AKADÉMIAI KIADÓ

The longitudinal associations between internet addiction and ADHD symptoms among adolescents

Journal of Behavioral Addictions

13 (2024) 1, 191–204

DOI:
10.1556/2006.2023.00080

JIN-LIANG WANG[1†*], XUE-QIN YIN[2†], HAI-ZHEN WANG[3], DANIEL L. KING[4] and DETLEF H. ROST[5]

[1] Center for Mental Health Education, Faculty of Psychology, Southwest University, Chongqing, 400715, China

[2] School of Literature and Journalism, Chongqing Technology and Business University, Chongqing, China

[3] School of Preschool Education, Chongqing Youth Vocational & Technical College, Chongqing, China

[4] College of Education, Psychology and Social Work, Flinders University, Adelaide, Australia

[5] Department of Psychology, Philipps-University of Marburg, Marburg, Germany

FULL-LENGTH REPORT

Received: March 23, 2023 • Revised manuscript received: July 5, 2023; August 14, 2023; December 8, 2023 • Accepted: December 10, 2023
Published online: January 9, 2024

ABSTRACT

Background and aims: Internet addiction has been linked to ADHD-related symptoms. However, the direction of the relationship and its potential for reciprocal relations is not well understood. This study examined the potential reciprocal relations between the three components of ADHD and Internet addiction, as well as the moderating effects of gender on these relations. *Methods:* Using a longitudinal design, we collected data of 865 Chinese adolescents across three waves (*Mage* = 13.78, *SD* = 1.56 in wave 1), with a time interval of 6 months. *Results:* Cross-lagged analyses revealed bidirectional associations between hyperactivity, inattention, impulsivity, and Internet addiction over time. Multi-group analyses did not yield any significant gender differences in these relationships. *Discussion and conclusions:* These findings enhance our understanding of the complex link between ADHD components and Internet addiction and have implications for interventions aimed at reducing the prevalence of Internet addiction and ADHD.

KEYWORDS

internet addiction, ADHD symptoms, hyperactivity, inattention problems, impulsivity, cross-lagged analysis

INTRODUCTION

The phenomenon of Internet addiction has attracted significant research and clinical attention. Although not technically recognized as a disorder, Internet addiction is a widely used term used to refer to addictive use of the Internet, and is considered synonymous with Internet Addiction Disorder, Pathological Internet Use, and Problematic Internet Use (Douglas et al., 2008). Previous research have indicated that individuals with Internet addiction are more likely to report ADHD symptoms, with comorbidity rates reaching as high as 58% among children and adolescents (Ha et al., 2006) and 14% in adult populations (Bernardi & Pallanti, 2009), respectively. Individuals with ADHD exhibit consistent attentional deficiency, hyperactivity, and impulsivity, which can have a negative impact on their cognitive functioning and development (American Psychiatric Association, 2013).

Despite the reported association between Internet addiction and ADHD symptoms in literature, there are still gaps that need to be addressed. Firstly, it remains unclear whether the

†Jin-Liang Wang and Xue-Qin Yin are co-first authors who contribute equally to this work.

*Corresponding author.
E-mail: wjl200789@163.com

AKJournals

association between Internet addiction and ADHD symptoms is unidirectional or reciprocal, due to the limitation of cross-sectional designs used in previous studies (see Koncz et al., 2023; Nikkelen, Valkenburg, Huizinga, & Bushman, 2014; Wang, Yao, Zhou, Liu, & Lv, 2017 for reviews). Recent longitudinal studies have mainly focused on gaming disorder rather than Internet addiction (Gentile, Swing, Lim, & Khoo, 2012; Lee, Bae, Kim, & Han, 2021; Marmet, Studer, Grazioli, & Gmel, 2018). Secondly, there is a paucity of studies using ADHD-specific measures that exclusively capture one or more of the core symptoms associated with ADHD (i.e., attention problems, hyperactivity, impulsivity) (Nikkelen et al., 2014). It is crucial to investigate the relationship between Internet addiction and these distinct components of ADHD given research indicating differential media effects for each symptoms domain (Marmet et al., 2018; Nikkelen et al., 2014; Yen, Chen, Tang, & Ko, 2009). For example, one longitudinal study reported that problematic social media use increased attention problems and impulsivity over time, rather than hyperactivity (Boer, Stevens, Finkenauer, & Eijnden, 2020). Additionally, the practice of using a composite ADHD variable rather than specific components may distort the observed relationship between Internet addiction and ADHD. For example, attentional deficiency has been found to be more closely associated with Internet addiction than impulsivity (Nikkelen et al., 2014; Yen et al., 2009). Therefore, it is imperative to differentiate ADHD-related behaviors and examine the potential associations between specific ADHD-related symptoms (namely, inattention problems, hyperactivity, and impulsivity) and Internet addiction. Furthermore, considering the increasing consensus that children's susceptibility to Internet-related effects depends on a range of person-based variables (such as age and sex), it is worthwhile to investigate whether there are any gender differences in these associations (Valkenburg & Peter, 2013).

The current study therefore aims to: (a) investigate the potential reciprocal relationships between Internet addiction and specific ADHD-related symptoms, and; (b) examine whether gender moderates the associations between ADHD symptoms and Internet addiction.

Internet addiction links to ADHD-related symptoms

Internet addiction refers to the inability to control one's Internet use, which results in psychological, social, academic and/or work-related difficulties (Spada, 2014). The literature has suggested that Internet addiction may serve as a predictor of attention-deficit/hyperactivity disorder (ADHD) (Boer et al., 2020; Kim, Lee, Lee, Namkoong, & Jung, 2017; Stockdale & Coyne, 2018). ADHD is a behavioral disorder characterized by attentional problems, hyperactivity, and impulsivity among children and adolescents (American Psychiatric Association, 2013). Considering the diverse nature of ADHD symptoms, this study used ADHD-related symptomatology to describe the continuous distribution of attention problems, hyperactivity, and impulsivity in the general population of adolescents as distinct from diagnosed cases (Nikkelen et al., 2014). Hyperactivity refers to excessive motor activity when it is not appropriate, or excessive fidgeting, tapping, or talkativeness (American Psychiatric Association, 2013). Thus, hyperactivity can indicate low self-control. Impulsivity refers to hasty actions that occur in the moment without forethought and have high potential for harm to the individual (e.g., darting into the street without looking). Inattention manifests behaviorally in ADHD as mind wandering off task, lacking persistence, having difficulty sustaining focus, and being disorganized (American Psychiatric Association, 2013), which can result in reduced motivation for tasks requiring self-regulation skills like reading and academic work.

Researchers have proposed that frequent engagement in Internet activities, which are more stimulating or impulsive compared to other activities (e.g., schoolwork), may alter a child's desired level of external stimulation (Gentile et al., 2012). According to the arousal-habituation hypothesis, fast-paced and highly exciting content in the Internet can increase the physiological arousal, such as the elevated heart rate, blood pressure, and skin conductance (Bushman & Huesmann, 2006), while frequent exposure to the Internet may habituate children to the arousal it provides (Nikkelen et al., 2014). Prolonged use of screen media can lead to a reduced experience arousal in less stimulating activities such as schoolwork, resulting in increased attention problems, hyperactivity, and impulsivity (Gentile et al., 2012). Boer et al. (2020) reported that addictive social media use increased ADHD-related symptoms over time.

The displacement hypothesis posits that time spent on the Internet may displace opportunities of impulse-control learning (Zimmerman & Christakis, 2007), as most online activities (e.g., Internet gaming) are characterized by attention-grabbing stimuli, fast pacing and rapid scene changes. Even though some Internet games could provide cognitive training and practice to enhance users' response inhibition (Leong, Yong, & Lin, 2022), most of them are designed to encourage quick responses and clicking rather than stimulate response inhibition abilities (Argyriou, Davison, & Lee, 2017). Therefore, excessive Internet use may have detrimental effects on cognitive abilities and be associated with increased impulsivity and lack of control (Cabelguen et al., 2021; Gentile et al., 2012). Empirically, the amount of time spent playing online video games has been found to be positively related to ADHD symptoms and inattention (Chan & Rabinowitz, 2006). Compared to normal users, adolescents who excessively engage in online gaming exhibit more severe ADHD symptoms and poorer impulse control (Stockdale & Coyne, 2018). Therefore, we hypothesized that Internet addiction may increase subsequent inattention problems, hyperactivity, and impulsivity.

Individuals with ADHD-related symptoms tend to use Internet addictively

Studies have also examined ADHD as a risk factor, i.e., whether individuals with greater ADHD symptoms exhibit a higher likelihood of addictive Internet use (Weiss, Baer, Allan, Saran, & Schibuk, 2011; Werling, Kuzhippallil, Emery, Walitza, & Drechsler, 2022; Yen et al., 2009). For example, a longitudinal study examined the predictive effects of ADHD, hostility, depression, and social phobia on Internet addiction, the results indicated that ADHD problems was a powerful predictor of Internet addiction, after controlling for age and gender (Ko, Yen, Chen, Yeh, & Yen, 2009). Further, based on a representative sample of 3,034 children and adolescents, a three-year longitudinal study also reported reciprocal associations between amount of video gaming, attentional problems, and impulsivity (Gentile et al., 2012). However, these findings did not challenge the hypothesis about Internet addiction leading to ADHD-related symptoms since they are two sides of the same coin.

