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2023

Computers in Human Behavior Reports 12 (2023) 100335

Contents lists available at ScienceDirect

Computers in Human Behavior Reports

journal homepage: www.sciencedirect.com/journal/computers-in-human-behavior-reports

Perceived smartphone addiction predicts ADHD symptomatology in middle school adolescents: A longitudinal study

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1. Introduction

The sentiment that youth are "addicted" to their smartphones has grown over recent years. Rising screen time, smartphone ownership and smartphone dependency among adolescents has contributed to this narrative, accompanied by escalating concerns of how these devices affect young peoples' development and mental health (Panova & Carbonell, 2018; Rideout, 2019; Twenge et al., 2019). *Smartphone Addiction* (SA*)*, a form of Problematic Media Use (PMU), is a proposed psychopathology used to describe individuals who suffer from dysfunctional smartphone use (Kwon et al., 2013; Montag et al., 2021; Panova & Carbonell, 2018). Smartphone Addiction is characterized by excessive use, psychological withdrawal, cravings, and dependency to the smartphone as a coping mechanism (Kwon et al., 2013). Addictive or problematic use of these devices may have negative consequences for adolescents' psychological, physiological and social development (Lissak, 2018). A recent meta-analysis found that SA is increasing globally among adolescents and young adults (Olson et al., 2022), denoting the importance of researching the complex relationship between the use of smartphone devices and adolescent mental health.

Despite the extant literature on SA, critics have questioned the construct validity of the proposed disorder (Billieux et al., 2014; Panova & Carbonell, 2018). This is largely due to a lack of studies examining SA, particularly longitudinal studies (Panova & Carbonell, 2018; Sahu et al., 2019). Panova and Carbonell (2018) outline several nosological issues with classifying problematic smartphone use as a form of *addiction*. In this study we consider one of these issues: could SA symptoms be related to another pre-existing condition? Billieux et al. (2014) cautions against the conceptualization of SA as a distinct psychopathology; rather, they suggest that SA may be a symptom of a pre-existing psychological disorder. According to this argument, SA may be a "secondary" dysfunction experienced as a result of a "primary" disorder. Despite recent longitudinal research providing some evidence that SA is a primary disorder and presents like an addiction rather than a secondary condition (S.-Y. Lee, Lee, et al., 2020), additional research is needed to corroborate these findings. Our study focuses on a prominent example of this nosological debate: the association between digital media addictions and *Attention-deficit/hyperactivity disorder (ADHD)*.

Attention-deficit/hyperactivity disorder is a neurodevelopmental disorder typically diagnosed in childhood, characterized by dysfunctional attentional control, hyperactivity and impulsivity (Nevid et al., 2019). Extant research has demonstrated that there is a weak association between ADHD and digital media use, however, the direction of this relationship remains unclear and, as the weak association indicates, results are not entirely consistent (Beyens et al., 2018). There is some longitudinal evidence of a positive association between ADHD symptomatology and adolescents' media usage (Gentile et al., 2012; George et al., 2018; Ra et al., 2018; Tiraboschi et al., 2022), however other research contradicts these findings (Jensen et al., 2019; Levelink et al., 2020). Understanding the direction of the ADHD-media use relationship is highly significant given the rising rate of SA across the globe (Olson et al., 2022) and preliminary evidence that problematic media use may exacerbate ADHD symptomatology (Lissak, 2018). Establishing if SA is related to a pre-existing condition, or is a risk factor for subsequent conditions, may address the taxonomical critiques of SA as a disorder and inform future research. In the following section, we review current literature regarding the ADHD-media use relationship.

1.1. Media use and Attention-Deficit/Hyperactivity Disorder symptomatology

There is evidence that ADHD symptomatology is positively correlated to digital media use in children and adolescents (Bolic Baric et al., 2018; Bourchtein et al., 2019; Lo et al., 2015; Nagata et al., 2021; Tamana et al., 2019). Pre-school children who exceed the recommended 2 h a day of screen time (Tremblay et al., 2016) have an 7.7 fold increased risk for meeting criteria for ADHD (Tamana et al., 2019). Adolescents with ADHD may prefer internet activities and video games

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https://doi.org/10.1016/j.chbr.2023.100335
Received 14 September 2022; Received in revised form 9 September 2023; Accepted 10 September 2023
Available online 12 September 2023

over other traditional leisure activities, such as meeting with friends, sports, acting, and dancing (Bolic Baric et al., 2018). Furthermore, adolescents with ADHD tend to have higher total technology time, cellphone usage, and television time, and use video games twice as much (Bourchtein et al., 2019; Lo et al., 2015). Boredom proneness, sensation seeking and heightened sensitivity to stimulating activities experienced by individuals with ADHD may lead to increased media usage due to the highly stimulating nature of media activities (Chou et al., 2018; Kocyigit et al., 2021; Malkovsky et al., 2012; Weiss et al., 2011). Thus, symptoms of SA (excessive use, perceived withdrawal without a device, cravings, and smartphone dependency) may be a secondary result of ADHD rather than a unique condition. However, limited experimental and longitudinal data provide evidence of technology's effect on subsequent ADHD symptomatology.

