associated with greater self-regulatory capacity and resistance to the adverse correlates of internet addiction tendencies. Thus, the present study reinforces that resting HF-HRV can buffer against the detrimental association between impulsivity and internet addiction.

However, contrary to our hypothesis, resting HF-HRV did not significantly moderate the association between impulsivity and smartphone multitasking. This result indicates that the protective role of high resting HF-HRV may be specific to behavioral pathways. Its moderating effect is more evident in the direct relationship between impulsivity and adverse outcomes such as internet addiction, whereas it shows limited influence on the association between impulsivity and smartphone multitasking. This divergence may stem from differences in the regulatory demands of the two paths. Internet addiction is widely recognized as a clinically relevant behavioral addiction, characterized by dysregulation of the reward system and deficits in top-down cognitive control [58], and resisting it requires repeated recruitment of self-regulatory resources, a process in which resting HF-HRV may serve as a protective buffer. In contrast, smartphone multitasking is generally considered a routine, context-dependent media behavior that is highly influenced by situational and cognitive factors and exhibits situational variability [69], and it is often triggered automatically by external cues such as notifications and device availability. Because such switching places fewer demands on deliberate self-regulation, individual differences in resting HF-HRV may be less consequential for whether impulsive individuals engage in it. This asymmetry may also reflect a difference in time scale: internet addiction is a long-term cumulative outcome, whereas smartphone multitasking is an immediate, situation-specific behavior. A stable physiological index such as resting HF-HRV is therefore more likely to moderate the former than the latter.

5.3. Limitations, Future Direction, and Implications

This study is subject to several limitations.

First, its cross-sectional design precludes causal inferences. Because all variables were measured simultaneously, reverse and bidirectional relationships cannot be ruled out. For instance, internet addiction may increase impulsivity or smartphone multitasking, and smartphone multitasking may further reinforce impulsive tendencies. Longitudinal designs with multiple measurement waves would help establish the temporal ordering of these variables and test potential reciprocal relations among impulsivity, smartphone multitasking, and internet addiction.

Second, the reliance on self-reported measures of impulsivity may introduce response bias. Future studies could complement self-reports with behavioral or neurophysiological measures of impulsivity, such as delay discounting tasks or go/no-go paradigms, to reduce shared-method variance and strengthen construct validity.

Third, the sample was predominantly female (97 females and 44 males), which may limit the generalizability of the findings to male populations. Although controlling for gender did not substantially change the main results, gender-stratified analyses were underpowered in the male subsample. Therefore, no definitive conclusions about gender differences can be drawn. Recruiting demographically balanced

samples with sufficient male participants would allow a more rigorous test of whether the mediating and moderating effects observed here generalize across genders.

Fourth, the lack of concurrent respiratory recordings calls for caution in interpreting the HF-HRV findings. HF-HRV is not a pure index of vagal activity: its amplitude is strongly modulated by respiratory rate and tidal volume, independent of cardiac vagal activity [33,34]. Thus, individuals with similar vagal activity may nonetheless differ in HF-HRV if their spontaneous breathing patterns differ. Because respiration was not recorded in the present study, we cannot rule out that individual differences in spontaneous breathing patterns contributed to the observed associations. The HF-HRV findings should therefore not be interpreted as reflecting vagal activity alone. Future research should record respiration alongside HRV and adjust for respiratory parameters or use paced breathing, so that the present moderation findings can be reexamined under controlled conditions.

Furthermore, interaction effects are typically smaller than main effects and require larger samples to detect reliably [70]. Moderation effects involving physiological variables are often small and therefore particularly demanding in terms of sample size. Although our a priori power analysis indicated adequate power for medium effects, the current sample size may not have been sufficient to reliably detect smaller moderation effects. Therefore, the nonsignificant moderation effect on the impulsivity–smartphone multitasking path should be interpreted with caution, as it may partly reflect limited statistical power rather than the absence of a true effect. Future research with larger samples and power analyses tailored to moderated mediation would help clarify this issue.

Finally, PROCESS is well suited for estimating conditional process models with observed variables and is widely accepted in this literature. However, the present framework involves both mediation and moderation and is conceptually complex. Structural Equation Modeling (SEM) may offer a stronger analytical strategy in two respects. It can model latent variables to account for measurement error, which is particularly relevant when interaction terms are involved, as measurement error in predictors and moderators can attenuate interaction effects. It also provides global fit indices that allow the overall adequacy of the hypothesized model to be evaluated. Future research could use latent variable SEM to account for measurement error more fully and to assess overall model fit.

Despite these limitations, the findings enrich our understanding of impulsivity's link to smartphone multitasking and internet addiction among college students, highlighting the protective role of resting HF-HRV. These results provide a basis for investigating the psychophysiological mechanisms behind these behaviors and offer guidance for intervention practices addressing internet addiction among college students. The research results suggest that preventive measures should consider the distinct pathways of different behavioral types for more targeted support.

6. Conclusions

Impulsivity was positively associated with college students' smartphone multitasking and internet addiction, and smartphone multitasking partially accounted for the association between impulsivity and internet addiction. In addition, resting HF-HRV moderated the association between impulsivity and internet addiction, with higher resting HF-HRV weakening this association. These findings suggest that both behavioral and physiological factors may be relevant to understanding internet addiction among college students. However, without concurrent respiratory recording, interpret the HF-HRV findings as preliminary and as reflecting broader autonomic/regulatory differences rather than a pure index of vagal tone.

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Author Contributions

Conceptualization, L.J. and X.Y.; Methodology, L.J. and X.Y.; Software, L.J.; Validation, L.J. and X.Y.; Formal Analysis, L.J.; Resources, X.Y.; Data Curation, L.J. and X.Y.; Writing—Original Draft Preparation, L.J.; Writing—Review & Editing, L.J. and X.Y.; Visualization, L.J.; Supervision, X.Y.; Project Administration, X.Y.; Funding Acquisition, X.Y.

Ethics Statement

The study was conducted in accordance with the Declaration of Helsinki and relevant laws and institutional guidelines, and was approved by the Ethics Committee of the School of Psychology, Shaanxi Normal University (Protocol Code: [CBA150155]; Date of Approval: 7 April 2018).

Informed Consent Statement

Written informed consent was obtained from all adult participants. For participants under 18 years of age, written informed consent was obtained from their parents or legal guardians, and age-appropriate assent was obtained from the adolescent participants.

Data Availability Statement

Data is available upon request. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Declaration of Competing Interest

The authors declare no conflicts of interest.

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