Several hypotheses have been proposed to explain why users with ADHD symptoms may use the Internet excessively (Acevedo-Polakovich, Lorch, & Milich, 2007; Durkin, 2010). According to the attraction hypothesis, adolescents exhibiting ADHD-related behaviors tend to engage in stimulating activities as a means of compensating for low baseline arousal (Roberti, 2004). This tendency is primarily driven by boredom proneness and aversion to delayed rewards, which are considered core symptoms of ADHD (Li, Zhang, Xiao, & Nie, 2016). Engaging in Internet activities, particularly fast-paced video games, can serve as high-arousal compensation for individuals with ADHD due to their ability to provide quick response, instant stimulation and multi-task interfaces that may alleviate feeling of boredom. For individuals with hyperactivity, Internet activities that are stimulating may be appealing due to their ability to facilitate rapid clicking and browsing, which requires minimal self-regulation (Baumeister, Vohs, & Tice, 2007).

ADHD is also linked to dysfunction in brain regions responsible for impulsivity, which manifests as a preference for immediate rewards or an inability to delay gratification (Rubia, Smith, Brammer, Toone, & Taylor, 2005). Internet activities provide adolescents with impulsive tendencies a sense of achievement through online features that offer instant feedback and social rewards. Furthermore, gaming has been observed to trigger striatal dopamine release, which can enhance gamers' focus and improve their performance (Koepp et al., 1998). Therefore, decreased self-control and heightened perceived success may serve as motivations for adolescents with ADHD symptoms, particularly those exhibiting impulsivity, to engage in online activities more frequently. As such, we hypothesized that hyperactivity, inattention, and impulsivity would increase subsequent Internet addiction.

Potential gender differences

Gender, as an important dispositional susceptibility variable, may impact the association between ADHD and Internet addiction (Valkenburg & Peter, 2013). Researchers have found that among individuals with depression, ADHD, social phobia, and hostility, ADHD was the most significant predictor of Internet addiction among females (Ko et al., 2009). Moreover, the association between inattention and Internet addiction was stronger in female students than males (Yen et al., 2009). However, evidence from a meta-analysis on the correlation between media use and ADHD-related behaviors showed that the positive association is more pronounced among males than females (Nikkelen et al., 2014). Therefore, we would examine the gender difference in the associations between Internet addiction and attention problems, hyperactivity, and impulsivity, to provide empirical evidence for the potential gender difference.

The present study

Based on the available research, there is a significant gap in our understanding of the potential reciprocal associations between ADHD and Internet addiction. Moreover, it is unclear whether distinct association patterns exist between Internet addition and the three subcomponents of ADHD symptoms. Further, there is emerging evidence that there may be gender differences in these relationships. To address these gaps, this study aimed to examine reciprocal associations between Internet addiction and inattention problems, hyperactivity, and impulsivity, and to test for possible gender differences in these associations.

METHOD

Sample and participant selection

In May 2019, participants were recruited for a three-wave panel study with a time interval of 6 months between waves (12 months from wave 1 to wave 3). The sample was adolescents aged between 11 and 17 years old who were selected from the seventh grade (i.e., middle school students) and tenth grade (i.e., high school students) at two schools in Guangxi Province in south China. A total of 1,020 students were invited to complete a paper and pencil survey that aims to investigate their Internet usage, and 922 participants completed all three waves survey. After excluding participants who reported nearly invariant responses on all items ($n = 57$), the final sample consisted of 865 individuals ($Mage = 13.78$, $SD = 1.56$ at the baseline). Within this sample, 49.2% were boys, and 50.6% were girls (2 participants failed to fill in their gender information).

During the survey, confidentiality was guaranteed by asking students to provide their identification data on separate forms and processing survey answers separately. Each respondent was also assigned a unique code to ensure that any identifying data could be deleted before processing. Based on the identification forms obtained during waves 1, 2 and 3, the respondents were tracked over time with an interval of 6 months between waves. We used a time interval of 6 months between waves because the extensive use of one semester (i.e., six months) as an time interval in prior research studying changes in behavioral patterns and mental health among adolescents (e.g., Teng et al., 2018). MANOVA was used to decide whether the missing data were conditional on key variables. Results revealed no significant difference in Internet addiction ($F_{(1,\ 1019)} = 0.51$, $p > 0.05$) and ADHD behaviors ($F_{(1,\ 1019)} = 0.65$, $p > 0.05$) between the adolescents who participated in wave one and those who participated in all three waves. The MANOVA results indicated the data were missing at random. Among the final 865 participants, missing data were replaced by their corresponding means and across the three waves, the missing items were between 0.1% and 2.1%.

Measures

Internet Addiction Scale. Internet addiction was assessed by the Internet Addiction Test-Adolescence Version (Teo & Kam, 2014). This scale consists of three aspects of Internet addiction, including loss of control (eleven items), dereliction of duty (six items), and excessive use (four items). Participants were asked to answer each item on a 5-point scale, ranging from 1 = "rarely" to 5 = "always". Sample items were "How often do you feel that you stay online longer than you intend" and "How often do you neglect homework to spend more time online". Two items in the subscale of dereliction of duty ("how often do you form new relationships with fellow online users?" and "how often do you check your e-mail before something else that you need to do?") were deleted due to factor loading below 0.40 in three time points, and remined 18 items. The items were summarized and averaged, with higher scores representing higher Internet addiction. The adapted Chinese version of the Internet Addiction Test has been used in a study by Lai et al. (2013), who reported good reliability in Chinese sample (Lai et al., 2013). The Cronbach's α coefficient for the present sample in Time 1 to Time 3 were 0.92, 0.93, and 0.93, respectively.

ADHD Scale. ADHD-related symptoms was measured using the subscales of Strengths and Difficulties Questionnaire (SDQ), which is applicable to individuals ranging from 4 to 16 years (Goodman, 1997). Participants responded to a 5-item questionnaire assessing three dimensions of ADHD symptoms, including hyperactivity, impulsivity, and attentional problems. Each item was rated on a 3-point Likert scale, ranging from 0 = "not true" to 2 = "certainly true". Specifically, hyperactivity and inattention symptoms were assessed by two items, respectively (hyperactivity symptoms: "Restless, overactive, cannot stay still for long" and "Constantly fidgeting or squirming"; inattention symptoms: "Sees tasks through to the end, good attention span (reversed)", and "Easily distracted, concentration wanders"). The assessment of impulsivity symptoms was conducted using a single item ("Thinks things out before acting" (reversed)). This scale has been adapted in a study among Chinese sample and has an acceptable reliability in Chinese sample (Zhang et al., 2009). In the present study, the Cronbach's α coefficient in Time 1 to Time 3 were 0.67, 0.69 and 0.70, respectively.

Analytic strategy

Data analysis in the current study consisted of preliminary analysis and main analysis. The preliminary analysis was conducted using SPSS 22.0 to assess normality and to generate descriptive statistics. A normal distribution test of the variables showed that the skewness values for all variables ranged from 0.07 to 0.88, and the kurtosis values ranged from −0.68 to 0.75, which were well within in the range of ±1.0 (Muthen & Kaplan, 1985), suggesting that study variables listed in Table 1 were normally distributed.

AMOS version 21.0 was used to examine the potential reciprocal relationships between Internet addiction and ADHD symptoms. Specifically, we first conducted a multigroup confirmatory factor analysis grouped by time points (i.e., longitudinal measurement invariance analysis) to test the invariance of Internet addiction scale across the three waves. We did not analyze the longitudinal invariance analysis of the three components of ADHD symptoms, due to the fact that ADHD scale comprises only 5 items across

Table 1. Gender differences on Internet addiction and ADHD symptoms at three waves

	All sample (N = 865)			Boys (n = 397)	Girls (n = 468)			
	M (SD)	Skewness	Kurtosis	M (SD)	M (SD)	t	p	d
T1 Internet addiction	2.21 (0.73)	0.81	0.66	2.24 (0.74)	2.20 (0.72)	0.80	0.423	−0.06
T2 Internet addiction	2.21 (0.82)	0.63	−0.07	2.24 (0.82)	2.18 (0.81)	1.19	235	−0.07
T3 Internet addiction	2.21 (0.73)	0.60	0.19	2.24 (0.73)	2.18 (0.73)	1.05	0.295	−0.08
T1 ADHD	0.71 (0.40)	0.46	0.06	0.74 (0.40)	0.69 (0.40)	1.59	0.111	−0.13
T2 ADHD	0.74 (0.43)	0.37	−0.21	0.77 (0.44)	0.72 (0.41)	1.66	0.097	−0.12
T3 ADHD	0.70 (0.41)	0.33	−0.02	0.71 (0.43)	0.70 (0.39)	0.44	0.657	−0.17
T1 Hyperactivity	0.50 (0.52)	0.78	−0.14	0.58 (0.54)	0.43 (0.50)	4.35***	<0.001	−0.29
T2 Hyperactivity	0.52 (0.58)	0.88	−0.09	0.59 (0.61)	0.46 (0.55)	3.50***	<0.001	−0.23
T3 Hyperactivity	0.53 (0.55)	0.83	0.02	0.58 (0.57)	0.48 (0.53)	2.71**	0.007	−0.18
T1 Impulsivity	0.81 (0.60)	0.10	−0.41	0.82 (0.60)	0.79 (0.59)	0.63	0.527	−0.05
T2 Impulsivity	0.90 (0.65)	0.11	−0.68	0.89 (0.66)	0.90 (0.65)	−0.18	0.859	0.02
T3 Impulsivity	0.77 (0.60)	0.13	−0.47	0.74 (0.62)	0.80 (0.57)	−1.39	0.166	0.10
T1 Inattention	0.88 (0.52)	0.16	−0.38	0.85 (0.54)	0.91 (0.50)	−1.65	0.100	0.12
T2 Inattention	0.89 (0.53)	0.07	−0.34	0.88 (0.55)	0.90 (0.51)	−0.38	0.707	0.04
T3 Inattention	0.84 (0.51)	0.13	0.28	0.82 (0.52)	0.86 (0.51)	−1.22	0.224	0.08

Note: M = mean. SD = standard deviations. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

three factors, with each factor containing fewer than three items, it failed to meet the minimum requirement for measurement model identification (Bollen, 1989). For testing the longitudinal measurement invariance of Internet addiction, we constructed a series of multi-group models across three points, and each model was tested through three sequential steps wherein increasingly restrictive constraints were incrementally applied. In the first step, an unconstrained model was tested for configural invariance (Model 1); this was followed by testing a multi-group model with constrained factor loadings (Model 2 and Model 3). Thereafter, scalar invariance was tested by constraining the factor loadings and intercepts (Model 4). Last, the unique variance was tested by constraining the factor loadings, intercepts, and error residuals (Model 5 and Model 6).