The temporal relationship between digital media use and ADHD symptomatology is not well established. Data from an ERP/EEG study by Peng et al. (2018) suggests that internet activities reduce attentional scope experienced by college students (Peng et al., 2018). Longitudinal research also suggests a dose-response association between media use and subsequent ADHD symptomatology in pre-school children (Tan & Zhou, 2022) and adolescents (Ra et al., 2018; Tiraboschi et al., 2022). However, these findings are not entirely consistent, as other studies have found no evidence of a longitudinal relationship between baseline technology usage and subsequent ADHD symptoms (Jensen et al., 2019) or later ADHD diagnosis (Levelink et al., 2020). Some longitudinal studies suggest that the ADHD-media use relationship is bidirectional (Gentile et al., 2012; George et al., 2018). Singaporean adolescents with greater ADHD symptomatology spend more time playing video games, which subsequently lead to increased ADHD symptoms (Gentile et al., 2012). George et al. (2018) used a longitudinal design to study adolescents at high risk of mental health problems to examine the relations among social media, internet and texting usage, and ADHD symptomatology. They found that digital media usage was associated with same-day ADHD symptoms; elevated ADHD symptoms were subsequently associated with increased digital media usage the next day (George et al., 2018). A bidirectional relationship functions as a positive feedback loop, where both digital media usage and ADHD symptoms exacerbate one another. Assuming a linear relationship, we expect that high ADHD symptomatology is associated with PMU and digital media addictions.

1.2. Problematic media use and Attention-Deficit/Hyperactivity Disorder symptomatology

There is evidence of an association between various forms of PMU and ADHD in children and adolescents (Chou et al., 2018; Dullur et al., 2021; González-Bueso et al., 2018; Kocyigit et al., 2021; Paulus et al., 2018; Wang et al., 2017; Wegmann et al., 2020). A systematic review reported a consistent positive correlation between IGD and ADHD, however a lack of longitudinal studies and inconsistent results make the direction of the relationship unclear (Dullur et al., 2021; González-Bueso et al., 2018). Likewise, Internet addiction appears to be positively associated to ADHD in children and adolescents (Ko et al., 2012; Wang et al., 2017). Other types of PMU have been found to correlate with ADHD symptomatology, such as Computer Gaming Disorder (CGD) in young children between the ages of 4 and 8 (Paulus et al., 2018), and social-networks-use disorder in adults with high attentional impulsivity (a core characteristic of ADHD) (Wegmann et al., 2020).

We found 4 studies which examined the relationship between smartphone addiction and ADHD in adolescents (Kim et al., 2019; Kocyigit et al., 2021; M. Lee, Chung, et al., 2020; S.-Y. Lee, Lee, et al., 2020). Kim et al. found that the presence of ADHD had a strong association with SA in middle- and high school students in South Korea (Kim et al., 2019). This is supported by Kocyigit et al., who found that SA scores were higher in adolescents with ADHD than in those without ADHD (2021). Conversely, M. Lee et al. found that ADHD symptoms were related to IA but not SA in Korean middle school students (2020). Finally, a study by S.-Y. Lee et al. found that impulsivity (a characteristic of ADHD) was a poor prognostic factor for SA in Korean adolescents (2020). Overall, there is still insufficient longitudinal research to inform us about the directionality of this relationship.

In summary, research on the PMU-ADHD relationship has paid little attention to SA. Internet Gaming Disorder (IGD) is the only screen time-related process addiction recognized in the 5th edition of the Diagnostics and Statistical Manual of Mental Disorders (DSM-5) and thus dominates the extant PMU-ADHD literature along with general IA (Leung & Chen, 2018). The lack of SA specific studies and otherwise inconclusive findings demonstrates the need for further research on the association between smartphone devices and ADHD symptoms.

1.3. The current study

The present study aimed to investigate the direction of the relationship between self-report smartphone addiction and ADHD symptomatology in middle school students. This paper uses data from a longitudinal study that examined the effects of school cellphone policies on students' academic performance, mental health, and well-being. By using a longitudinal design, our study addresses a significant gap in the ADHD-SA literature. Smartphone addiction in this study is measured by the Smartphone Addiction Scale-Short Version (SAS-SV) (Kwon et al., 2013), which has been validated for adolescent research in several countries (Andrade et al., 2020; De Pasquale et al., 2017; Harris et al., 2020).

