2020

Bidirectional Associations Between Passive and Active Technology Use and Sleep: A Longitudinal Examination in Young Adolescents with and without ADHD

Elizaveta Bourchtein
Virginia Commonwealth University

Bidirectional Associations Between Passive and Active Technology Use and Sleep: A Longitudinal Examination in Young Adolescents with and without ADHD

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

by

Elizaveta Bourchtein,
Master of Science, Clinical Psychology
Virginia Commonwealth University, 2016

Major Director: Joshua M. Langberg, Ph.D.
Professor, Department of Psychology

Virginia Commonwealth University
Richmond, VA
April, 2020

Acknowledgment

In this time of global uncertainty, it is easy for me reflect on all of the people and circumstances that have brought me to this point in my graduate training. My mentor and dissertation chair, Joshua Langberg, has been instrumental in my growth as a researcher and writer throughout my entire time as a graduate student. Through his mentorship, he modeled not only how to conduct innovative, relevant, and meaningful research, but also how to be a compassionate, fair, and thoughtful educator, supervisor, mentor, and colleague. I am immensely grateful for his warm, tireless, and student-focused support over the past six years. I also appreciate the environment that he and my labmates cultivated in the PASS lab. The hardworking ethic of our lab was an inspiration for me, and our numerous lake days and game nights bolstered my energy throughout graduate school. I am also thankful to my dissertation committee members, Heather Jones, Bruce Rybarczyk, Cecelia Valrie, and Jennifer Accardo, for their feedback and guidance on my dissertation. In addition, I am incredibly grateful for the faculty at VCU and my clinical supervisors who were pivotal in my journey to becoming a pediatric psychologist.

The brightest part of my graduate school experience in general and writing this dissertation in particular has been the unwavering support of my friends and family. I am especially appreciative of the strong, kind, positive, and inspirational group of women that makes up my graduate school cohort. I am immensely grateful to my parents, Marina and Mikhail, for their support and patience throughout all of our international moves and stages of my life that brought me to this point. The love, laughter, and lightheartedness from my brother, Alexey, and my maternal grandparents, Bela and Mikhail, buoyed me during this process. My paternal grandmother, Tatiana, instilled in me a passion for and curiosity towards research and learning. My partner, Logan: with the unconditional love and encouragement you show me every day, there is nothing I can’t do. You motivate me to work hard and remind me to always consider the bigger picture. Lastly, my paternal grandfather, Abram – his sage advice (delivered over the phone from Russia) and level-headed approach to all aspects of life were crucial in helping me achieve my goal of preparing this dissertation and attaining my degree in clinical psychology. Спасибо вам всем – I am forever thankful.

This dissertation study was supported by funding (R305A150207) awarded to Virginia Commonwealth University (VCU) from the Institute of Educational Sciences (IES). The findings, conclusions, and recommendations expressed in this document are those of the author and do not necessarily reflect the views of IES.

List of Tables v
List of Figures vii
Abstract 1
Introduction 3
Measurement of Sleep 3
Sleep and Attention Problems 5
Sleep and Technology Use 7
Technology Use and ADHD 10
Statement of the Problem 12
Present Study 13
Method 18
Participants 18
Procedure 18
Measures 21
Analytic Plan 25
Power 26
Missing Data 26
Results 28
Discussion 33
Group Differences in Technology Use 34
Technology Use and Subsequent Sleep 37
Sleep and Subsequent Technology Use 40
Limitations and Future Directions 41
Implications and Conclusion 44
References 47

List of Tables

Table 1. Sample Characteristics…………………………………………………………….63

Table 2. Variable Summary Information………………...……………………………………64

Table 3. Bivariate Correlations between Study Variables…………………………………….65

Table 4. Differences in Passive Technology Use Between Adolescents with
and without ADHD……………………………………………………………………66

Table 5. Differences in Active Technology Use Between Adolescents with
and without ADHD……………………………………………………………………67

Table 6. Association Between Passive Technology Use and Sleep Quality
Moderated by ADHD Status…………………………………………………………..68

Table 7. Association Between Passive Technology Use and Sleep Duration
Moderated by ADHD Status…………………………………………………………..69

Table 8. Association Between Active Technology Use and Sleep Quality
Moderated by ADHD Status…………………………………………………………..70

Table 9. Association Between Active Technology Use and Sleep Duration
Moderated by ADHD Status…………………………………………………………..71

Table 10. Association Between Sleep Quality and Passive Technology Use
Moderated by ADHD Status…………………………………………………………..72

Table 11. Association Between Sleep Duration and Passive Technology Use
Moderated by ADHD Status…………………………………………………………..73

Table 12. Association Between Sleep Quality and Active Technology Use
Moderated by ADHD Status…………………………………………………………..74

Table 13. Association Between Sleep Duration and Active Technology Use

Moderated by ADHD Status……………………………………………………………..75

List of Figures

Association between Weekday Passive Technology Use and Actigraphy-Measured Sleep Duration Moderated by ADHD Status……………………………………………………………76

Abstract

BIDIRECTIONAL ASSOCIATIONS BETWEEN PASSIVE AND ACTIVE TECHNOLOGY USE AND SLEEP: A LONGITUDINAL EXAMINATION IN YOUNG ADOLESCENTS WITH AND WITHOUT ADHD

By Elizaveta Bourchtein, M.S.

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

Virginia Commonwealth University, 2020.

Major Director: Joshua M. Langberg, Ph.D., Professor, Department of Psychology

Many adolescents do not receive recommended amounts of sleep, and prevalence rates of sleep problems are particularly high among adolescents with attention-deficit/hyperactivity disorder (ADHD). One factor that may contribute to these sleep difficulties is technology use, and there is some evidence that the association between technology use and sleep may be bi-directional. Further, type of technology use (i.e., passive versus active) may be differentially associated with sleep. To date, most studies have evaluated these associations cross-sectionally and relied upon global and subjective ratings of technology use and sleep, which masks important day-to-day variability. The present study evaluated bi-directional associations between passive and active technology use and sleep (measured subjectively and objectively), and to determine whether these associations differ between adolescents with and without ADHD. The study involved a large (N=302) sample of eighth grade students, approximately half of whom were comprehensively diagnosed with ADHD. Importantly, a multi-method approach was used to assess sleep, including daily diary and actigraphy data. Results indicated that adolescents with ADHD engaged in greater levels of weekday active technology use than those without ADHD. Weekday passive technology use was positively associated with sleep duration only in adolescents without ADHD. In addition, poorer weekday sleep quality was associated with less passive but more active next-day technology use, regardless of ADHD diagnosis. Overall, the association between technology use and sleep is nuanced but not stronger in adolescents with ADHD, despite a greater amount of weekday active technology use. Clinical implications for adolescents, parents, and healthcare providers are discussed.

Keywords: sleep, technology, attention-deficit/hyperactivity disorder, adolescence

Introduction

Sleep is an important physiological process that is linked to numerous aspects of health and functioning. In children and adolescents, sleep affects a variety of domains, including mental health, social functioning, and academics (Bartel et al., 2015). Optimal sleep amount varies over the course of development, with 9-11 hours recommended for children ages 6-13 years and 8-10 hours recommended for adolescents ages 13-17 years (Hirshkowitz et al., 2015). However, many youth do not receive recommended amounts of sleep, with around one-third of school-aged youth experiencing at least one night of inadequate sleep each week (Smaldone et al., 2007).

Sleep problems are especially prevalent during adolescence, with up to 70% of adolescents sleeping less than the recommended nine hours each night and 20% sleeping fewer than six hours on weeknights (Roberts et al., 2009). It has been posited that this period of development is the “perfect storm” in terms of risk factors that may reduce sleep duration and quality (Carskadon, 2011). With the onset of puberty, youth experience a delay in their circadian timing system, leading to later desired bed- and wake times. Early school start times often do not align with adolescents’ natural sleep cycle and therefore contribute to reduced sleep duration. This is typically coupled with increased autonomy, including fewer parental restrictions and reduced monitoring of sleep. Lastly, internalizing problems often increase in prevalence at the onset of puberty, which may interfere with sleep patterns (Dahl & Lewin, 2002).