Secondly, we explored the longitudinal associations between the three components of ADHD and Internet addiction, followed by a test of possible gender differences. During this phase, we constructed three separate cross-lagged models via AMOS to examine the relationship between Internet addiction (measured by loss of control, dereliction of duty, and excessive use) and each component of ADHD symptoms. Given that the three components of ADHD-related symptoms were assessed by five items, we used hyperactivity, impulsivity, and attentional problems as observed variables in the cross-lagged model. The multi-group SEM analyses allows for the examination of gender differences in the estimated path coefficients between hyperactivity, inattention, impulsivity, and Internet addiction. Initially, a multi-group SEM model was conducted with freely estimated structural paths across gender groups while all other parameters were constrained (i.e., factor loadings, intercepts and item variance). Subsequently, we ran a model where all parameters were set equal across genders.

In all analyses, the default estimation of method of maximum likelihood was used. Model fit was assessed with χ^2/df, a root mean square error of approximation (RMSEA), a comparative fit index (CFI), a Tucker-Lewis index (TLI), and a standardized root mean square residual (SRMR). The recommended range for χ^2/df is greater than 1 and smaller than 5 (Salisbury, Chin, Gopal, & Newsted, 2002). The CFI and TLI should be greater than 0.90 (Salisbury et al., 2002). For the RMSEA and the SRMR, values less than 0.08 represent an acceptable fit (Byrne, 2001).

When reporting the evidence of invariance, two criteria were used. Firstly, the multi-group models must show an acceptable fit to the data. Secondly, given that model chi-square tests are sensitive to sample size, the CFI difference should be considered as a more robust evaluation criteria (e.g., Cheung & Rensvold, 2002; Little, 1997; Vandenberg & Lance, 2000). Therefore, we used χ^2 difference tests and assessed the changes in CFI and RMSEA between competing models to determine whether further restrictions significantly impaired model fit. Invariance was established if the χ^2 difference was not significant, or if the decrease in CFI values between models was less than 0.01 and change in RMSEA was less than 0.015 (Cheung & Rensvold, 2002; Dimitrov, 2010).

Ethics

All procedures in this study were in accordance with the Declaration of Helsinki, and the study protocol was approved by the Ethical Committee of the the Southwest University China. All adolescents and their school teachers, and parents were informed about the study and all provided informed consent.

RESULTS

Preliminary analysis

Table 1 presents the descriptive statistics for the entire sample, as well as separately for boys and girls. To test the gender differences in the study variable across three waves, *t*-test was conducted. As shown in Table 1, boys reported higher scores of hyperactivity than girls in all three waves (p_s<0.01). No significant gender differences were found in Internet addiction and other two ADHD symptoms. The zero-order correlations among the study variables for the whole sample are presented in Table 2, which indicated that Internet addiction was positively correlated to hyperactivity,

Table 2. The zero-order correlations between all study variables ($N = 865$)

Variables	1	2	3	4	5	6	7	8	9	10	11	12
1. T1 Internet addiction	–											
2. T2 Internet addiction	0.74***	–										
3. T3 Internet addiction	0.72***	0.74***	–									
4. T1 Hyperactivity	0.42***	0.39***	0.34***	–								
5. T2 Hyperactivity	0.31***	0.42***	0.33***	0.52***	–							
6. T3 Hyperactivity	0.31***	0.31***	0.36***	0.50***	0.51***	–						
7. T1 Impulsivity	0.21***	0.15***	0.20***	0.14***	0.09**	0.10**	–					
8. T2 Impulsivity	0.17***	0.18***	0.21***	0.15***	0.14***	0.18***	0.42***	–				
9. T3 Impulsivity	0.14***	0.17***	0.22***	0.16***	0.12***	0.16***	0.39***	0.39***	–			
10. T1 Inattention	0.45***	0.37***	0.38***	0.37***	0.26***	0.28***	0.34***	0.25***	0.28***	–		
11. T2 Inattention	0.41***	0.47***	0.45***	0.32***	0.41***	0.39***	0.28***	0.37***	0.30***	0.54***	–	
12. T3 Inattention	0.38***	0.39***	0.48***	0.30***	0.26***	0.40**	0.29***	0.26***	0.40***	0.54***	0.55***	–

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

attentional problems and impulsivity at all three time points (p_s<0.001). Correlations between variables for boys and girls can be found in Appendix Table A1.

Phase 1: measurement invariance test for Internet Addiction Scale

A second-order factor model comprising of three first-order factors of Internet addiction was assessed through confirmatory factor analysis (CFA) at each of the three time points. The factor loadings for each item ranged from 0.47 to 0.78 at T1, 0.54 to 0.80 at T2, and 0.46 to 0.78 at T3. Additionally, we also presented all specific factor loadings of Internet addiction in appendix (see Appendix Table A2). The goodness-of-fit indexes in Table 3 showed a very good model fit for each wave, demonstrating configural invariance of the CFA models over time.

Testing for factorial invariance was conducted using the sequence of nested models as previously described (Model 1-Model 6). As shown in Table 3, all models have good fit. The chi-square differences in Table 3 shows that these nested constrained models provide direct evidence of invariant first-order (M2-M1) and second-order factor loadings (M3-M2), as well as first-order disturbances (M5-M4), with no significant chi-square differences observed (p_s > 0.05). However, the other chi-square differences for the comparisons of models (M4-M3 and M6-M5) were significant (p_s < 0.05), suggesting that invariances did not hold. However, considering that difference in chi-square is sensitive to sample size and our study has a large sample, we relied on changes in CFI and RMSEA as indicators of invariance.

According to prior research (Cheung & Rensvold, 2002; Dimitrov, 2010), only the decrease of CFI larger than 0.01 (i.e., △ CFI < −0.01) and the change of RMSEA larger than 0.015 (i.e., △ RMSEA > 0.015) indicate a lack of invariance. As shown in Table 3, the decreases in CFI between M2-M1, M4-M3 and M6-M5 are all less than 0.01, and the changes of RMSEA are below 0.015. Therefore, it can be concluded that first-order loadings, item intercepts and item residual variance are invariant. In summary, the longitudinal factorial invariance of the second-order CFA of Internet scales across the three waves is supported by the invariance of first- and second-order factor loadings, item intercepts, first-order factor disturbances and item residual variances.

Phase 2: testing the hypothesized models of the relations between ADHD-related symptoms and Internet addiction

Figures 1–3 presents the associations between hyperactivity, inattention, and impulsivity symptoms and Internet addiction. In terms of the relation between hyperactivity and Internet addiction, the autoregressive cross-lagged model fit the data well, with χ^2/df = 5.313, p < 0.001, CFI = 0.978, TLI = 0.962, RMSEA = 0.071 (90% CI = [0.061, 0.081]),

Table 3. Fit statistics for measurement models of Internet addiction

Model	ML χ^2	*df*	CFI	TLI	RMSEA	SRMR	Comparison	△ χ^2	*p*	△ CFI	△ RMSEA
M1	1,859.75	387	0.931	0.918	0.038	0.037	–	–	–	–	–
M2	1,898.15	417	0.931	0.924	0.037	0.038	M2-M1	38.40	0.140	0.000	−0.001
M3	1,904.64	421	0.930	0.924	0.037	0.038	M3-M2	6.50	0.165	−0.001	0.000
M4	2,039.80	457	0.926	0.925	0.037	0.038	M4-M3	135.16	0.000	−0.004	0.000
M5	2,047.56	463	0.926	0.926	0.036	0.038	M5-M4	7.76	0.256	0.000	−0.001
M6	2,175.67	505	0.922	0.929	0.036	0.039	M6-M5	128.11	0.000	−0.002	0.000

Note: M1 = configural invariance model in which none parameters were constrained to be equal; M2 = first-order factor loadings were constrained to be equal; M3 = first-order and second-order factor loadings were constrained to be equal; M4 = first-order and second-order factor loadings, and item intercepts were constrained to be equal; M5 = first-order and second-order factor loadings, item intercepts, and first-order factor disturbances were constrained to be equal; M6 = first-order and second-order factor loadings, item intercepts, first-order factor disturbances, and item residual variance were constrained to be equal.