We hypothesized that higher SAS-SV scores at Time 1 predict a larger change in ADHD symptomatology between Time 1 and Time 2. This is based on evidence that digital media usage is associated with reduced attentional scope (Peng et al., 2018), same-day (George et al., 2018) and subsequent ADHD symptomatology (Ra et al., 2018; Tiraboschi et al., 2022) in adolescents. We also hypothesized that high levels of ADHD symptomatology at Time 1 will predict higher SAS-SV scores at Time 2. This is based on evidence that individuals with ADHD are more likely to prefer digital media over in-person activities, and use digital media for longer periods of time (Bolic Baric et al., 2018; Lo et al., 2015; Tamana et al., 2019). Furthermore, these hypotheses are supported by evidence that ADHD and media addictions are strongly related (Chou et al., 2018; Dullur et al., 2021; González-Bueso et al., 2018; Kim et al., 2019; Kocyigit et al., 2021; M. Lee, Chung, et al., 2020; S.-Y. Lee, Lee, et al., 2020; Paulus et al., 2018; Wang et al., 2017; Wegmann et al., 2020).

2. Methods

2.1. Participants

Three middle schools (Grade 6–8) in Canada agreed to participate in the study after being informed of the research goals. Each participating school distributed information about the study to parents, who were given the option to opt their child out of the study. Remaining students were then recruited as participants after informed consent was received from the school district, superintendent, school administration, parents, and students. Inclusion criteria required all participants to be: a) male or female, b) in grades 6 to 8, c) a smartphone owner, and d) attending the schools selected for the study. Students who lacked the necessary English comprehension to complete the questionnaire were excluded from the study. The final sample included 111 adolescents aged 11–14 years old (45% males), ranging from Grades 6 to 8 (27 in grade 6, 58 in grade 7 and 26 in grade 8) for whom identifiable information was available for both time points.

2.2. Procedure

Data was collected using a self-administered questionnaire at two time points over yearlong intervals between 2017 and 2020.

Questionnaires were completed electronically during class time at each respective school via the web program Survey Monkey, or on paper in the case students refused to complete the questionnaire via computer. Teachers were present during completion of the survey in case participants had any questions. While classmates and teachers were aware of students' participation in this study, measures were taken to provide anonymity. All participants were assigned numerical identifiers, and only identifiers were used in the data analysis, however demographic information was collected including age, gender, and Socio-Economic Status (SES) as measured by parents' education level. This study was approved by the authors' institutional Human Research Ethics Board and followed the research protocol outlined in the *Tri-Council Policy Statement on the Ethical Conduct for Research Involving Humans.*

2.3. Measures

2.3.1. Perceived smartphone addiction

We measured perceived smartphone addiction using the Smartphone Addiction Scale-Short Version (SAS-SV) (Kwon et al., 2013) (see appendix, Table A1). The SAS-SV is a 10-item, self-report questionnaire examining how cellphones affect individuals' day-to-day lives, such as dependence, withdrawal, and usage levels. Response options range from 1 (strongly disagree) to 6 (strongly agree). The SAS-SV was developed to assess risk for smartphone addiction in adolescent populations. The SAS-SV has shown high internal consistency and concurrent validity (Cronbach's alpha = 0.911). It was originally used with a sample of Korean adolescents (Kwon et al., 2013) but has been validated with adolescents in Italy (De Pasquale et al., 2017) and Brazil (Andrade et al., 2020), and with young adults in the United States (Harris et al., 2020). The scale accounts for gender differences in smartphone addiction and is scored out of 60. Boys are considered addicted with scores above 31 and at high risk of addiction with scores between 22 and 31, while girls are considered addicted with scores above 33 and at high risk of addiction when scores range from 22 to 33. The cut-off scores were determined by Kwon et al. (2013) after carrying out receiver operating characteristic curves using a sample of adolescents (n=150), with consultation from clinical psychologists.

2.3.2. ADHD symptoms (dependent variable)

Attention-deficit/hyperactivity disorder symptom levels were measured using a 17-item, four-point rating scale (see appendix, Table A2). Each item was adapted from the DSM-5 symptom list for ADHD. Participants reported the frequency they experienced each symptom, ranging from 1 (never or rarely) to 4 (very often). One symptom, "often does not seem to listen when spoken to directly" (Sibley & Kuriyan, 2016) was excluded from the rating scale. This scale is similar to the one used by Murphy and Barkley (1996), while being reworded for self-assessment. This measure is scored out of 68, with a higher score indicating greater levels of self-reported ADHD symptomatology, however this scale has yet to be standardized.

2.4. Statistical analysis

Statistical analyses were conducted using the IBM software SPSS Statistics Processor™ (Version 24). This study used a two-tailed alpha value of 0.05. Based on our research questions, the following hypotheses were tested: H1). SAS-SV scores at Time 1 predict a significant change in ADHD symptoms at Time 2; H2. ADHD symptoms at Time 1 predict a significant change in SAS-SV symptoms at Time 2. A cross-lagged regression model (Fig. 1) outlines the conceptual relationship between our study variables. Cross-lagged models are commonly used in psychology to test longitudinal data while controlling for autoregression of variables (Baribeau et al., 2022).