Measurement of Sleep

Sleep is defined as a “reversible behavioral state of perceptual disengagement from and unresponsiveness to the environment” (Carskadon & Dement, 2011). The measurement of sleep is complex, and there are many different ways to evaluate sleep. Some of the most commonly reported sleep parameters include total sleep time (i.e., sleep duration), sleep onset latency (SOL;

how long it takes one to initiate sleep after beginning their attempt to sleep), wake after sleep onset (i.e., how long one is awake during the sleep period after initial sleep onset), sleep efficiency (percent of time in bed that one spends asleep, calculated by dividing total sleep time by total time in bed), and sleep quality (a subjective evaluation of how well one slept). These and other sleep parameters can be measured both subjectively (from both the adolescent and parent perspectives) and objectively.

Subjective measures of sleep are gathered by asking participants (or proxies, such as parents in younger children) to report on various aspects of their sleep. These may be collected via global assessments, such as rating scales, or day-to-day measures, most commonly via a daily sleep diary. Global assessments typically require raters to think back over a (sometimes unspecified) period of time and provide an aggregate estimate of sleep parameters. The accuracy of these kinds of assessments for sleep has been brought into question (Matricciani, 2013). As such, guidelines for collecting subjective measures of sleep include asking about a recent and time-limited period (e.g., the last five days) and specifying weekdays and/or weekends (Matricciani, 2013). For this reason, daily diaries, which are less prone to recall bias and more likely to detect intra-night variability, may be an optimal way to subjectively assess a number of sleep parameters.

Objective measures of sleep are collected using technological devices. The gold standard of sleep assessment is polysomnography (PSG), which examines a multitude of sleep-related markers in detail using, among other devices, an electroencephalogram, an electromyogram, and an electrooculogram (Carskadon & Dement, 2011). However, PSG is costly and must be interpreted within the context of known first-night effects. As such, studies that incorporate objective measures of sleep architecture often use the more cost-effective and less intrusive actigraphy device. This device records the wearer's movement and uses these data to estimate a sleep/wake pattern using validated scoring algorithms. Because the device is relatively inexpensive and unobtrusive, it is especially useful for multi-night data collection. Numerous studies indicate that actigraphy has high (94%) overall agreement with PSG and is a reliable way to estimate most sleep parameters in youth (Sadeh, 2011). However, actigraphy has been shown to overestimate wake after sleep onset in adolescents, particularly in clinical populations, due to the misinterpretation of sleep movements as wakefulness (Short et al., 2012). In addition, actigraphy is not able to assess the subjective quality of one's sleep. As such, sleep diaries are especially useful for assessing certain aspects of sleep, including sleep quality (Paquet et al., 2007). Given that sleep quality and duration are independent domains of sleep that are poorly correlated and are differentially associated with outcomes (Dewald et al., 2010), it is imperative that both subjective measures of sleep quality and objective measures of sleep duration are included when examining factors related to sleep.

Sleep and Attention Problems

Sleep problems are particularly salient for youth with mental health conditions, including attention-deficit/hyperactivity disorder (ADHD). ADHD is a prevalent neurodevelopmental disorder characterized by clinically elevated levels of inattention and/or hyperactivity/impulsivity (American Psychiatric Association, 2013; Visser et al., 2013). Youth with ADHD also display impairment in multiple domains of functioning, including academics, social development, and emotional functioning (Daley & Birchwood, 2010). However, much of the variance in understanding the functional outcomes of adolescents with ADHD remains unexplained (Langberg et al., 2011).

One possible reason that youth with ADHD are at greater risk for negative outcomes is inadequate sleep; between 25% and 50% of youth with ADHD also display sleep difficulties (Meltzer & Mindell, 2006). Children with ADHD consistently report difficulty across a number of areas of sleep, such as going to bed, returning to wakefulness, and overall sleep quality (LeBourgeois et al., 2004). A meta-analysis by Cortese et al. (2009) found that, according to subjective reports, children with ADHD have increased difficulty in the following areas: bedtime resistance, SOL, night awakenings, problems with morning awakenings, daytime sleepiness, and sleep disordered breathing. The same meta-analysis also indicated elevated problems on some objective sleep measures (i.e., PSG, actigraphy, and multiple sleep latency test), including SOL, shifts in sleep stages per hour, sleep disordered breathing, sleep efficiency, sleep duration, and daytime sleepiness. It is important to note that this meta-analysis excluded studies in which participants were taking any psychotropic medication; as such, sleep differences could not be attributed to ADHD medication use. Another meta-analysis consisting solely of PSG studies concluded that youth with ADHD were more likely to display periodic limb movements in sleep, but did not differ on any other sleep parameters or sleep disordered breathing in comparison to youth without ADHD (Sadeh et al., 2006). These discrepancies between subjective and objective metrics of sleep in youth with ADHD further highlight the importance of collecting both types of measurements (Cortese et al., 2013; Morgenthaler et al., 2006).

Despite evidence for increased sleep problems for youth with ADHD, there is a paucity of research evaluating why this is the case (i.e., predictors of sleep problems; Davidson et al., 2019). Further, the majority of sleep and ADHD research completed to date has been with elementary-school-age youth (Cortese et al., 2009; Diaz-Roman et al., 2016). In fact, a recent systematic review of sleep in adolescents with ADHD identified a total of 25 studies, with only six including objective assessments of sleep or longitudinal data (Lunsford-Avery et al., 2016). This is noteworthy given the important developmental considerations for sleep during adolescence and the likelihood that developmentally unique predictors of sleep problems exist.

Sleep and Technology Use

Technology use – the use of electronic media including, but not limited to, mobile phones, television, tablets, computers, and video games – is highly prevalent among adolescents, with the average adolescent engaging in several hours of screen time each day (Rideout et al., 2015). Further, 92% of teenagers report going online daily and 24% report using the internet "constantly" (Lenhart et al., 2015). Importantly, as related to sleep, technology use extends to the bedroom, where 97% of US adolescents report having access to at least one form of technology (National Sleep Foundation, 2006).

There is ample correlational research documenting a negative association between technology use and sleep duration and quality in youth. Specifically, greater amounts of technology use are associated with reduced sleep duration, longer SOL, and a delayed bedtime (Cain & Gradisar, 2010; Hysing et al., 2016). As such, limiting technology is often a strategy included in sleep hygiene recommendations given by healthcare providers (Allen et al., 2016). However, the majority of studies on technology use and sleep assesses technology use globally (e.g., a rating scale asking about general television viewing practices), and few studies have examined the impact of technology use on sleep experimentally or longitudinally. In one longitudinal study, the weekly frequency of technology use specifically in the hour before going to sleep predicted reduced actigraphy-measured sleep duration during school nights and greater SOL during non-school nights in high school students (Harbard et al., 2016). Another study that experimentally manipulated technology use (i.e., by showing movies and computer games) in a small (*N*=11) sample of young adolescent boys found reduced subjectively- and objectively-rated sleep efficiency and SOL, but no differences in sleep duration (Dworak et al., 2007). A large-scale (*N*=1713) study of young children (ages 2 and 6 years) determined that longer television viewing (i.e., more than 1.5 hours per day) predicted reduced parent-reported child sleep duration 2-3 years later, when controlling for a number of relevant factors (Marinelli et al., 2014). Overall, more experimental and longitudinal studies that incorporate objective measures of sleep are needed to evaluate whether technology use has deleterious effects on subsequent sleep duration in adolescents.