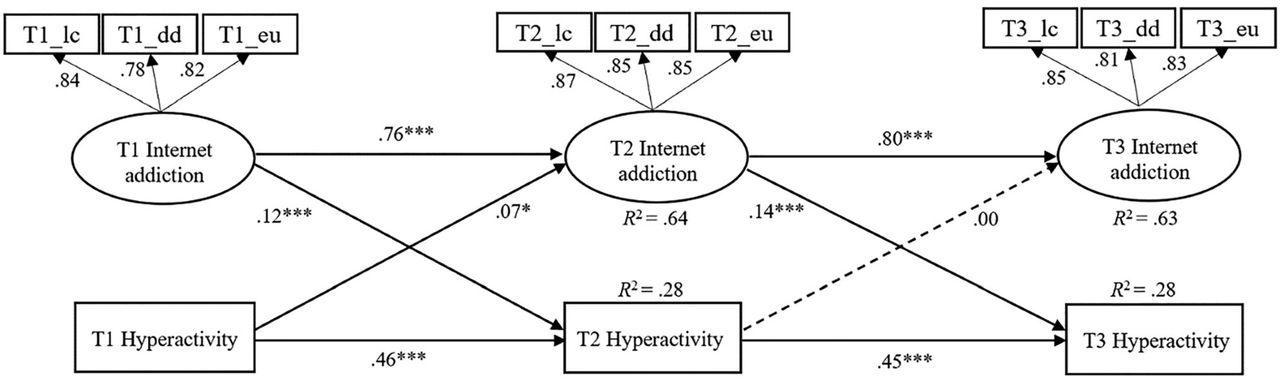

Fig. 1. Reciprocal relation between hyperactivity and Internet addiction

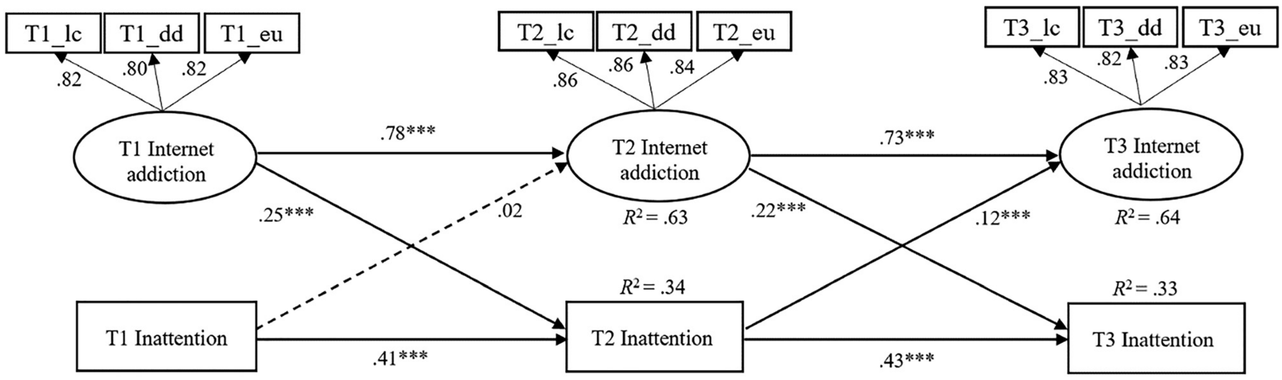

Fig. 2. Reciprocal relation between inattention and Internet addiction

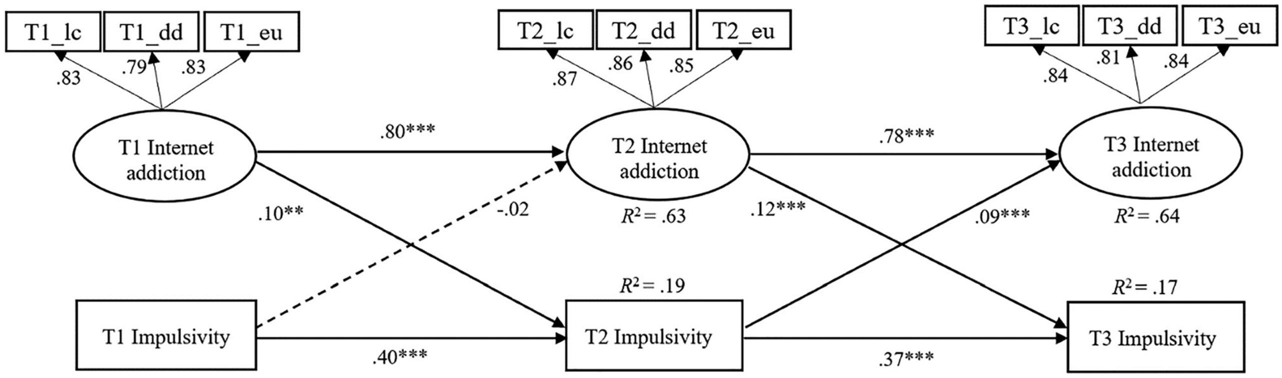

Fig. 3. Reciprocal relation between impulsivity and Internet addiction

Note: Values reflect standardized coefficients. Dashed lines are nonsignificant. dd = dereliction of duty; eu = excessive use; lc = loss of control. For all cross-lagged models, we allowed the measurement error of each indicator across time and the residual variance between variables within time to be correlated. For clarity, error terms and covariances are not shown. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

SRMR = 0.042. Hyperactivity at Time 1 was significantly related to Internet addiction at Time 2 ($\beta = 0.07$, $p = 0.011$), while hyperactivity at Time 2 was not related to Internet addiction at Time 3 ($\beta = 0.00$, $p = 0.970$; see Fig. 1). Besides, we also found that Internet addiction at a prior time point could positively predict the subsequent hyperactivity ($p_s < 0.001$). In order to compare the strength of these relations, we further constrained structural parameters including auto-regression and cross-lagged coefficients to be equivalent across the two intervals, results indicated that the relations between Time1 and Time 2 were similar with those between Time2 and Time3, with $\triangle \chi^2$ (4) = 30.873, $p < 0.001$, △ CFI = −0.003 and △ RMSEA = 0.002. This finding indicated that there was no significant change in the strength of relationships over time.

Figure 2 presents the baseline model for inattention and Internet addiction, which fits the data well, with $\chi^2/df = 6.433$, $p < 0.001$, CFI = 0.974, TLI = 0.953, RMSEA = 0.079 (90% CI = [0.070, 0.089]), SRMR = 0.047. Internet addiction at earlier time points were found to predict inattention at later time points, with $\beta = 0.25$, $p < 0.001$ and $\beta = 0.22$, $p < 0.001$, respectively. Moreover, inattention could positively predict subsequent Internet addition, but that was only significant at Time 3 ($\beta = 0.12$, $p < 0.001$). We then used a constrained model that set auto-regression and cross-lagged relations to be equivalent across two intervals for the comparison of standardized effect sizes. Results revealed that the strength of above relations were not significantly different, with $\triangle \chi^2$ (4) = 29.338, $p < 0.001$, △ CFI = −0.004 and △ RMSEA = 0.001, suggesting little change in these relations strength over time.

Regarding the link between impulsivity and Internet addition, the baseline model showed a good fit to the data, with $\chi^2/df = 5.213$, $p < 0.001$, CFI = 0.978, TLI = 0.960, RMSEA = 0.070 (90% CI = [0.060, 0.080]), SRMR = 0.043. Figure 3 illustrates that Internet addiction at earlier time points positively predicted impulsivity at later time points, with $\beta = 0.10$, $p = 0.010$ and $\beta = 0.12$, $p < 0.001$, respectively. We also found that impulsivity at Time 2 was positively related to Internet addiction at Time 3 ($\beta = 0.09$, $p < 0.001$), indicating a reciprocal relation between impulsivity and Internet addition. Further constrained model indicated that these auto-regression and cross-lagged paths coefficients between Time 1 and Time 2 did not significantly differ from those between Time 2 and Time 3, with $\triangle \chi^2$ (4) = 38.050, $p < 0.001$, △ CFI = −0.005 and △ RMSEA = 0.003.

Taken together, results from cross-lagged models revealed that there were significant cross-lagged associations between Internet addiction and three components of ADHD symptoms (i.e., hyperactivity, attentional problems, and impulsivity). These results suggest that Internet addiction and hyperactivity, attentional problems, as well as impulsivity can be reciprocally related over time.

Multi-group differences across gender

To examine the gender difference in the models aforementioned, we conducted a multi-group analysis grouped by gender. We first established three unconstrained models separately for hyperactivity, attentional problems, and impulsivity, allowing the structural paths to be freely estimated between different genders, and the model fit indexes and corresponding regression coefficients were presented in Tables 4 and 5, respectively. As shown in Table 4, these unconstrained cross-lagged models fit data well. Then we constructed three equal models that constrained the structural weights to be equivalent, which also demonstrated excellent model fits (see Table 4). Finally, we compared freely estimated model with equal model to determine whether there was a gender difference. The results showed that imposing the equality constrains did not significantly deteriorate the fits of models, with all $\triangle\ \chi^2 \geq 5.239$, $p_s > 0.05$, $\triangle$ CFI < 0.01, and $\triangle$ RMSEA <0.015 (See Table 4). Hence, we concluded that the cross-lagged models between Internet addiction and hyperactivity, inattention and impulsivity were equivalent across gender.