Hierarchical regression modelling was employed to test both hypotheses. Due to research showing a higher prevalence of ADHD in boys (Niemczyk et al., 2015; Vasiliadis et al., 2017), gender was added as a

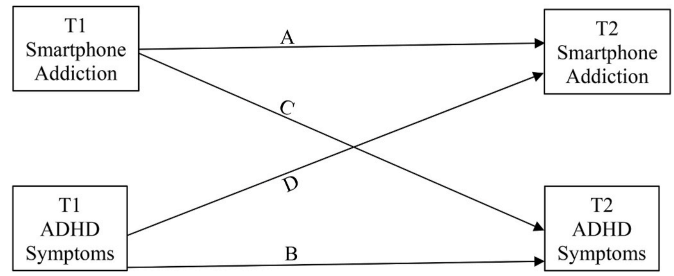

Fig. 1. Conceptual model of relationship between SA and ADHD symptomatology
Note: path a = stability of smartphone addiction; path b = stability of ADHD symptoms; path c = hypothesis 1; path D = hypothesis 2.

control variable. Additionally, by nature of using a cross lagged model, we controlled for longitudinal stability effects of study variables. Because this study was interested in extreme scores (i.e., extreme behaviours characterized by addiction or ADHD), we did not define cut-offs for outliers.

Structural Equation Modelling (SEM), which examines the relationship between multiple measured independent and dependent variables (Ullman & Bentler, 2012), is preferred to regression as it accounts for measurement error through Confirmatory Factor Analysis (CFA). However, SEM is considered a large sample analysis, and a minimum sample size is required for valid results and sufficient statistical power. The literature boasts a variety of methods to determine this minimum, including a benchmark of 200 participants or greater, or a ratio of 10 observations per indicator or greater (Dash & Paul, 2021; Koran, 2020). Other examples include Muthén and Muthén (2002), who found that a sample size of 150 is sufficient for a CFA. Alternatively, Hoyle and Gottfredson (2015) found that performance of estimators in samples around 100 can be problematic, and suggests a minimum sample of 200 for typical SEM analyses. Given our sample is less than 200, and the ratio of n to total indicators across all variables is low, SEM is likely inappropriate for our study. Even Partial Least Squares (PLS) SEM, which is often used with small samples, must be justified given a small population relative to the sample (Rigdon, 2016). Based on Krejcie & Morgan's (1970) sample size estimation table, PLS-SEM is also inappropriate for this study as the population of middle school students is too large relative to our study's sample. Additionally, we calculated the minimum sample size needed for PLS-SEM using the inverse square root method from Kock and Hadaya (2018), given a significance level of 0.05 and a path coefficient of 0.2.

$$For\ \alpha = .05, n_{min} > \left(\frac{2.486}{|\beta|_{min}}\right)^2$$

$$n_{min} > \left(\frac{2.486}{0.2}\right)^2 = 154.51$$

Based on the above calculations, the minimum sample size needed for PLS-SEM is 155. Considering these various benchmarks which suggest that a small sample size may invalidate the results of SEM, regression was used for our analysis. We comment on this issue in the limitation section of our discussion.

3. Results

In this section we report the descriptive statistics of the sample. Next, we report the test-retest reliability of our measures. We then report the results of the tests conducted to check whether the assumptions of multiple regression were met for our data (Ernst & Albers, 2017; Osborne & Waters, 2002; Tranmer & Elliot, 2008). Finally, we report the statistical results of the two hierarchical regression analyses to test our hypotheses.

3.1. Descriptives statistics

Descriptive statistics are reported in Table 1 for all measures used in this study. In our sample a majority of participants reported having two parents attend university ($n = 67$) while a substantial number were unsure of their parent's education levels ($n = 34$). Due to the lack of variability in parents' education level, SES was dropped as a control variable in the hierarchical regressions for both hypotheses.

3.2. Reliability

Cronbach's alpha was calculated to test the internal consistency and reliability of study measures. The SAS-SV (T1 $\alpha = 0.82$; T2 $\alpha = 0.88$), and the ADHD symptom measure (T1 $\alpha = 0.90$; T2 $\alpha = 0.91$), demonstrated good to excellent reliability. Cronbach's alpha of the SAS-SV is similar to other literature examining Korean ($\alpha = 0.911$) (Kwon et al., 2013), Chinese ($\alpha = 0.829$ and $\alpha = 0.881$) (Zhao et al., 2022), Spanish ($\alpha = 0.88$) (Lopez-Fernandez, 2017), French ($\alpha = 0.90$) (Lopez-Fernandez, 2017) and Iranian ($\alpha = 0.85$) (Esmaeilpour et al., 2021) populations. Intraclass correlation coefficients (ICC) with 95% confidence intervals using an absolute agreement, two-way mixed effects model was also calculated for both measures to determine test-retest reliability. Koo and Li (2016) recommend using the 95% confidence interval of the ICC estimate to determine the level of reliability rather than the ICC estimate itself. Consequently, the ADHD symptom measure (ICC = 0.76, 95% CI: 0.65–0.84) and the SAS-SV (ICC = 0.81, 95% CI: 0.72–0.87) both demonstrated moderate to good test-retest reliability. The ICC of the SAS-SV is comparable with, but lower than Zhao et al. (ICC = 0.975) (2022).