Several explanations for the association between technology use and sleep have been proposed (Cain & Gradisar, 2010; Moorman et al., 2019). First, technology use may displace time that would normally be reserved for sleep. Second, the content accessed via screens may increase physiological arousal that interferes with the sleep process. Lastly, light from screens may interfere with melatonin secretion, thus reducing drowsiness. However, the link between technology use and sleep may be nuanced, and the *type* of technology being used may be important.

A distinction between passive and active technology use has emerged in the literature (Sweetser et al., 2012). Whereas passive technology use involves simply viewing content on a screen (e.g., watching television/movies), active technology use is more interactive (e.g., playing video or computer games). This interactive aspect may have physiological consequences: video game play has been linked to increases in diastolic and systolic blood pressure, heart rate, and oxygen consumption (Wang & Perry, 2006). Although there is some evidence that certain types of active technology use (e.g., video games that require movement, such as those used on the Wii platform) may increase physical activity levels in youth (Maddison et al., 2007), it is also conceivable that the physiological changes that occur during electronic game play could interfere with sleep processes. For instance, self-reported computer game play is negatively correlated with self-reported time in bed in adolescents; similarly, adolescent-reported video game play is inversely associated with sleep quality (Turel et al., 2017; Van den Bulck, 2004). One experiment exposed children to either excessive television or excessive computer game play two to three hours before bedtime and measured their consequent sleep period using PSG (Dworak et al., 2007). Results indicated that computer games, but not television, decreased slow-wave sleep (possibly reflecting an increased arousal state) and increased SOL to a clinically elevated level (>30 minutes). Television viewing reduced sleep efficiency, although it continued to be within normal limits (>85%). However, other studies relying on adolescent- or parent-report of passive technology use and sleep have found that television viewing is also negatively associated with time in bed and sleep quality (Brockmann et al., 2015; Van den Bulck, 2004). Given possible differences between the impact of active and passive technology use on sleep, there have been increased calls for tailored recommendations regarding technology use for adolescents (Neumann, 2015). However, more research on specific day-to-day longitudinal effects of active versus passive technology use on outcomes, including sleep, is needed before best-practice recommendations can be adapted.

There is some evidence to suggest that the link between sleep and technology use is bidirectional, although this is not a consistent finding (Cain & Gradisar, 2010; de Zambotti et al., 2018). For instance, children who have trouble sleeping may use technology to help themselves fall asleep or to fill the time until their later sleep onset. A cross-sectional population-based study of a large sample of youth in Greece found that those with insufficient sleep reported significantly more technology use (approximately one hour more of screen time per week in both children and adolescents; Tambalis et al., 2018). In one longitudinal study, parent-reported daily diary data revealed a bidirectional relation between sleep duration and media use over a four-year period starting in preschool, such that sleep predicted later media use and vice versa (Magee et al., 2014). Interestingly, in a sample of university students, sleep problems predicted later technology use, whereas technology use was not related to later sleep difficulties (Tavernier & Willoughby, 2014). These findings suggest that associations between technology use and sleep are complex and may change over development, further highlighting the importance of longitudinal research. Notably, all of the studies cited above relied solely on subjective assessment of sleep.

Technology Use and ADHD

Emerging but largely cross-sectional research indicates that youth with ADHD or elevated ADHD symptoms may be especially prone to engaging in problematic technology use. Adolescents with ADHD spend twice as much time per day playing video games relative to those without ADHD (61 vs. 31 minutes, respectively; Bourchtein et al., 2019). This group also engages in longer daily television/movie viewing, although the differences are smaller (59 vs. 51 minutes). Similarly, a study conducted in Turkey found that adolescents with ADHD used social media (via technology) more than their non-ADHD counterparts (Gul et al., 2018). Results of two longitudinal studies conducted in Taiwan suggest that youth who display symptoms of ADHD are more likely to engage in later problematic internet use, defined by the authors as showing signs of internet addiction (Chen et al., 2015; Ko et al., 2009). Further, there is some evidence that boys with ADHD have greater access to video games in their bedroom and engage in higher levels of problematic (i.e., addictive) video game play relative to boys without ADHD (Mazurek & Engelhardt, 2013). However, this study consisted solely of parent-report of technology use and focused on video game use occurring in the bedroom to the exclusion of other instances and locations of technology use. In sum, youth with ADHD may engage in greater amounts of technology use, but these cross-sectional and global estimates need to be confirmed using nuanced, daily measures.

Further, although there appear to be differences in technology use between youth with and without ADHD, almost no studies have examined the link between technology use and sleep in this population. One cross-sectional study used parent report to examine the association between technology use and sleep in youth with developmental disabilities, 33% of whom met criteria for ADHD (Aishworiya et al., 2018). In this sample, greater rates of technology use were associated with shorter sleep duration, with sleep being reduced by 1 minute for each additional 9 minutes of screen time. However, this study did not include a typically-developing comparison group. One study with a comparison group found that the association between media use in the bedroom and sleep duration did not differ between boys with and without ADHD (Engelhardt et al., 2013). However, this study was cross-sectional and only examined media use in the child's bedroom rather than cumulative effects of screen time overall, and sleep was assessed using parent report only. Similarly, a cross-sectional study by Bourchtein et al. (2019) using the present sample also found that although technology use was associated with sleep parameters (such as sleep duration and sleep/wake problems), ADHD status did not moderate this relation. Conversely, ADHD status did moderate the association between technology use and teacher-reported daytime sleepiness, such that the association was only significant for adolescents with ADHD. Overall, the literature base is limited, and a lack of longitudinal studies precludes the ability to determine the directionality of the association between technology use and sleep in adolescents with ADHD.

It is possible that the effects of technology use on sleep in youth with ADHD may differ or be amplified relative to youth without ADHD. There are known physiological markers of ADHD. For instance, youth and adults with ADHD show elevated parasympathetic activity (Musser et al., 2011), unstable vigilance regulation (Geissler et al., 2014), greater heart rate variability (Börger & Van Der Meere, 2000), and dysregulated respiratory sinus arrythmia withdrawal (which is linked to emotion regulation; McQuade & Breaux, 2017). Given these baseline physiological differences, the effects of technology use, particularly active use, in children with ADHD may differ in magnitude relative to youth without ADHD. Interestingly, one study of Korean children with ADHD found that internet usage time and problematic internet use were significantly reduced after eight weeks of treatment with OROS-methylphenidate (Han et al., 2009). The authors posited that youth with ADHD may be engaging in internet use (and specifically internet-based video games) in order to self-medicate their ADHD symptoms. An evaluation of bidirectional associations between passive and active technology use and subjectively- and objectively-measured sleep outcomes in youth with and without ADHD is needed to begin to evaluate whether type of technology use matters, and whether any associations are stronger in youth with ADHD.

Statement of the Problem

As summarized above, there is a relative dearth of research on the interplay between technology use and sleep, particularly in youth with ADHD. First, although there is preliminary evidence that adolescents with ADHD engage in greater amounts of technology use, prior studies have used global ratings, which provide estimates of ranges of time for typical technology use instead of specific amounts of daily technology use. Second, despite the demonstrated link between technology use and sleep problems in the general adolescent population, no studies have evaluated the longitudinal effects of technology use on sleep in adolescents with ADHD, and whether they differ from adolescents without ADHD. Additionally, the reverse relation (effects of sleep on later technology use) has been inadequately examined, and there is some evidence suggesting a bidirectional link. Third, although there are known differences between passive and active technology use, little is known about whether different types of technology use differentially impact sleep. Further, whereas youth with ADHD have been found to engage in significantly greater rates of active and somewhat greater rates of passive technology use relative to youth without ADHD, no study has examined differential associations between these two types of technology use and sleep in adolescents with ADHD.