Table 5 presents the subtle differences in the strength of relationships on the unconstrained models for boys and girls. In the model of hyperactivity, hyperactivity at Time 1 was positively related to boys' Internet addiction at Time 2 ($\beta = 0.08$, $p = 0.016$), which in turn could positively predict their increased hyperactivity at Time 3 ($\beta = 0.14$, $p = 0.003$). While for girls, the paths from Internet addiction to hyperactivity were significant across two intervals, $\beta = 0.16$, $p < 0.001$ and $\beta = 0.15$, $p = 0.001$, respectively. No significant path from hyperactivity to Internet addiction was observed for girls across two intervals ($\beta = 0.07$, $p = 0.097$, and $\beta = -0.04$, $p = 0.266$).

In terms of the Inattention model, whether for boys or girls, Internet addiction at earlier time points were found to be positively related to attention problems at the latter points ($p_s < 0.001$). Meanwhile, inattention symptoms at Time 2 predicted increased Internet addiction at Time 3 for both boys ($\beta = 0.12$, $p < 0.001$) and girls ($\beta = 0.12$, $p < 0.001$). These links further confirmed that the relationship between internet addiction and inattention was similar for both boys and girls. That is, Internet addiction could positively predict their increased attention problems, which in turn was positively related to Internet addiction in the future.

As for impulsivity symptoms, we found that Internet addiction at earlier time points could positively predict impulsivity symptoms at the latter time points for boys ($\beta = 0.14$, $p = 0.004$, and $\beta = 0.12$, $p = 0.019$), but for girls, only Internet addiction at Time 2 could predict the increased impulsivity at Time 3 ($\beta = 0.12$, $p = 0.007$). Further, impulsivity at Time 2 could increase Internet addiction at Time 3 for both boys ($\beta = 0.07$, $p = 0.013$) and girls ($\beta = 0.10$, $p < 0.001$; see Table 4). These results indicated that reciprocal association between Internet addiction and impulsivity was similar on both boys and girls.

DISCUSSION

The aim of this study was to investigate the potential longitudinal associations between three components of ADHD and Internet addiction among adolescents. Further, we examined gender differences in these paths. The longitudinal design allowed the present study to provide stronger evidence regarding the directionality of effects compared to cross-sectional studies. Results from this sample revealed reciprocal associations between ADHD total score, hyperactivity, inattention problems, impulsivity, and Internet addiction. However, no significant gender differences were revealed in the relationships between hyperactivity, inattention, impulsivity, and Internet addiction.

A reciprocal relationship between hyperactivity and Internet addiction was found. The initial wave hyperactivity could predict Internet addiction symptoms over time, and Internet addiction was associated with subsequent increases in hyperactivity symptoms. The significant path from hyperactivity to Internet addiction supported the strength model of self-control. This model proposes that individuals with lower self-control may frequently engage in stimulating internet activities that do not require exertion of self-control (Baumeister et al., 2007). The rapid and effortless navigation characteristic of the Internet may align with the cognitive style of children exhibiting more hyperactive symptoms. Our

Table 4. Fit statistics for multi-group SEM Models across gender

Model	ML χ^2	*df*	CFI	TLI	RMSEA	SRMR	$\triangle\ \chi^2$	*p*	$\triangle$ CFI	$\triangle$ RMSEA
Hyperactivity										
Betas freely estimated	368.522	113	0.961	0.957	0.053	0.050				
Equality model	390.508	121	0.961	0.959	0.052	0.054	10.888	0.208	0	0.001
Inattention										
Betas freely estimated	407.732	113	0.962	0.957	0.055	0.049				
Equality model	413.017	121	0.962	0.961	0.053	0.050	5.239	0.732	0	0.002
Impulsivity										
Betas freely estimated	382.301	113	0.962	0.958	0.053	0.052				
Equality model	391.051	121	0.962	0.960	0.051	0.051	8.553	0.381	0	0.002

Table 5. Path coefficients in betas freely estimated models for boys and girls groups

Parameter	Boys (n = 397)				Girls (n = 468)			
	b	β	SE	p	b	β	SE	p
Hyperactivity model								
Auto-regression								
T2 Internet addiction ← T1 Internet addiction	0.86	0.76	0.05	<0.001	0.86	0.77	0.05	<0.001
T3 Internet addiction ← T2 Internet addiction	0.69	0.79	0.04	<0.001	0.69	0.81	0.04	<0.001
T2 hyperactivity ← T1 hyperactivity	0.56	0.50	0.05	<0.001	0.45	0.41	0.04	<0.001
T3 hyperactivity ← T2 hyperactivity	0.46	0.48	0.04	<0.001	0.38	0.40	0.04	<0.001
Cross-lagged								
T2 hyperactivity ← T1 Internet addiction	0.08	0.08	0.05	0.093	0.14	0.16	0.04	<0.001
T3 hyperactivity ← T2 Internet addiction	0.11	0.14	0.04	0.003	0.11	0.15	0.04	0.001
T2 Internet addiction ← T1 hyperactivity	0.11	0.08	0.05	0.016	0.07	0.05	0.04	0.097
T3 Internet addiction ← T2 hyperactivity	0.03	0.02	0.04	0.471	−0.04	−0.04	0.04	0.266
Inattention model								
Auto-regression								
T2 Internet addiction ← T1 Internet addiction	0.90	0.78	0.05	<0.001	0.90	0.79	0.05	<0.001
T3 Internet addiction ← T2 Internet addiction	0.64	0.74	0.04	<0.001	0.62	0.73	0.04	<0.001
T2 inattention ← T1 inattention	0.43	0.43	0.04	<0.001	0.40	0.40	0.04	<0.001
T3 inattention ← T2 inattention	0.40	0.43	0.04	<0.001	0.44	0.44	0.04	<0.001
Cross-lagged								
T2 inattention ← T1 Internet addiction	0.24	0.28	0.04	<0.001	0.19	0.24	0.04	<0.001
T3 inattention ← T2 Internet addiction	0.14	0.19	0.04	<0.001	0.17	0.23	0.03	<0.001
T2 Internet addiction ← T1 inattention	0.03	0.03	0.04	0.446	0.02	0.01	0.04	0.654
T3 Internet addiction ← T2 inattention	0.13	0.12	0.04	<0.001	0.14	0.12	0.04	<0.001
Impulsivity model								
Auto-regression								
T2 Internet addiction ← T1 Internet addiction	0.92	0.80	0.05	<0.001	0.92	0.80	0.05	<0.001
T3 Internet addiction ← T2 Internet addiction	0.68	0.79	0.03	<0.001	0.66	0.77	0.03	<0.001
T2 impulsivity ← T1 impulsivity	0.40	0.38	0.04	<0.001	0.48	0.43	0.04	<0.001
T3 impulsivity ← T2 impulsivity	0.30	0.34	0.04	<0.001	0.36	0.39	0.03	<0.001
Cross-lagged								
T2 impulsivity ← T1 Internet addiction	0.15	0.14	0.05	0.004	0.06	0.06	0.05	0.209
T3 impulsivity ← T2 Internet addiction	0.10	0.12	0.04	0.019	0.10	0.12	0.04	0.007
T2 Internet addiction ← T1 impulsivity	−0.01	−0.01	0.03	0.679	−0.03	−0.03	0.04	0.332
T3 Internet addiction ← T2 impulsivity	0.07	0.07	0.03	0.013	0.10	0.10	0.03	<0.001

Note: b = unstandardized coefficient; β = standardized coefficient; SE = standard error.

finding in terms of the paths from Internet addiction to hyperactivity also support the displacement hypothesis. Addictive Internet users tend to spend a large amount time on Internet, which reduces the time for other activities that could facilitate the development of cognitive functions relevant to hyperactivity (Zimmerman, Frederick, & Christakis, 2007). Hence it is possible that the self-control ability among addictive Internet users would decrease over time.

The cross-lagged model of Internet addition and impulsivity also revealed a reciprocal relationship. This finding indicates that Internet addiction may aggravate impulsivity problems across time, and impulsivity may further lead to more Internet addiction symptoms. The predictive effect of impulsivity on Internet addiction has also been reported in a recent study by Jo, Na, and Kim (2018), suggesting that impulsivity may be one of the factors contributing to smartphone addiction proneness (Jo et al., 2018). Impulsivity may involve a preference for immediate rewards or an inability to delay gratification, and the Internet provides an environment where users can satisfy their various needs instantly (Foregger, 2008). Our finding is also consistent with other prior research reporting positive associations between impulsivity and addictive gaming (Argyriou et al., 2017; Billieux et al., 2011; Mann, 2017; Nuyens et al., 2016) and others forms of behavioral addiction (Billieux et al., 2012; Grant & Chamberlain, 2014). Impulsivity is, to some extent, caused by the impaired inhibition control function, which is a fundamental aspect of executive function. Individuals with impaired inhibition control system tend to be unable to resist the disruption of addiction relevant cues, and may consequently spend excessive time on Internet activities like gaming. In other words, high levels of impulsivity can lead to poor self-regulation and lack of control over Internet use (Argyriou et al., 2017). It is worth noting that despite the separate assessment of impulsivity and hyperactivity in the present study, their respective relationships with Internet addiction provide evidence for Baumeister et al.'s (2007) strength model of self-control, suggesting that poor self-regulation is at the core of all types of addiction and impulse control disorders.