3.3. Assumptions of multiple regression

We tested 6 assumptions that must be met for multiple regression to be computed: linearity, multicollinearity, independence of residuals, homoscedasticity, normality of residuals and influential cases. Scatterplots indicate that the assumption of linearity between the IV's and DV's were met for the regression analyses used to test the first and second hypothesis. The variability inflation factor (VIF) for all factors in all models remained below 10, indicating the assumption of multicollinearity were met (Tranmer & Elliot, 2008). Obtained values from the Durbin-Watson test for both the regression used to test the first hypothesis (Durbin-Watson = 2.12) and the second hypothesis (Durbin--Watson = 2.03) indicate that both analyses met the assumption of independence of residuals (Durbin & Watson, 1971). Scatterplots of standardized residuals indicate no significant heteroscedasticity for both hypotheses. Examining the normal P–P plot of regression standardized residuals indicate that the assumption of normality of residuals may be violated for both hypotheses. Finally, Cooks distance values remained under 1 for all data, suggesting a lack of influential cases in our sample (Stevens, 1984). Overall, all assumptions of multiple regression were met with the exception of normality of residuals. Because linear regression models with sufficient sample size and observations per variable (greater than 10) are robust against violations of normality assumptions (Schmidt & Finan, 2018) we did not correct for this violation.

Table 1
Descriptives.

	Minimum	Maximum	Mean	Standard Deviation	N
ADHD 1	17	58	26.53	7.80	111
ADHD 2	17	59	26.44	8.42	111
SAS-SV 1	10	36	19.05	6.43	111
SAS-SV 2	10	38	20.14	7.33	111

Note: ADHD 1 = ADHD Symptoms Levels; SAS-SV= Smartphone addiction scale (short form); 1 = Time 1; 2 = Time 2.

3.4. Relationship between ADHD symptoms and smartphone addiction

Table 2 displays the correlations between gender, ADHD symptom level and SAS-SV at time 1 and time 2. The following section outlines the results of the analyses used to test both research hypotheses.

A hierarchical regression analysis was conducted predicting ADHD symptom levels at time 2 from SAS-SV scores at Time 1. Results of this regression are reported in Table 3. Gender was entered into the first block as a control and accounted for 4% of the variance. Attention-deficit/hyperactivity symptom levels at Time 1 was subsequently added in block 2 as additional control. This model explained an additional 35% of the variance. Finally, SAS-SV scores at Time 1 were entered into block three. This model explained an additional 4% of the variance. After controlling for gender and ADHD symptom levels at time 1, smartphone addiction scores at Time 1 were a significant predictor of ADHD symptom levels at Time 2.

A second hierarchical regression analysis was conducted predicting SAS-SV scores at Time 2 from ADHD symptom levels at time 1. Results of this regression are reported in Table 4. Gender was entered into the first block as a control and accounted for less than 1% of the variance. Smartphone addiction scale (short form) scores at Time 1 was added in block 2 as additional control; this model explained an additional 48% of the variance. Finally, ADHD symptom level scores at Time 1 were entered into block three. This model explained an additional 1% of the variance. After controlling for gender and SAS-SV scores at Time 1, ADHD symptom levels at Time 1 was not a significant predictor of SAS-SV scores at Time 2.

4. Discussion

The aim of this study was to investigate the directionality of the relationship between perceived smartphone addiction and ADHD symptomatology. In this section we discuss our findings in the context of extant literature, outline strengths and limitations of our study, make recommendations for future research, and discuss the implications of our study.

4.1. Smartphone addiction and ADHD symptomatology

We found a moderate correlation between ADHD symptoms and SAS-SV scores, which is consistent with previous research reporting an association between ADHD symptomatology and various digital media addictions (Chou et al., 2018; Dullur et al., 2021; González-Bueso et al., 2018; M. Lee, Chung, et al., 2020; Paulus et al., 2018; Wang et al., 2017; Wegmann et al., 2020). Our findings are also consistent with extant research reporting a correlation between ADHD and Smartphone Addiction in particular among adolescents (Kim et al., 2019; Kocyigit et al., 2021; S.-Y. Lee, Lee, et al., 2020). Our correlations are most comparable to the moderate correlation found between ADHD symptoms and SA ($r = 0.43$) in Korean middle-to-high school students by Kim et al. (2019).

Our first research hypothesis was supported by our results; baseline smartphone addiction scores predicted ADHD symptoms at Time 2 after

Table 2
Correlations (r).