Finally, no study has examined these associations using day-to-day measures, such as daily diaries and actigraphy, instead choosing to aggregate data to mean estimates of typical technology use and sleep duration. Emerging evidence suggests that there is significant day-to-day variability in sleep in adolescence, particularly among those with ADHD (Langberg et al., 2019). As such, it is imperative to evaluate the direct, immediate effects of technology use on that night's sleep, as well as whether the prior night's sleep relates to next-day technology use. Determining whether these associations are different in adolescents with ADHD as compared to those without ADHD has clinical implications.

Present Study

The present study sought to elucidate bi-directional associations between passive and active technology use and sleep, and whether they vary as a function of ADHD status. These questions were evaluated in a large sample of comprehensively-diagnosed adolescents with ADHD and a well-matched comparison sample using objective and subjective measures. Specifically, data from actigraphy and daily sleep diaries were used to reduce recall bias and enhance ecological validity. Importantly, the study focused on late middle school, a developmental period when significant changes in sleep occur (Carskadon, 2011).

It is important to note that two recent studies have examined sleep in the present sample, and these studies helped inform the aims of the current study. In the first study, sleep was assessed subjectively and objectively among participants with and without ADHD (Becker et al., 2019). Subjective sleep measures (i.e., adolescent daily diaries) indicated that that 20% of adolescents with ADHD and 10% of those without ADHD reported obtaining fewer than seven hours of sleep per night on weekdays. Objectively-assessed sleep duration (i.e., actigraphy) on weekdays was slightly greater, with 13% and 8% of adolescents with and without ADHD obtaining fewer than seven hours of sleep per night, respectively. This is relatively in line with prior studies that have found that 20% of adolescents (with a larger age range) report obtaining fewer than 6 hours of sleep per night (Roberts et al., 2009), and suggests that the present sample is representative of young adolescents generally with regards to sleep. Additionally, parent and adolescent ratings at the group level indicated the presence of significantly more sleep problems in participants with ADHD compared to those not diagnosed with the disorder (Becker et al., 2019). Specifically, daily diaries from adolescents revealed that those with ADHD had significantly longer SOL, earlier wake time, and reduced sleep duration. Actigraphy supported some of these findings, with adolescents diagnosed with ADHD having a shorter sleep duration relative to their non-ADHD peers. These findings were in line with previous studies of sleep in youth with ADHD, wherein some, but not all, sleep problems were amplified relative to youth without ADHD, depending on how sleep was assessed and the type of sleep problem.

Second, participants with ADHD in this sample were found to have greater rates of some (i.e., video games), though not all, types of technology use according to both parent and adolescent global ratings of technology use (Bourchtein et al., 2019). Further, total technology use was associated with more adolescent-rated sleep-wake problems and shorter school-night sleep duration. Moderation analyses revealed no significant differences between youth with and without ADHD. These findings were in line with prior research finding no differential effects of ADHD diagnosis on the link between technology use and sleep (Engelhardt et al., 2013). However, this study by Bourchtein et al. (2019) was cross-sectional, limiting conclusions about the directionality of the association between sleep and technology use. Further, technology use and sleep were assessed through global and subjective estimates (parent and adolescent ratings) rather than through day-to-day measures such as daily diaries and actigraphy, and passive versus active technology use was not differentiated. Thus, the present study builds on these findings by examining daily passive (i.e., television/movies) and active (i.e., video games) technology use and bi-directional associations with objectively- and subjectively-measured sleep among adolescents with and without ADHD.

Aim 1. Evaluate differences in passive (i.e., television) and active (i.e., video game) technology use between adolescents with and without ADHD.

Hypothesis 1. Based on prior cross-sectional findings that adolescents with ADHD engage in significantly greater levels of television and video game use (Bourchtein et al., 2019), it was hypothesized that adolescents with ADHD would have greater passive and active technology use relative to adolescents without ADHD based on adolescent daily diary report.

Aim 2. Evaluate whether passive technology use is differentially longitudinally associated with sleep in adolescents with ADHD as compared to those without ADHD.

Hypothesis 2a: Passive technology use and subjective assessment of sleep (i.e., sleep quality). Based on prior research (Brockmann et al., 2016), we predicted a negative association between passive technology use and sleep quality. Given previous findings that ADHD status does not moderate the cross-sectional association between global screen time and subjectively-report sleep problems (Bourchtein et al., 2019; Engelhardt et al., 2013), we predicted that ADHD status would not moderate the longitudinal association between passive technology use and adolescent-reported sleep quality.

Hypothesis 2b: Passive technology use and objective assessment of sleep (i.e., sleep duration). Given prior findings that television use is negatively correlated with adolescent-reported time in bed (Van den Bulck, 2004), we predicted a negative association between passive technology use and sleep duration. We predicted that ADHD status would not moderate the longitudinal association between passive technology use and objectively-measured sleep duration.

Aim 3. Evaluate whether active technology use is differentially longitudinally associated with sleep in adolescents with ADHD as compared to those without ADHD.

Hypothesis 3a: Active technology use and subjective assessment of sleep (i.e., sleep quality). Based on prior research (Turel et al., 2017), we predicted that active technology use and sleep quality would be negatively associated. Given the known baseline physiological differences between youth with and without ADHD (e.g., McQuade & Breaux, 2017) as well as the physiological changes that active technology use produces (Wang & Perry, 2006), we hypothesized that the longitudinal association between active technology use and adolescent-reported sleep quality would be significantly stronger in adolescents with ADHD relative to adolescents without ADHD.

Hypothesis 3b: Active technology use and objective assessment of sleep (i.e., sleep duration). We hypothesized a negative association between active technology use and sleep duration. We also hypothesized that active technology use would be more strongly longitudinally associated with sleep duration in adolescents with ADHD relative to those without the disorder.

Aim 4. Evaluate whether sleep is differentially longitudinally associated with next-day passive technology use in adolescents with ADHD as compared to those without ADHD.

Hypothesis 4a: Subjective assessment of sleep (i.e., sleep quality) and passive technology use. Based on prior findings that general sleep problems are associated with overall media use (Tavernier & Willoughby, 2014), we predicted that adolescent-reported sleep quality would be significantly associated with next-day passive technology use, regardless of ADHD status.

Hypothesis 4b: Objective assessment of sleep (i.e., sleep duration) and passive technology use. Based on prior research indicating that sleep duration is linked to media use (Magee et al., 2014), we hypothesized a negative association between sleep duration and next-day passive technology use. We also predicted that the association between objectively-measured sleep duration and next-day passive technology use would be significant, regardless of ADHD status.

Aim 5. Evaluate whether sleep is differentially longitudinally associated with next-day active technology use in adolescents with ADHD as compared to those without ADHD.

Hypothesis 5a: Subjective assessment of sleep (i.e., sleep quality) and active technology use. We hypothesized that sleep quality would be negatively associated with next-day active technology use. Given youth with ADHD have greater levels of impulsivity and baseline levels of video game use (Bourchtein et al., 2019), we predicted that adolescent-reported sleep quality would be more strongly associated with next-day active technology use in youth with ADHD relative to those without ADHD.

Hypothesis 5b: Objective assessment of sleep (i.e., sleep duration) and active technology use. We hypothesized that sleep duration and next-day active technology use would be negatively associated. We predict that the association between objectively-measured sleep duration and next-day active technology use would be stronger in adolescents with ADHD relative to those without ADHD.

Method

Participants

Three-hundred and two adolescents (12-14 years; *M*age=13.17 years) enrolled in the eighth grade were recruited from local public schools across two sites in the Midwestern and Southeastern United States. Slightly over half (*n*=162) of the sample was comprehensively diagnosed with ADHD, with the remainder (*n*=140) comprising a comparison non-ADHD sample. See Procedures section for information on diagnostic procedures.