Additionally, Internet addiction was found to be associated with more impulsive symptoms over time. It is plausible that video game addiction creates biological changes in the neural network, which impair cognitive functioning and impulse control (Stockdale & Coyne, 2018). Additionally, prior fMRI studies have demonstrated an association between Internet addiction disorders and impulsivity, indicating that the excessive use of Internet gaming may lead to lower grey matter volume in certain brain regions, which is believed to underline deficits in inhibition control (Dong, DeVito, Du, & Cui, 2012).

Inattention symptoms and Internet addiction

A 'vicious cycle' was found in terms of the relationship between inattention symptoms and Internet addiction. The addictive use of Internet can increase greater inattention problems over time, which may further induce more subsequent Internet addiction symptoms. These findings are consistent with previous research (Boer et al., 2020; Gentile et al., 2012). Adolescents with attention deficits tend to experience boredom during tasks requiring sustained cognition engagement, yet exhibit heightened engagement when participating in stimulating online activities and when afforded the opportunity to switch between tasks promptly. Even though engaging in online activities may alleviate boredom and facilitate task-switching, such behaviors can impede adolescents' ability to maintain attentional focus, resulting in diminished performance (Xie, Rost, Wang, Wang, & Monk, 2021).

Despite the significant relationship between ADHD-relevant symptoms and Internet addiction, it should be noted that hyperactivity at Time 2 did not predict Internet addiction at Time 3, and inattention and impulsivity at Time 1 did not predict Internet addiction at Time 2. This may indicate that the predictive effects of ADHD-relevant symptoms on Internet addiction were not robust and consistent. A possible explanation for these insignificant findings is that a 6-month interval may not be sufficient to observe the effects. Another possibility is that varying levels of academic stress experienced by Chinese adolescents during different semesters could be a confounding factor in relation to Internet addiction.

Our findings of multi-group analyses for three cross-lagged SEM models across gender suggest that the reciprocal relationship between ADHD and Internet addiction is similar across boys and girls. Similarly, some prior research has reported that gender had no effect on the relationships between ADHD and disruptive disorders (Bauermeister et al., 2007) or substance use disorder (Elkins et al., 2018; Ottosen, Petersen, Larsen, & Dalsgaard, 2016). While this finding is not consistent with other study reporting a stronger association between inattention and Internet addiction among females than in males (Yen et al., 2009). This might be due to the fact that gender differences in Internet use have disappeared as the Internet has become integrated into our daily lives (CNNIC, 2023). Specifically, prior research indicated that both girls and boys were motivated to use Internet to escape real life problems (Kardefelt-Winther, 2014). Males and females with ADHD symptoms may face comparable risks of excessive Internet use, which in turn could equally exacerbate their ADHD symptoms. However, it is possible that boys and girls with ADHD symptoms may engage in different online activities; for example, boys might be more prone to excessive Internet gaming, while girls may excessively use social media (Su, Han, Yu, Wu, & Potenza, 2020). Hence, gender differences may exist in the relationship between ADHD and specific Internet addiction, instead of general Internet addiction that we measured in the present study.

LIMITATIONS AND FUTURE DIRECTIONS

Several limitations of this study should be noted. Firstly, this study used a relatively homogeneous sample recruited from two schools through convenience sampling, which may not be representative of a broader population of Chinese adolescents. Secondly, the measures of Internet addiction and ADHD symptoms could be improved in the future: On the one hand, Internet addiction in this study was not measured by the complete adolescent version of the Internet Addiction Test (Teo & Kam, 2014) due to the exclusion of two items, which might limit the comparison of the results with other studies using the same scale. On the other hand, the longitudinal invariances of the ADHD subscales were not assessed in our study, as they did not meet the criteria for latent variables due to insufficient items for certain subscales, especially for impulsivity, which was measured by a single item. This may lead to less accurate estimation in the models (e.g. underestimation of the relationships). Therefore, future researchers are recommended to choose a ADHD measure with more items (e.g., the Conners Rating Scale – Revised, CRS-R; Conners, 1997) that enables them to specify ADHD symptoms as latent variables in order to further validate findings in our study. Additionally, it is recommended that future research use specific problematic Internet use constructs to enhance generalizability our findings. The present study focused on the relationship between general Internet addiction and ADHD symptoms, which may differ from those associated with specific Internet activities (e.g., social media use; Boer et al., 2020). Thirdly, future studies can enhance the accuracy of estimating the relationships between Internet addiction and ADHD symptoms by employing more advanced statistical methods for handling missing data (e.g., full information maximum likelihood; Lee & Shi, 2021) instead of mean imputation method used in this study which may underestimate the associations among variables. Although all the study variables exhibited normal distribution in the current sample, the problem of non-normal distribution might be unavoidable in practice. Therefore, future studies are recommended to replace ML estimation with robust ML estimation procedure as so to provide more accurate estimations for the relationships between Internet addiction and ADHD symptoms (Schermelleh-Engel, Moosbrugger, & Müller, 2003). Moreover, cross-lagged models hinder us to separate the within-person effects from between-person effects in longitudinal associations between Internet addiction and ADHD symptoms. In order to gain a more comprehensive understanding of the causal effects between variables, future research could consider utilizing random intercept cross-lagged analysis to address the current limitation (Hamaker, Kuiper, & Grasman, 2015). Finally, our cross-lagged models did not control for potential confounding factors (e.g., depression, anxiety) which have been shown to be related to both Internet addiction and ADHD symptoms (e.g., Morita et al., 2022; Yen, Ko, Yen, Wu, & Yang, 2007). To understand the reciprocal relationship between Internet addiction and ADHD symptoms, future research may benefit from including these confounding variables.

CONCLUSIONS

The present study significantly contributes to our understanding of the relationships between Internet addiction and ADHD components. Reciprocal relationships exist between ADHD components and Internet addiction, even though no significant gender difference is revealed. Our findings indicate that Internet addition may increase adolescents' hyperactivity, inattention, and impulsivity and undermine their self-control ability, which in turn leads to more Internet related activities, forming a vicious cycle. Therefore, preventing Internet addiction may help in reducing the likelihood of developing ADHD-related behaviors. Adolescents exhibiting ADHD symptoms require special attention as they are at a higher risk of developing Internet addiction. Teachers and parents can provide alternative activities to compensate for their lower baseline arousal levels, such as engaging in healthy sporting activities. Therefore, effective interventions aimed at reducing the likelihood of technology addiction should acknowledge ADHD components as a significant risk factor.

Funding sources: This work was supported by the "The Influence of Cu-mulative risk factors on mental health of left-behind children in urban- rural areas of Chongqing and the related Interventions (2021WT03)".

Authors' contribution: Jin-Liang Wang and Xue-Qin Yin: conceptualization, methodology, formal analysis, writing (writing – original draft, and writing – editing), visualization. Hai-Zhen Wang: conceptualization, and writing – review & editing. Daniel L. King: review & editing. Detlef H. Rost: review & editing. The authors would like to thank Xiao-Bing Liang for her helps in data collection.

Conflict of interest: The authors report no conflict of interest. Daniel L. King is an associate editor of the Journal of Behavioral Addictions.

REFERENCES

Acevedo-Polakovich, I. D., Lorch, E. P., & Milich, R. (2007). Comparing television use and reading in children with ADHD and non-referred children across two age groups. *Media Psychology*, *9*(2), 447–472. https://doi.org/10.1080/15213260701291387.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: Author.

Argyriou, E., Davison, C. B., & Lee, T. T. C. (2017). Response inhibition and internet gaming disorder: A meta-analysis. *Addictive Behaviors*, *71*, 54–60. https://doi.org/10.1016/j.addbeh.2017.02.026.

Bauermeister, J. J., Shrout, P. E., Chávez, L., Rubio-Stipec, M., Ramírez, R., Padilla, L., … Canino, G. (2007). ADHD and gender: Are risks and sequela of ADHD the same for boys and girls? *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *48*(8), 831–839. https://doi.org/10.1111/j.1469-7610.2007.01750.x.

Baumeister, R. F., Vohs, K. D., & Tice, D. M. (2007). The strength model of self-control. *Current Directions in Psychological Science*, *16*(6), 351–355.

Bernardi, S., & Pallanti, S. (2009). Internet addiction: A descriptive clinical study focusing on comorbidities and dissociative symptoms. *Comprehensive Psychiatry*, *50*(6), 510–516. https://doi.org/10.1016/j.comppsych.2008.11.011.

Billieux, J., Chanal, J., Khazaal, Y., Rochat, L., Gay, P., Zullino, D., & Van Der Linden, M. (2011). Psychological predictors of problematic involvement in massively multiplayer online role-playing games: Illustration in a sample of male cybercafé players. *Psychopathology*, *44*(3), 165–171. https://doi.org/10.1159/000322525.

Billieux, J., Lagrange, G., Van der Linden, M., Lançon, C., Adida, M., & Jeanningros, R. (2012). Investigation of impulsivity in a sample of treatment-seeking pathological gamblers: A multidimensional perspective. *Psychiatry Research*, *198*(2), 291–296. https://doi.org/10.1016/j.psychres.2012.01.001.

Boer, M., Stevens, G., Finkenauer, C., & Eijnden, R. Van Den. (2020). Attention deficit hyperactivity disorder-symptoms, social media use intensity, and social media use problems in adolescents: Investigating directionality. *Child Development*, *91*(4), e853–e865. https://doi.org/10.1111/cdev.13334.

Bollen, K. A. (1989). *Structural equations with latent variables*. Wiley-Interscience Publication.