	ADHD 1	ADHD 2	SAS-SV 1	SAS-SV 2
Gender	-.23*	-.19*	-.10	-.05
ADHD 1		.62**	.40**	.38**
ADHD 2			.43**	.47**
SAS-SV 1				.70**

Note: ADHD 1 = ADHD Symptom Levels at time 1; ADHD 2 = ADHD symptom levels at time 2; SAS-SV 1 = Smartphone addiction scale (short form) score at time 1; SAS-SV 2 = Smartphone addiction scale (short form) score at time 2. *$p < .05$ **$p < .01$.

Table 3
H1: Hierarchical regression analysis predicting ADHD symptom levels at Time 2 from SAS-SV at Time 1.

	Std β	ΔR^2	ΔF	df
Model 1		.04	4.18*	1, 109
Gender	-.19*			
Model 2		.35	60.21***	1, 108
Gender	-.06			
ADHD 1	.60***			
Model 3		.04	7.41**	1, 107
Gender	-.52			
ADHD 1	.52***			
SAS-SV 1	.22**			

Note: model 1 predictors: gender; model 2 predictors: gender, ADHD 1; model 3 predictors: gender, ADHD 1, SAS-SV 1.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Table 4
H2: Hierarchical regression analysis predicting SAS scores at Time 2 from ADHD symptom levels at Time 1.

	Std β	ΔR^2	ΔF	Df
Model 1		<.01	.25	1, 109
Gender	-.05			
Model 2		.48	100.47***	1, 108
Gender	.02			
SAS-SV 1	.70***			
Model 3		.01	2.46	1, 107
Gender	.05			
SAS-SV 1	.65***			
ADHD 1	.12			

Note: model 1 predictors: gender; model 2 predictors: gender, ADHD 1; model 3 predictors: gender, ADHD 1, SAS-SV 1.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

controlling for stability effects and gender. This finding is consistent with extant longitudinal research examining other types of digital media use (Boer et al., 2020; Gentile et al., 2012; George et al., 2018; Ra et al., 2018; Tiraboschi et al., 2022), however methodological differences in measurement tools, time periods and study design make comparisons to these studies difficult. Our longitudinal evidence suggests that smartphone addiction symptoms may be a risk factor for the development of ADHD in adolescents. Overall, our results are similar to the few extant longitudinal studies in the PMU literature, however none of these studies examine SA specifically.

Unexpectedly, our second research hypothesis was not supported: baseline ADHD symptomatology did not predict smartphone addiction scores at Time 2 after controlling for prior smartphone addition (i.e., stability effects) and gender. This finding is inconsistent with several studies, which suggest that ADHD may increase the risk of developing a digital media addiction or PMU (Chou et al., 2018; Kocyigit et al., 2021; Malkovsky et al., 2012; Weiss et al., 2011). Our finding mirrors that of Tiraboschi et al. (2022), but it is unclear whether we can compare smartphone use and video gaming. Our lack of defined cut-off scores for outliers and clinical levels of SA or ADHD symptoms may have created a floor effect, affecting the variability of our findings, and may explain why our second hypothesis was not supported. Future research should examine adolescents with clinically defined levels of SA and ADHD to increase variability and avoid a possible floor effect in study variables. For example, Ra et al. (2018) used more stringent criteria when examining ADHD symptomatology, binarily differentiating between adolescents who did experience 6 or more symptoms in either hyperactivity-impulsivity or inattention and those who did experience fewer than 6 ADHD symptoms. Additionally, the time intervals between baseline ADHD symptoms and follow-up ADHD symptoms may have been too great to accurately predict any effects. Multiphase longitudinal designs could be implemented in future research with additional time points in order to increase sensitivity to developmental changes in ADHD symptomatology. For example, Ra et al. (2018) conducted 4 follow-ups at 6-month intervals over a 24-month period and found that high frequency of ADHD use was correlated to increased odds of ADHD symptoms across follow-ups.

Notably, the work of Boer et al. (2020) used the same time interval and found similar unidirectional results regarding the relationship between social media use and ADHD symptomatology in adolescents. Using a larger sample ($n = 543$) than the present study, and a random intercept cross-lagged panel model, Boer et al. (2020) did not find an effect of ADHD symptoms on future social media use (frequency and problematic use), however problematic use of social media did increase future ADHD symptoms. The authors highlighted that the "addiction-like aspect of problematic use" (but not frequency of use) increased the risk of ADHD symptoms in their study.

4.2. *Strengths of the current study*

Our study used a longitudinal design, addressing a significant gap in the current literature examining the relationship between ADHD symptomatology and SA. Several authors noted a need for longitudinal research in this area of study (Kim et al., 2019; Nathanson & Beyens, 2018; Panova & Carbonell, 2018; Sahu et al., 2019). Furthermore, few studies have specifically investigated Smartphone Addiction's relationship to ADHD. Rather, many studies examined other types of digital media usage such as gaming or general screen time. We also provide evidence for the stability of Smartphone Addiction, which was previously lacking in the literature (Panova & Carbonell, 2018) over time. Additional longitudinal research is needed to gather evidence for the stability of SA beyond a one-year period.