The majority of participants were male (55.3% of the total sample), with a greater proportion of males (64.8%) in the ADHD sample, in line with population-based gender prevalence rates in youth with ADHD (Szatmari et al., 1989). Additional demographic information can be found in Table 1.

Procedure

Students in eighth grade were recruited across two consecutive years to participate in a longitudinal study examining changes in sleep as well as predictors and outcomes of these changes in youth with and without ADHD. All baseline data were collected during the Fall of 8th grade. For the present study, only baseline data were used as data collection is ongoing. The study was approved by the Virginia Commonwealth University’s and Cincinnati Children’s

Hospital Medical Center's Institutional Review Boards. Written parental consent and child assent were collected from each family.

Recruitment occurred via flyers and letters sent to schools. Schools disseminated study information using a number of different methods, such as emails to parents, including flyers in an informational packet at the start of the academic year, and/or providing details during events held for families of eighth grade students. Interested families (n=405) contacted the research team and completed a phone screen to determine initial eligibility inclusion in the study. Families who had a child enrolled in regular education eighth grade classes and who did not have a diagnosed organic sleep condition (n=360) were invited to attend an in-person assessment, which 313 families completed. The assessment included a structured diagnostic interview (i.e., the Children's Interview for Psychiatric Syndromes [ChIPS]; Weller et al., 2000) and a number of rating scales administered separately to parents and participants. In addition, participants were administered the *Wechsler Abbreviated Scale of Intelligence, Second Edition* (WASI-II; Wechsler, 2011).

Inclusionary criteria were as follows: (1) enrolled in eighth grade; (2) estimated Full Scale IQ≥80 based on the WASI-II; and (3) enrolled in regular education classes. Exclusionary criteria were: (1) meeting criteria for autism spectrum disorders, bipolar disorder, a dissociative or psychotic disorder; (2) previous diagnosis of an organic sleep disorder (e.g., obstructive sleep apnea, narcolepsy, restless leg syndrome, periodic limb movement disorder) according to parent report during the phone screen, and (3) not meeting criteria for either the ADHD or comparison groups as described below.

Immediately after the initial evaluation, adolescents were given paper versions of daily diaries as well as an actigraph for assessment over the following two weeks. Participants were instructed to wear the actigraph day and night and only take it off if they were engaging in active sports or in/near the water (e.g., showering, swimming). Participants also were asked to complete diaries twice a day; once immediately prior to going to bed about their day's activities and once immediately upon waking up about the previous night's sleep.

ADHD Diagnosis

All screened participants underwent a comprehensive diagnostic ADHD evaluation in line with criteria of the Fifth Edition of the Diagnostic and Statistical Manual for Mental Disorders (DSM-5; American Psychiatric Association, 2013). In order to be included in the ADHD group, participants were required to meet criteria for ADHD combined presentation or predominantly inattentive presentation according to the parent version of the ChIPS (P-ChIPS; Weller et al., 2000). Specifically, this required: (1) six or more symptoms of inattention at clinically significant levels; (2) presence of ADHD symptoms prior to age 12 years; (3) presence of ADHD symptoms in two or more settings (e.g., home, school); (4) evidence that symptoms contribute to impairment in home, academic, and/or social functioning according to the P-ChIPS or parent or teacher report on the Impairment Rating Scale (IRS; Fabiano et al., 2006), wherein scores ≥ 3 indicate impairment; and (5) symptoms of ADHD not better explained by another mental disorder (e.g., anxiety, depression). Participants were eligible to be included in the comparison (i.e., non-ADHD) group if the parent endorsed fewer than four symptoms of ADHD across both domains (i.e., inattention, hyperactivity/impulsivity) on the P-ChIPS. Additionally, all participants were assessed for common comorbid mental health conditions (e.g., mood and anxiety disorders, disruptive behavior disorders, obsessive compulsive disorder). Every participant's information was reviewed by a licensed clinical psychologist to determine eligibility and diagnoses.

Measures

Daily diaries from adolescents provided information on subjective sleep as well as passive and active technology use. Adolescent report (rather than parent report) was chosen for several reasons. First, parents may not be witnessing the full extent of their adolescents' sleep and technology use on a daily basis. Thus, it is recommended that self-report, rather than parent-report, is used when examining sleep in older children and adolescents (e.g., Matricciani, 2013). Second, parents of youth with ADHD have been found to over-report their children's sleep problems relative to objective sleep data, which may in part be due to the influence of children's negative pre-sleep behaviors on parental report (Wiggs et al., 2005). Actigraphy provided objective information about sleep.

Adolescent Daily Diaries

Adolescents completed daily diaries on paper two times each day for at least 14 consecutive days. These diaries assessed a variety of sleep and sleep-related factors. For the purposes of the present study, items pertaining to technology use and sleep quality were used.

Technology Use. Passive and active technology use was assessed using two separate items. These items were completed by adolescents in the evening immediately prior to going to sleep. The item assessing passive technology use read, "How much total time did you spend *watching TV/movies* tonight?" and responses were recorded in minutes. Active technology use was assessed using an item that read, "How much total time did you spend *playing video games* tonight?" and responses were also recorded in minutes. These items were created for the study and modelled after global items used in a national poll that assessed multiple technology- and sleep-related factors (National Sleep Foundation, 2006).

Sleep. In order to assess adolescent-reported sleep quality, a single item was used. The item was completed by adolescents immediately upon waking up each morning and was worded as, “How would you rate last night’s sleep overall?” Responses were rated on a 5-point Likert scale (1 = “Very good”, 2 = “Fairly good”, 3 = “Okay”, 4 = “Fairly bad”, 5 = “Very bad”). This item was also modelled after items in a national poll that assessed a number of sleep-related variables (National Sleep Foundation, 2006).

Actigraphy

Objective evaluation of sleep was conducted using ActiGraph GT9X Link, worn on the participants’ nondominant wrist for at least two weeks after the baseline assessment took place. Participants were instructed to wear the actigraph at all times, unless they were playing contact sports or bathing/in water. Data were then download using Actilife software, version 6. Epochs were set to 60 seconds. The data were first validated using the built-in wear-time sensor as well as using a validation algorithm; this sought to eliminate times when the actigraph was not worn based on consecutive epochs of zero. Next, the Sadeh sleep scoring algorithm was used to calculate sleep parameters (Sadeh et al., 1994). Adolescent report on daily diaries was used to aid in determining sleep periods.

For the present study, sleep duration was calculated by subtracting actigraphy-determined sleep onset time (i.e., when the participant was estimated to fall asleep) from sleep offset time (i.e., when the participant was estimated to wake up). This method is recommended to be the best estimate of sleep duration in children and adolescents with ADHD, given sleep movements can be misidentified as wakefulness in this population thus leading to underestimation of sleep duration if actigraphy-measured wake after sleep onset is considered (Sadeh, 2011).

Covariates

A number of covariates were included to ensure that findings were not better explained by other factors that are known in the literature to affect sleep and technology use in adolescents. For Aim 1, sex and race were included as covariates, given known differences in technology use between girls and boys and among adolescents of different racial background (Kowalski et al., 2019; Lange et al., 2017; Lee et al., 1999). For Aims 2-5, which examined both technology use and sleep, factors that have been empirically linked to both were included. First, the onset of pubertal maturation is linked to a number of sleep-related changes; during this time, sex differences in sleep patterns and problems also develop (Johnson et al., 2006). Female adolescents rate their sleep quality lower relative to male adolescents (Matthews et al., 2014). Further, there are also pubertal-status and sex differences in actigraphy measurement (e.g., Badin et al., 2016; Short et al., 2012). Studies also indicate significant differences in sleep parameters, including shorter sleep duration, more fragmented sleep, and higher levels of subjective sleep problems, in African American youth relative to White youth, even after controlling for SES differences (Buckhalt et al., 2007; Matthews et al., 2014). In addition, a number of psychotropic and sleep medications have been linked to sleep changes (Kidwell et al., 2015). Lastly, there is a vast, well-developed literature evaluating the bidirectional links between sleep and internalizing problems and, to a lesser extent, the presence of a co-occurring externalizing (i.e., oppositional defiant disorder or conduct disorder) diagnosis (Becker et al., 2015; Corkum et al., 1999). In addition, both internalizing problems and externalizing diagnoses are present in greater rates in youth with ADHD (Reale et al., 2017). Thus, in order to assess the association between technology use and sleep beyond any effects of these factors, the following variables were included as covariates in the analyses for Aims 2-5: pubertal development, sex, race, medication use, internalizing symptoms, and externalizing diagnosis.