Bushman, B. J., & Huesmann, L. R. (2006). Short-term and long-term effects of violent media on aggression in children and adults. *Archives of Pediatrics and Adolescent Medicine*, *160*(4), 348–352. https://doi.org/10.1001/archpedi.160.4.348.

Byrne, M. (2001). Structural equation modeling with AMOS: Basic concepts, applications, and programming. In *Routledge*. Routledge. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=psyc5&NEWS=N&AN=2006-03173-000.

Cabelguen, C., Rocher, B., Leboucher, J., Schreck, B., Challet-Bouju, G., Hardouin, J. B., & Grall-Bronnec, M. (2021). Attention deficit hyperactivity disorder and gaming disorder: Frequency and associated factors in a clinical sample of patients with Gaming Disorder. *Journal of Behavioral Addictions*, *10*(4), 1061–1067. https://doi.org/10.1556/2006.2021.00074.

Chan, P. A., & Rabinowitz, T. (2006). A cross-sectional analysis of video games and attention deficit hyperactivity disorder symptoms in adolescents. *Annals of General Psychiatry*, *5*. https://doi.org/10.1186/1744-859X-5-16.

Cheung, G. W., & Rensvold, R. B. (2002). Evaluating goodness-of-fit indexes for testing measurement invariance. *Structural Equation Modeling*, *9*(2), 233–255. https://doi.org/10.1207/S15328007SEM0902_5.

CNNIC (2023). *The 51th statistical report on China's internet development*.

Conners, C. K. (1997). *Conners rating scales — Revised*. Multi-Health Systems, Inc.

Dimitrov, D. M. (2010). Testing for factorial invariance in the context of construct validation. *Measurement and Evaluation in Counseling and Development*, *43*(2), 121–149. https://doi.org/10.1177/0748175610373459.

Dong, G., DeVito, E. E., Du, X., & Cui, Z. (2012). Impaired inhibitory control in "internet addiction disorder": A functional magnetic resonance imaging study. *Psychiatry Research - Neuroimaging*, *203*(2–3), 153–158. https://doi.org/10.1016/j.pscychresns.2012.02.001.

Douglas, A. C., Mills, J. E., Niang, M., Stepchenkova, S., Byun, S., Ruffini, C., … Blanton, M. (2008). Internet addiction: Meta-synthesis of qualitative research for the decade 1996-2006. *Computers in Human Behavior*, *24*(6), 3027–3044. https://doi.org/10.1016/j.chb.2008.05.009.

Durkin, K. (2010). Videogames and young people with developmental disorders. *Review of General Psychology*, *14*(2), 122–140. https://doi.org/10.1037/a0019438.

Elkins, I. J., Saunders, G. R. B., Malone, S. M., Keyes, M. A., McGue, M., & Iacono, W. G. (2018). Associations between childhood ADHD, gender, and adolescent alcohol and marijuana involvement: A causally informative design. *Drug and Alcohol Dependence*, *184*, 33–41. https://doi.org/10.1016/j.drugalcdep.2017.11.011.

Foregger, S. K. (2008). *Uses and gratifications of Facebook.com*. ProQuest.

Gentile, D. A., Swing, E. L., Lim, C. G., & Khoo, A. (2012). Video game playing, attention problems, and impulsiveness: Evidence of bidirectional causality. *Psychology of Popular Media Culture*, *1*(1), 62–70. https://doi.org/10.1037/a0026969.

Goodman, R. (1997). The strengths and difficulties questionnaire: A research note. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *38*(5), 581–586. https://doi.org/10.1111/j.1469-7610.1997.tb01545.

Grant, J. E., & Chamberlain, S. R. (2014). Impulsive action and impulsive choice across substance and behavioral addictions: Cause or consequence? *Addictive Behaviors*, *39*(11), 1632–1639. https://doi.org/10.1016/j.addbeh.2014.04.022.

Ha, J. H., Yoo, H., Cho, I. H., Chin, B., Shin, D., & Kim, J. H. (2006). Psychiatric comorbidity assessed in Korean children and adolescents who screen positive for Internet addiction. *The Journal of Clinical Psychiatry*, *67*(5), 821–826.

Hamaker, E. L., Kuiper, R. M., & Grasman, R. P. P. P. (2015). A critique of the cross-lagged panel model. *Psychological Methods*, *20*(1), 102–116. https://doi.org/10.1037/a0038889.

Jo, H., Na, E., & Kim, D. (2018). The relationship between smartphone addiction predisposition and impulsivity among Korean smartphone users. *Addiction Research & Theory*, *26*(1), 77–84. https://doi.org/10.1080/16066359.2017.1312356.

Kardefelt-Winther, D. (2014). A conceptual and methodological critique of internet addiction research: Towards a model of compensatory internet use. *Computers in Human Behavior*, *31*(1), 351–354. https://doi.org/10.1016/j.chb.2013.10.059.

Kim, D., Lee, D., Lee, J., Namkoong, K., & Jung, Y. C. (2017). Association between childhood and adult attention deficit hyperactivity disorder symptoms in Korean young adults with Internet addiction. *Journal of Behavioral Addictions*, *6*(3), 345–353. https://doi.org/10.1556/2006.6.2017.044.

Ko, C.-H., Yen, J.-Y., Chen, C.-S., Yeh, Y.-C., & Yen, C.-F. (2009). Predictive values of psychiatric symptoms for internet addiction in adolescents: A 2-year prospective study. *Archives of Pediatrics & Adolescent Medicine*, *163*(10), 937–943. https://doi.org/10.1001/archpediatrics.2009.159.

Koepp, M. J., Gunn, R. N., Lawrence, A. D., Cunningham, V. J., Dagher, A., Jones, T., … Grasby, P. M. (1998). Evidence for striatal dopamine release during a video game. *Nature*, *393*(6682), 266–268. https://doi.org/10.1038/30498.

Koncz, P., Demetrovics, Z., Takacs, Z. K., Griffiths, M. D., Nagy, T., & Király, O. (2023). The emerging evidence on the association between symptoms of ADHD and gaming disorder: A systematic review and meta-analysis. *Clinical Psychology Review*, *106*(October). https://doi.org/10.1016/j.cpr.2023.102343.

Lai, C.-M., Mak, K.-K., Watanabe, H., Ang, R. P., Pang, J. S., & Ho, R. C. M. (2013). Psychometric properties of the internet addiction test in Turkish. *Journal of Behavioral Addictions*, *38*(7), 794–807. https://doi.org/10.1556/2006.4.2015.042.

Lee, J., Bae, S., Kim, B. N., & Han, D. H. (2021). Impact of attention-deficit/hyperactivity disorder comorbidity on longitudinal course in internet gaming disorder: A 3-year clinical cohort study. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *62*(9), 1110–1119. https://doi.org/10.1111/jcpp.13380.

Lee, T., & Shi, D. (2021). A comparison of full information maximum likelihood and multiple imputation in structural equation modeling with missing data. *Psychological Methods*, *26*(4), 466–485. https://doi.org/10.1037/met0000381.

Leong, A. Y. C., Yong, M. H., & Lin, M. H. (2022). The effect of strategy game types on inhibition. *Psychological Research*, *86*(7), 2115–2127. https://doi.org/10.1007/s00426-021-01632-0.

Li, W., Zhang, W., Xiao, L., & Nie, J. (2016). The association of Internet addiction symptoms with impulsiveness, loneliness, novelty seeking and behavioral inhibition system among adults with attention-deficit/hyperactivity disorder (ADHD). *Psychiatry Research*, *243*, 357–364. https://doi.org/10.1016/j.psychres.2016.02.020.

Little, T. D. (1997). Mean and covariance structures (MACS) analyses of cross-cultural data: Practical and theoretical issues. *Multivariate Behavioral Research*, *32*(1), 53–76. https://doi.org/10.1207/s15327906mbr3201.

Mann, K. (2017). Neurobiological correlates of internet gaming disorder : Similarities to pathological gambling. *Addictive Behaviors*, *64*, 349–356. https://doi.org/10.1016/j.addbeh.2015.11.004.

Marmet, S., Studer, J., Grazioli, V. S., & Gmel, G. (2018). Bidirectional associations between self-reported gaming disorder and adult attention deficit hyperactivity disorder: Evidence from a sample of young Swiss men. *Frontiers in Psychiatry*, *9*, 649. https://doi.org/10.3389/fpsyt.2018.00649.

Morita, M., Ando, S., Kiyono, T., Morishima, R., Yagi, T., Kanata, S., … Kasai, K. (2022). Bidirectional relationship of problematic internet use with hyperactivity/inattention and depressive symptoms in adolescents: A population-based cohort study. *European Child & Adolescent Psychiatry*, *31*(10), 1601–1609. https://doi.org/10.1007/s00787-021-01808-4.

Muthen, B., & Kaplan, D. (1985). A comparison of some methodologies for the factor analysis of non- normal Likert variables. *British Journal of Mathematical and Statistical Psychology*, *38*, 171–189. https://doi.org/10.1111/j.2044-8317.1985.tb00832.x.

Nikkelen, S. W. C., Valkenburg, P. M., Huizinga, M., & Bushman, B. J. (2014). Media use and ADHD-related behaviors in children and adolescents : A meta-analysis. *Developmental Psychology*, *50*(9), 2228–2241.