Additionally, our study used an autoregressive hierarchical regression model, controlling for stability effects in SAS-SV scores and ADHD symptomatology. Despite our conservative design, smartphone addiction scores at Time 1 remained a significant predictor ($\Delta R^2 = 0.04$) of ADHD symptomatology at Time 2. According to Cohen (1988) guidelines, this effect can be considered small. However, we must consider the nature of longitudinal designs when interpreting this result. Adachi and Willoughby (2015) note that autoregressive models that control for stability effects deflate effect size, as a significant amount of variance is removed that is shared between predictors and outcomes. Therefore, longitudinal designs which use autoregressive modelling will *always* have smaller effect sizes. Beyens et al. (2018) suggests that even very small effects may still be meaningful when results demonstrate stability. Moreover, our zero-order correlations produced a medium-large effect size, ranging from $r^2 = 0.18$ to $r^2 = 0.23$. In their literature review, Beyens et al. (2018) found research on the relation between media effects and ADHD typically yields an effect size between $r = +0.10$ to $r = +0.20$. To summarize, the use of autoregressive modelling deflated variance accounted for in this study. Because we observed a large effect size compared to past cross-sectional literature, and our outcome variable demonstrated stability, the observed effect size in this study demonstrates a meaningful relationship between self-report SA and ADHD symptomatology.

4.3. *Limitations of the current study*

Our study has several limitations. Namely, the small sample size affected our choice of statistical analysis and the interpretation of our results. Given the lack of statistical power needed to conduct SEM, we instead used hierarchical regression to test our hypotheses. Linear regression has several disadvantages compared to SEM, such as failing to account for measurement error, and the inability to simultaneously test relationships between variables (Ullman & Bentler, 2012). Given the insufficient power for SEM and the limitations of regression, our results should be interpreted with caution. Future research with a sufficient sample size should replicate this study using techniques from Boer et al.

(2020) and SEM to yield greater detail on the relationship between smartphone addiction and ADHD symptomatology.

Furthermore, our sample had an unusually high socio-economic status (SES), limiting the generalizability of our findings. Socio-economic status is correlated to ADHD; lower SES populations have a higher incidence of ADHD (Russell et al., 2016). Thus, we expect our sample had a relatively lower incidence of ADHD compared to the general population. As a result, the SES of our sample may have influenced reported ADHD symptomology. This may explain why we did not detect the predicted relationship between ADHD symptomatology and SAS-SV scores. Unfortunately, due to the number of participants who did not know their parents' educational level, the variable was dropped from further statistical analyses. Future research should examine the role of SES in the relationship between smartphone addiction scores and ADHD symptomatology using a sample with normally distributed SES.

Our study also did not account for possible mediators or moderators of the relationship between smartphone usage and ADHD symptomatology. Future research should examine the nature of the relationship between these two variables. For example, research has found that digital media usage is negatively correlated with sleep quality in adolescents (Clifford et al., 2020; Mireku et al., 2019; Parent et al., 2016; Woods & Scott, 2016). A review of the literature found that poor sleep is related to and may exacerbate symptoms of ADHD (Cavalli et al., 2021; Lundahl et al., 2015). Future research should examine the mediating or moderating role of sleep in the relationship between smartphone usage and ADHD symptomatology.

Our study did not differentiate between clinical levels and sub-or-non-clinical levels of ADHD symptomatology. Thus, our findings cannot generalize to clinical samples of adolescents, and causal inferences between clinical ADHD and SA remain unclear. Future studies should emulate Ra et al. (2018), who categorically differentiated between participants with and without clinical levels of ADHD symptomatology. Additionally, future studies should examine the cut-off scores in the SAS-SV. Creating these categorical variables allows for between-group comparisons, providing additional information on smartphone addiction in clinical adolescent samples, a notable gap in the literature (Panova & Carbonell, 2018).

Additionally, some researchers have cited concerns about self-report data and problematic media usage questionnaires. First, self-report data, while convenient, is unreliable and does not strongly correlate to objective digital media usage (Ellis et al., 2019; Scharkow, 2016; Shaw et al., 2020). Self-report data on screen time demonstrates regression towards the mean; high screen time individuals tend to under-report, while low screen time individuals over-report (Scharkow, 2016). Furthermore, the use of smartphone addiction scales may inflate the relationship between screen time and health outcomes (i.e. ADHD symptoms) when compared to objective measures (Ellis et al., 2019; Shaw et al., 2020), or measures with less-biased wording (Panova & Carbonell, 2018). Some researchers suggest objective measures of screen time should be used as opposed to self-report scales when examining the relationship between screen time and health outcomes (Ellis et al., 2019; Shaw et al., 2020). However, only examining objective measures of screen time would ignore a significant predictor of health outcomes, perceived psychological distress (Barry et al., 2020). The purpose of this study was not to examine time spent on mobile devices as a variable of interest, rather we focused on the relationship participants had with their smartphones and its effect on health outcomes. Future longitudinal research should investigate the relationship between objective measures of smartphone use and ADHD symptomatology.