Pubertal Development. The Physical Development Scale is a validated, non-invasive self-report measure assessing pubertal development (Petersen et al., 1988). There are separate forms for males and females to complete (six items on each). A mean score of five of the items pertaining to physical changes was calculated for analyses, in line with scoring guidelines for the scale, with greater scores indicating greater levels of pubertal development; one item pertaining to participants' perception of their own pubertal development relative to peers was omitted (α=.70 and .76 for females and males, respectively, for the five included items).

Sex. The participants' sex was assessed on a demographics form completed by parents.

Race. Parents also reported on participants' race via a demographics form. For the present study, the participants' racial background was dichotomized into White and non-White categories, regardless of ethnicity.

Medication Use. The Services for Children and Adolescents Parent Interview is a clinician-administered interview that asks parents whether their children are receiving a variety of pharmacological and nonpharmacological treatment (Jensen et al., 2004). In the present study, an item assessing whether the participant is taking any medication for attention, behavioral, emotional, or sleep problems (including melatonin) was included as a binary (yes/no) covariate.

Internalizing Symptoms. The Revised Children's Anxiety and Depression Scale (RCADS; Chorpita et al., 2005) is a 47-item adolescent-report measure that assesses *DSM*-based anxiety and depression symptoms on a 4-point scale (1 = "never", 4 = "always"). The RCADS has demonstrated excellent reliability and validity in clinical and school-based samples (Ebesutani et al., 2011). For the present study, all items except three that related to sleep were summed for a total internalizing score that was independent of sleep difficulty (α=.96).

Externalizing Diagnoses. The P-ChIPS and ChIPS were used to evaluate whether adolescents met criteria for externalizing diagnoses, specifically oppositional defiant disorder (ODD) and/or conduct disorder (CD). Only parents were asked about the presence of ODD symptoms, whereas both parents and adolescents were asked about the presence of CD symptoms. Participants who had a diagnosis of ODD according to parent report or of CD according to parent and/or adolescent report were classified as having an externalizing disorder.

Analytic Plan

All analyses were run in SPSS version 25. Technology use and actigraphy sleep variables were examined at the daily item level; items that were greater than three standard deviations from the mean were considered outliers and were excluded from analyses. All daily item-level data for adolescent-reported sleep quality were included, given the Likert-scale nature of the responses. In order to obtain a reliable sampling of one's sleep, gathering at least five days of data is recommended (Acebo et al., 1999). As such, participants that had fewer than five days of daily diary or actigraphy data were excluded from the analyses. Based on these criteria, 17 participants were excluded from analyses. Participants included in the present study had a mean of 12.13 days of weekday daily diary data (*SD* = 1.94, range = 6 – 20) and a mean of 12.10 days of weekday actigraphy data (*SD* = 1.97, range = 6 - 22). They had a mean of 4.79 days of weekend daily diary data (*SD* = 1.07, range = 2 – 8) and a mean of 4.77 weekend days of actigraphy data (*SE* = 1.12, range = 2 – 9). Based on recommended guidelines that weekday and weekend sleep data be evaluated separately, analyses were run across all available weekdays; exploratory analyses were also conducted separately with weekend day data given less data available for weekend days (Matricciani, 2013). Weekdays were considered Sunday evening through Friday day; weekends were considered Friday evening through Sunday morning.

Power

Simulation studies examining sample sizes for multilevel modeling have found that only higher-level (i.e., level two) sample size, and not lowest-level sample size or varying intraclass correlations, are associated the accuracy of the estimation (Maas & Hox, 2005). Specifically, samples of 50 or less at the second level only are shown to lead to biased estimates of second-level standard errors. In addition, regression coefficients and standard errors are robust to sample size at both lowest- and higher-levels. Further, for cross-level moderations, level one and two sample sizes, standard deviation of slopes, and the magnitude of the cross-level interaction are associated with statistical power to detect an interaction. Larger level two sample sizes are associated with greater statistical power for cross-level moderation analyses. One simulation study found that in samples of N = 115 at level two, statistical power was up to 0.6, depending on the strength of the cross-level interaction (Mathieu et al., 2012). Further, this study recommended that an average level one sample size of at least 10 is needed for adequate power. Given the present full sample after excluding those who had fewer than five days of data contains 285 participants (i.e., level two sample size), which had an average of 12 days of daily data (i.e., level one sample size), the study is sufficiently powered for accurate estimation of direct and cross-level interaction effects across weekdays. The study may not be sufficiently powered to estimate effects across weekends due to relatively small level one sample size, and therefore this subset of analyses is exploratory and must be interpreted with caution.

Missing Data

Missing data were accounted for using restructured maximum-likelihood estimation (REML; Kwok et al., 2008). REML reduces downwardly-biased variance estimates that are present when using full maximum likelihood (FML) estimation (Hoyle & Gottfredson, 2015). As such, it is recommended that analyses with normally-distributed outcome variables should rely on REML rather than FML estimation, particularly if there are greater than 30 higher-level groups (Maas & Hox, 2005).

Aim 1: Differences in Technology Use

In order to examine group-level differences in daily passive and active technology use between adolescents with and without ADHD, two-level (i.e., days nested within participants) multilevel models (MLM) were run using the MIXED command in SPSS. Specifically, repeated-measures random-intercept MLMs were run with ADHD status as the level 2 predictor and passive or active technology use as the outcome variable. Sex and race were included as level 2 time-invariant covariates.

Aims 2-5: Moderation of Bi-Directional Associations between Passive/Active Technology Use and Sleep

In order to examine whether ADHD status moderates associations between sleep (quality or duration) and technology use (passive or active) and vice versa, a series of MLM analyses was conducted. All independent variables (i.e., technology use for Aim 2 and 3, sleep parameters for Aim 4 and 5) were person-mean-centered for ease of interpretability, to reduce multicollinearity, and to disaggregate within- and between-person effects (Wang & Maxwell, 2015). Repeated measures random-intercept MLMs were run using the MIXED command in SPSS to estimate whether daily passive (Aim 2) or active (Aim 3) technology use predicted next-day sleep quality or duration. Similarly, repeated measures random-intercept MLMs were run using the MIXED command in SPSS to estimate whether nightly sleep quality or duration predicted next-day passive (Aim 4) or active (Aim 5) technology use, and whether ADHD status moderated any of these effects. For Aims 2-5, two models were run per Aim, each with both subjective and objective sleep parameters. Further, for Aims 2-5, level 1 variables were those measured repeatedly (i.e., sleep and technology use) and thus nested within participants. ADHD status (yes/no) was entered as a level 2 variable. Interaction terms were created between the predictor variables (i.e., technology use in Aims 2 and 3, sleep parameters in Aims 4 and 5) and ADHD status and included in the models as moderator variables. Covariates (i.e., sex, race, pubertal development, medication status, internalizing symptoms, externalizing diagnosis) were included as level 2 variables in all analyses for Aims 2-5. First-order autoregressive error structure was used in all analyses to account for the increased covariance of observations that are temporally closer to each other.