Nuyens, F., Deleuze, J., Maurage, P., Griffiths, M. D., Kuss, D. J., & Billieux, J. (2016). Impulsivity in multiplayer online battle arena gamers: Preliminary results on experimental and self-report measures. *Journal of Behavioral Addictions*, *5*(2), 351–356. https://doi.org/10.1556/2006.5.2016.028.

Ottosen, C., Petersen, L., Larsen, J. T., & Dalsgaard, S. (2016). Gender differences in associations between attention-deficit/hyperactivity disorder and substance use disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, *55*(3), 227–234. https://doi.org/10.1016/j.jaac.2015.12.010.

Roberti, J. W. (2004). A review of behavioral and biological correlates of sensation seeking. *Journal of Research in Personality*, *38*(3), 256–279. https://doi.org/10.1016/S0092-6566(03)00067-9.

Rubia, K., Smith, A. B., Brammer, M. J., Toone, B., & Taylor, E. (2005). Abnormal brain activation during inhibition and error detection in medication-naive adolescents with ADHD. *American Journal of Psychiatry*, *162*(6), 1067–1075. https://doi.org/10.1176/appi.ajp.162.6.1067.

Salisbury, W. D., Chin, W. W., Gopal, A., & Newsted, P. R. (2002). Research report: Better theory through measurement—developing a scale to capture consensus on appropriation. *Information Systems Research*, *13*(1), 91–103. https://doi.org/10.1287/isre.13.1.91.93.

Schermelleh-Engel, K., Moosbrugger, H., & Müller, H. (2003). Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. *Methods of Psychological Research Online*, *8*(2), 23–74. https://doi.org/10.1002/0470010940.

Spada, M. M. (2014). An overview of problematic Internet use. *Addictive Behaviors*, *39*(1), 3–6. https://doi.org/10.1016/j.addbeh.2013.09.007.

Stockdale, L., & Coyne, S. M. (2018). Video game addiction in emerging adulthood : Cross-sectional evidence of pathology in video game addicts as compared to matched healthy controls. *Journal of Affective Disorders*, *225*, 265–272. https://doi.org/10.1016/j.jad.2017.08.045.

Su, W., Han, X., Yu, H., Wu, Y., & Potenza, M. N. (2020). Do men become addicted to internet gaming and women to social media? A meta-analysis examining gender-related differences in specific internet addiction. *Computers in Human Behavior*, *113*(June), 106480. https://doi.org/10.1016/j.chb.2020.106480.

Teng, Z., Nie, Q., Guo, C., Zhang, Q., Liu, Y., & Bushman, B. J. (2018). A longitudinal study of link between exposure to violent video games and aggression in Chinese adolescents: The mediating role of moral disengagement. *Developmental Psychology*, *55*(1), 184–195. https://doi.org/10.1037/dev0000624.

Teo, T., & Kam, C. (2014). Validity of the internet addiction test for adolescents and older children (IAT-A): Tests of measurement invariance and latent mean differences. *Journal of Psychoeducational Assessment*, *32*(7), 624–637. https://doi.org/10.1177/0734282914531708.

Valkenburg, P. M., & Peter, J. (2013). The differential susceptibility to media effects model. *Journal of Communication*, *63*(2), 221–243. https://doi.org/10.1111/jcom.12024.

Vandenberg, R. J., & Lance, C. E. (2000). A review and synthesis of the measurement invariance literature: Suggestions, practices, and recommendations for organizational research. *Organizational Research Methods*, *3*(1), 4–70. https://doi.org/10.1177/109442810031002.

Wang, B. qian, Yao, N. qi, Zhou, X., Liu, J., & Lv, Z. tao. (2017). The association between attention deficit/hyperactivity disorder and internet addiction: A systematic review and meta-analysis. *BMC Psychiatry*, *17*(1), 1–12. https://doi.org/10.1186/s12888-017-1408-x.

Weiss, M. D., Baer, S., Allan, B. A., Saran, K., & Schibuk, H. (2011). The screens culture: Impact on ADHD. *ADHD Attention Deficit and Hyperactivity Disorders*, *3*(4), 327–334. https://doi.org/10.1007/s12402-011-0065-z.

Werling, A. M., Kuzhippallil, S., Emery, S., Walitza, S., & Drechsler, R. (2022). Problematic use of digital media in children and adolescents with a diagnosis of attention-deficit/hyperactivity disorder compared to controls. A meta-analysis. *Journal of Behavioral Addictions*, *11*(2), 305–325. https://doi.org/10.1556/2006.2022.00007.

Xie, J.-Q., Rost, D. H., Wang, F.-X., Wang, J.-L., & Monk, R. L. (2021). The association between excessive social media use and distraction: An eye movement tracking study. *Information and Management*, *58*(2), 103415. https://doi.org/10.1016/j.im.2020.103415.

Yen, J. Y., Ko, C. H., Yen, C. F., Wu, H. Y., & Yang, M. J. (2007). The comorbid psychiatric symptoms of Internet addiction: Attention deficit and hyperactivity disorder (ADHD), depression, social phobia, and hostility. *Journal of Adolescent Health*, *41*(1), 93–98. https://doi.org/10.1016/j.jadohealth.2007.02.002.

Yen, J. Y., Yen, C. F., Chen, C. S., Tang, T. C., & Ko, C. H. (2009). The association between adult ADHD symptoms and internet addiction among college students: The gender difference. *Cyberpsychology and Behavior*, *12*(2), 187–191. https://doi.org/10.1089/cpb.2008.0113.

Zhang, C., Ling, Y., Xiao, J., Yang, X., Yang, J., & Yao, S. (2009). Application of Chinese version of the self-report strengths and difficulties questionnaire in a sample of 832 adolescent. *Chinese Journal of Clinical Psychology*, *17*(1), 8–11.

Zimmerman, F. J., & Christakis, D. A. (2007). Associations between content types of early media exposure and subsequent attentional problems. *Pediatrics*, *120*(5), 986–992. https://doi.org/10.1542/peds.2006-3322.

Appendix

Table A1. Correlations between all study variables for boys and girls

Variables	1	2	3	4	5	6	7	8	9	10	11	12
1. T1 Internet addiction	–	0.73***	0.71***	0.39***	0.32***	0.31***	0.27***	0.16**	0.15**	0.45***	0.40***	0.40***
2. T2 Internet addiction	0.75***	–	0.73***	0.34***	0.45***	0.29***	0.20***	0.18***	0.20***	0.38***	0.48***	0.42***
3. T3 Internet addiction	0.73***	0.76***	–	0.26***	0.29***	0.35***	0.26***	0.24***	0.22***	0.39***	0.44***	0.50***
4. T1 Hyperactivity	0.45***	0.43***	0.42***	–	0.49***	0.43***	0.20***	0.20***	0.17***	0.39***	0.29***	0.25***
5. T2 Hyperactivity	0.30***	0.39***	0.37***	0.53***	–	0.46***	0.11*	0.16**	0.02	0.27***	0.40***	0.22***
6. T3 Hyperactivity	0.30***	0.33***	0.37***	0.55***	0.55***	–	0.17***	0.24***	0.12**	0.32***	0.42***	0.37***
7. T1 Impulsivity	0.14**	0.08	0.13**	0.07	0.07	0.02	–	0.49***	0.40***	0.42***	0.34***	0.33***
8. T2 Impulsivity	0.17**	0.18***	0.18***	0.09	0.12*	0.12*	0.35***	–	0.44***	0.30***	0.40***	0.30***
9. T3 Impulsivity	0.14**	0.15**	0.23***	0.18***	0.23***	0.20***	0.39***	0.35***	–	0.26***	0.27***	0.40***
10. T1 Attentional problems	0.45***	0.36***	0.38***	0.39***	0.28***	0.25**	0.26***	0.18***	0.30**	–	0.51***	0.55***
11. T2 Attentional problems	0.43***	0.46***	0.45***	0.37***	0.42***	0.36***	0.23***	0.34***	0.33***	0.57***	–	0.55***
12. T3 Attentional problems	0.36***	0.37***	0.47***	0.37***	0.33***	0.43***	0.23***	0.21***	0.40***	0.53***	0.54***	–

Note: The lower right bottom presents correlations for boys ($n = 397$), and the upper right bottom presents correlations for girls ($n = 468$).
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table A2. Factor loadings for Internet addiction at all time points

Factors/items	Factor loading		
	T1	T2	T3
Factor 1: Lose of control	**0.89**	**0.94**	**0.89**
IA3	0.57	0.63	0.61
IA5	0.57	0.62	0.62
IA9	0.47	0.54	0.46
IA10	0.59	0.66	0.65
IA11	0.60	0.65	0.65
IA12	0.62	0.68	0.70
IA13	0.69	0.71	0.64
IA15	0.75	0.77	0.72
IA18	0.64	0.64	0.63
IA19	0.63	0.69	0.63
IA20	0.66	0.67	0.66
Factor 2: Dereliction of duty	**0.94**	**0.99**	**0.95**
IA2	0.73	0.70	0.72
IA6	0.68	0.70	0.71
IA8	0.60	0.62	0.63
IA14	0.67	0.71	0.72
Factor 3: Excessive use	**0.94**	**0.93**	**0.96**
IA1	0.69	0.73	0.72
IA16	0.74	0.75	0.72
IA17	0.78	0.80	0.78

Note. All factor loadings were standardized. All indicators are significant at the 0.001 level. Item 4 and item 7 under the factor of dereliction of duty were deleted from final analysis due to factor loadings lower than 0.40.