Furthermore, smartphone addiction scales may mask the addictive or specific problematic behaviour enacted on devices (i.e., gambling, gaming, pornography) (Panova & Carbonell, 2018). Thus, specific purposes of smartphone use may drive the relationship between smartphone addiction scales and ADHD symptomatology in this study. Future research should examine the relationship between objective measures of screen time, self-report data, specific types of digital media activities (i.e., pornography, social media, shopping, exercise/health aids, education, work, gaming), and health outcomes. Exploring these three aspects of digital media behaviour (objective measures, self-report data and purpose of use) may help to further clarify the complex relationship between digital media use and health outcomes. Indeed, recent research suggests that mental health outcomes may vary with the purpose of use (Twenge & Farley, 2021).

5. Conclusions

Our findings provide evidence that perceived smartphone addiction predicts self-reported ADHD symptomatology in a community sample of middle school adolescents. These results suggest that the *quality* of adolescent users' relationship with devices may predict future mental health outcomes. For example, adolescents with an unhealthy relationship with smartphones, characterized by perceived symptoms of smartphone addiction (i.e., cravings, urges, distress due to smartphones) may have an increased risk of future ADHD symptoms. Likewise, an adolescent who uses smartphones but does not experience symptoms of SA may be at lower risk. Our study provides guidance for future studies on the relationship between smartphone use on ADHD symptoms, an area of research where many gaps remain.

Funding

This study was supported by the Social Sciences and Humanities Research Council (SSHRC).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

I would like to thank Professor Jonathan Rush (Department of Psychology, University of Victoria) for offering his time and providing consultation for our statistical analysis.

Appendix A

Table A1
Smartphone Addiction Scale (Short Version)

	Items	Strongly disagree	Disagree	Weakly disagree	Weakly agree	Agree	Strongly agree
1	Missing planned work due to smartphone use	1	2	3	4	5	6

(*continued on next page*)

Table A1 (*continued*)

Items		Strongly disagree	Disagree	Weakly disagree	Weakly agree	Agree	Strongly agree
2	Having a hard time concentrating in class, while doing assignments, or while working due to smartphone use	1	2	3	4	5	6
3	Feeling pain in the wrists or at the back of the neck while using a smartphone	1	2	3	4	5	6
4	Won't be able to stand not having a smartphone	1	2	3	4	5	6
5	Feeling impatient and fretful when I am not holding my smartphone	1	2	3	4	5	6
6	Having my smartphone in my mind even when I am not using it	1	2	3	4	5	6
7	I will never give up using my smartphone even when my daily life is already greatly affected by it.	1	2	3	4	5	6
8	Constantly checking my smartphone so as not to miss conversations between other people on Twitter or Facebook	1	2	3	4	5	6
9	Using my smartphone longer than I had intended	1	2	3	4	5	6
10	The people around me tell me that I use my smartphone too much.	1	2	3	4	5	6

Note: from Kwon et al. (2013).

Table A.2
Attention-Deficit/Hyperactivity Disorder symptomatology scale

Items		Never or rarely	Sometimes	Often	Very
1	In the past 30 days, I fail to give close attention to details or make careless mistakes in my work	1	2	3	4
2	In the past 30 days, I fidget with hands or feet or squirm in seat	1	2	3	4
3	In the past 30 days, I have difficulty sustaining my attention in tasks or fun activities	1	2	3	4
4	In the past 30 days, I leave my seat in classroom or in other situations in which seating is expected	1	2	3	4
5	In the past 30 days, I feel restless	1	2	3	4
6	In the past 30 days, I don't follow through on instructions and fail to finish work	1	2	3	4
7	In the past 30 days, I have difficulty engaging in leisure activates or doing fun things quietly	1	2	3	4
8	In the past 30 days, I have difficulty organizing tasks and activates	1	2	3	4
9	In the past 30 days, I feel "on the go" or "driven by a motor"	1	2	3	4
10	In the past 30 days, I avoid, dislike, or I am reluctant to engage in work that requires sustained mental effort	1	2	3	4
11	In the past 30 days, I talk excessively	1	2	3	4
12	In the past 30 days, In the past 30 days, I lose things necessary for tasks or activities	1	2	3	4
13	In the past 30 days, I blurt out answers before question have completed something that happened to me.	1	2	3	4
14	In the past 30 days, I get easily distracted	1	2	3	4
15	In the past 30 days, I have difficulty waiting turn	1	2	3	4
16	In the past 30 days, I am forgetful in daily activates	1	2	3	4
17	In the past 30 days, I interrupt or intrude on others	1	2	3	4

Note: based on Murphy and Barkley (1996).

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