Results

The variables of interest (i.e., technology use and sleep) were examined for normality of distribution after the removal of outliers as described above. All variables were distributed normally based on recommendations that the absolute value of skewness not exceed 3 (absolute values of skewness in present study = 0.05 – 2.03) and the absolute value of kurtosis not exceed 10 (absolute values of kurtosis in present study = 0.03 – 3.82) when sample size is greater than 200 (Tabachnik & Fidell, 2013). Variable summary information can be found in Table 2 and correlations between variables of interest can be found in Table 3.

Aim 1: Differences in Technology Use

Passive Technology Use

Random-intercept MLMs were conducted to evaluate overall differences in passive technology use between adolescents with and without ADHD when controlling for effects of sex and race (Table 4). Results indicated no significant differences between adolescents with (M = 54.86 minutes, SE = 4.01, 95% CI = [46.91, 62.75]) and without ADHD (M = 49.25 minutes, SE

= 4.14, 95% CI = [41.09, 57.40]) on amount of weekday daily passive technology use, *t*(270.08) = -1.15, *p* = .253. Similarly, there were no significant differences between adolescents with (*M* = 65.69 minutes, *SE* = 4.62, 95% CI = [56.59, 74.80]) and without ADHD (*M* = 56.98 minutes, *SE* = 4.69, 95% CI = [47.76, 66.21]) on amount of weekend daily passive technology use, *t*(257.50) = -1.56, *p* = .120.

Active Technology Use

Random-intercept MLMs were conducted to evaluate overall differences in active technology use between adolescents with and without ADHD when controlling for effects of sex and race (Table 5). Results indicated that adolescents with ADHD were engaging in significantly more weekday daily active technology use (*M* = 30.88 minutes, *SE* = 3.27, 95% CI = [24.44, 37.32]) relative to adolescents without ADHD (*M* = 21.49 minutes, *SE* = 3.39, 95% CI = [14.82, 28.15]), *t*(267.89) = -2.34, *p* = .020. On weekends days, there were no significant differences between adolescents with (*M* = 39.62 minutes, *SE* = 4.51, 95% CI = [30.75, 48.50]) and without ADHD (*M* = 36.70 minutes, *SE* = 4.57, 95% CI = [27.69, 45.71]) on amount of daily active technology use, *t*(257.29) = -0.53, *p* = .596.

Aim 2: Effects of Passive Technology Use on Sleep

Subjective Sleep (Sleep Quality)

Controlling for sex, race, pubertal status, internalizing symptoms, externalizing diagnoses, and medication status, passive technology use was not associated with consequent sleep quality on weekdays, *B* = 0.00, *SE* = 0.00, *t*(2656.13) = 0.17, *p* = .862, and ADHD status did not moderate any association between the two, *B* = 0.00, *SE* = 0.00, *t*(2643.26) = -0.79, *p* = .429 (Table 6). Examining this association on weekend days only, the relation between passive technology use and sleep quality was nonsignificant, *B* = 0.00, *SE* = 0.00, *t*(1042.90) = 1.44, *p* = .152, and was not moderated by ADHD status, *B* = 0.00, *SE* = 0.00, *t*(1022.34) = -0.21, *p* = .838.

Objective Sleep (Sleep Duration)

Controlling for sex, race, pubertal status, internalizing symptoms, externalizing diagnoses, and medication status, passive technology use was not associated directly with sleep duration on weekdays, *B* = -0.02, *SE* = 004, *t*(2309.12) = -0.53, *p* = .599. However, ADHD status did moderate that association, *B* = 0.11, *SE* = 0.06, *t*(2304.41) = 2.07, *p* = .038 (see Table 7). Follow-up simple slopes analyses indicated that weekday television viewing was significantly positively associated with subsequent sleep duration among adolescents without ADHD, *B* = 0.09, *SE* = 0.04, *t*(1101.38) = 2.38, *p* = .017, but not those with ADHD, *B* = -0.02, *SE* = 0.04, *t*(1188.95) = -0.61, *p* = .544. Specifically, this means that for every 1-minute increase in weekday television viewing, there was a 5.4 second increase in sleep duration (totaling 5.4 minutes of sleep per additional hour of passive technology use) among adolescents without ADHD (Figure 1). On weekend days, passive technology use was not associated with sleep duration, *B* = 0.04, *SE*= 0.08, *t*(924.05) = 0.54, *p* = .592, and ADHD status did not moderate any association, *B* = -0.01, *SE* = 0.12, *t*(889.50) = -0.12, *p* = .903.

Aim 3: Effects of Active Technology Use on Sleep

Subjective Sleep (Sleep Quality)

Controlling for sex, race, pubertal status, internalizing symptoms, externalizing diagnoses, and medication status, active technology use did not significantly predict subsequent adolescent-reported sleep quality on weekdays, *B* = 0.00, *SE* = 0.00, *t*(2534.89) = -0.22, *p* = .828, and ADHD status was not a significant moderator, *B* = 0.00, *SE* = 0.00, *t*(2554.33) = 1.14, *p* = .255 (Table 8). This association was also not significant on weekend days, *B* = 0.00, *SE* = 0.00, *t*(1014.89) = 1.83, *p* = .067, and was not moderated by ADHD status, *B* = 0.00, *SE* = 0.00, *t*(1011.84) = -1.19, *p* = .233.

Objective Sleep (Sleep Duration)

Controlling for sex, race, pubertal status, internalizing symptoms, externalizing diagnoses, and medication status, active technology use did not significantly predict subsequent actigraphy-measured sleep duration on weekdays, *B* = 0.03, *SE* = 0.04, *t*(2210.80) = 0.63, *p* = .532, and ADHD status did not significantly moderate any association between the two, *B* = -0.13, *SE* = 0.07, *t*(2251.30) = -1.83, *p* = .068 (Table 9). Similarly, active technology use did not predict sleep duration on weekend days, *B* = -0.16, *SE* = 0.09, *t*(830.20) = -1.80, *p* = .073. and the association was not moderated by ADHD status, *B* = 0.11, *SE* = 0.13, *t*(790.73) = 0.82, *p* = .415.

Aim 4: Effects of Sleep on Passive Technology Use

Subjective Sleep (Sleep Quality)

Controlling for sex, race, pubertal status, internalizing symptoms, externalizing diagnoses, and medication status, adolescent-reported sleep quality was marginally associated with subsequent passive technology use on weekdays, *B* = -2.93, *SE* = 1.54, *t*(2481.75) = -1.90, *p* = .058 (Table 10). It is important to note that greater numbers are indicative of poorer sleep quality; as such, this negative association indicates that poorer sleep quality is associated with decreased passive technology use. This means that for every 1-point (on a 5-point Likert scale) worsening in sleep quality, next-day passive technology use decreased by nearly 3 minutes. ADHD status did not moderate this association, *B* = 4.10, *SE* = 2.33, *t*(2483.25) = 1.76, *p* = .079. On weekend days, this association was not significant, *B* = 3.82, *SE* = 2.95, *t*(1054.42) = 1.30, *p*

= .195, and ADHD status did not moderate the association, *B* = -2.72, *SE* = 4.27, *t*(1012.27) = -0.64, *p* = .524.

Objective Sleep (Sleep Duration)

Controlling for sex, race, pubertal status, internalizing symptoms, externalizing diagnoses, and medication status, actigraphy-measured sleep duration was not significantly associated with subsequent passive technology use, *B* = 0.04, *SE* = 0.02, *t*(2166.93) = 1.78, *p* = .075, and ADHD status was not a significant moderator, *B* = -0.05, *SE* = 0.03, *t*(2162.03) = -1.57, *p* = .116 (Table 11). Similarly, the association was not significant on weekend days, *B* = 0.00, *SE* = 0.03, *t*(729.52) = 0.14, *p* = .890, and was not moderated by ADHD status, *B* = 0.03, *SE* = 0.04, *t*(768.25) = 0.81, *p* = .420.

Aim 5: Effects of Sleep on Active Technology Use

Subjective Sleep (Sleep Quality)

Controlling for sex, race, pubertal status, internalizing symptoms, externalizing diagnoses, and medication status, adolescent-reported sleep quality was significantly associated with subsequent active technology use on weekdays, *B* = 2.80, *SE* = 1.30, *t*(2354.71) = 2.16, *p* = .031 (Table 12). Again, greater numbers indicate poorer sleep quality; as such, this positive association indicates that poorer sleep quality is associated with greater active technology use. This means that for every 1-point worsening in sleep quality (on a 5-point Likert scale), next-day active technology use increased by 2.8 minutes. ADHD status did not significantly moderate this association, *B* = -2.11, *SE* = 1.94, *t*(2358.80) = -1.09, *p* = .277. On weekend days, the association between sleep quality and active technology use was not significant, *B* = -2.23, *SE* = 2.55, *t*(959.12) = -0.87, *p* = .383, and ADHD status did not moderation this association, *B* = -0.10, *SE* = 3.60, *t*(917.90) = -0.03, *p* = .976.

Objective Sleep (Sleep Duration)

Controlling for sex, race, pubertal status, internalizing symptoms, externalizing diagnoses, and medication status, actigraphy-measured sleep duration was not significantly associated with next-day active technology use, $B = 0.00$, $SE = 0.02$, $t(2104.02) = 0.25$, $p = .375$, and ADHD status did not significantly moderate any association between these variables, $B = 0.02$, $SE = 0.03$, $t(2052.62) = 0.89$, $p = .375$ (Table 13). Similarly, there was no significant association on weekend days, $B = -0.01$, $SE = 0.03$, $t(665.64) = -0.48$, $p = .630$, and this was not moderated by ADHD status, $B = 0.00$, $SE = 0.04$, $t(714.21) = -0.04$, $p = .970$.

Discussion

The present study is the first to (1) examine day-to-day weekday and weekend differences in passive and active technology use between adolescents with and without ADHD and (2) evaluate bi-directional associations between passive (i.e., television viewing) and active (i.e., video game play) technology use and sleep, and whether these associations are moderated by ADHD status. Findings revealed that adolescents with ADHD engaged in significantly greater amounts of active, but not passive, daily weekday technology use relative to those without ADHD, beyond any effects of sex and race. Second, controlling for multiple relevant covariates, neither passive nor active technology use was significantly *directly* associated with consequent sleep quality or sleep duration. However, ADHD status did *moderate* the association between weekday passive technology use and *sleep duration*: adolescents without ADHD exhibited a significant positive association between amount of daily passive technology use and objectively-measured sleep duration, whereas this association was not statistically significant among adolescents with ADHD. Third, daily weekday *sleep quality* was positively associated with next-day passive technology use but negatively associated with next-day active technology use, regardless of ADHD status. This indicates that after experiencing a night of poorer sleep quality, adolescents engaged in less television viewing but more video game use. Daily weekday *sleep duration* and weekend sleep quality and duration were not associated with next-day technology use, and ADHD status did not moderate the association.

Group Differences in Technology Use

Television viewing did not differ between adolescents with and without ADHD on weekdays or weekends (when controlling for sex and race), although both groups engaged in slightly more television viewing on weekends relative to weekdays (11 more minutes among adolescents with ADHD and 8 more minutes among adolescents without ADHD). Adolescents with ADHD engaged in approximately 9 minutes more of video game use per *weekday* relative to youth without ADHD, whereas *weekend* video game play was comparable between the groups. This equates to 45 minutes per week of additional video game use for adolescents with ADHD. Similar to television viewing, video game use was higher in both groups on weekends relative to weekdays. Specifically, adolescents with ADHD engaged in 9 additional minutes of daily video game use on weekends relative to weekdays; adolescents without ADHD engaged in 15 more minutes of video game use on weekends relative to weekdays. Overall, adolescents in the present study, regardless of ADHD diagnosis, appear to be using technology for a shorter time relative to rates reported in prior studies (Rideout et al., 2015). This may indicate that the finding that adolescents engage in multiple hours of overall technology use each day may be explained in part by other types of technology use (e.g., smartphones) or by technology use that occurs during in school for educational purposes.

This study advances the understanding of technology use among adolescents with ADHD relative to their peers without ADHD. Specifically, whereas several studies have found greater and more problematic use of technology defined broadly among those with ADHD or elevated ADHD symptoms (Bourchtein et al., 2019; Chen et al., 2015; Gul et al., 2018; Mazurek & England, 2013), the present study indicates it is specifically weekday active technology use that may be more common among youth with ADHD. Prior studies have found that youth engage in multiple hours of overall technology use daily; therefore, it remains unclear whether the 9-minute difference in active technology use between adolescents with and without ADHD is clinically meaningful. (Rideout et al., 2015). Given the present study found that active technology use was not associated with subsequent sleep quality or duration, it is important to determine whether this difference in active technology use is relevant for other outcomes.

Notably, the present study is the first to evaluate technology use via daily weekday and weekend ratings rather than global estimates among adolescents with ADHD. Comparing this study to a previous study with this sample that used cross-sectional global ratings (Bourchtein et al., 2019), adolescents with ADHD reported lower active technology use but similar rates of passive technology use based on day-to-day ratings (as compared to global rating scales). Specifically, whereas parents in the cross-sectional study reported that adolescents *with ADHD* were watching television/movies for 59 minutes and playing video/computer games for 61 minutes per day, daily diaries from adolescents with ADHD in the current study showed 55 minutes of daily weekday television time, but only 31 minutes of daily weekday video game time. Interestingly, parent cross-sectional/global ratings of adolescents *without ADHD* were more in line with daily data from their adolescents. Parents in the prior study reported that adolescents without ADHD were spending 51 and 31 minutes on passive and active technology use, respectively; adolescents without ADHD in the present study reported 49 minutes of passive and 21 minutes of active technology use on weekdays. This suggests that parents of adolescents with

ADHD may be overreporting their children's global active technology use on rating scales. However, it is important to note that parents in Bourchtein et al. (2019) were asked about "video/computer game" use, whereas adolescents in the present study reported on "video game" play. Thus, it may be that total daily active technology use among adolescents in ADHD is greater when including computer game play.

The present study did not find that adolescents with ADHD engaged in significantly greater weekday or weekend passive technology use, diverging from prior findings that there are small but significant differences according to global parent report (Bourchtein et al., 2019). The present study accounts for effects of both race and sex, whereas the prior study only controlled for effects of sex. As such, it may be that differences in global passive technology use are partially driven by differences in racial backgrounds. Supporting this hypothesis, Black and Hispanic/Latinx adolescents may be more likely to engage in excessive television viewing (i.e., > 2 hours per day) relative to White adolescents, but these differences do not extend to video games (Kowalski et al., 2019; Lowry et al., 2002).

In line with the previous study and our hypothesis, adolescents with ADHD engaged in greater amounts of weekday video game use relative to those without ADHD, although this difference was not statistically significant on weekend days. Taken together, these results appear to support the possibility that youth with ADHD are more drawn to active technology use, perhaps in part due to the increased stimulation that video games provide (Wang & Perry, 2006). However, it may also indicate that parents of adolescents without ADHD have more restrictions or rules regarding their children's technology use on weekdays. Greater levels of parental control regarding screen time specifically have been linked with significantly reduced levels of technology use in the general population; specifically, adolescents in households that have limits on technology use engage in three hours less technology use per *day* (Gentile et al., 2012; Pieters et al., 2014).

Technology Use and Subsequent Sleep

Overall, technology use was not associated with subsequent sleep duration or quality on a daily basis, with one exception: passive technology use on weekdays was positively associated with longer actigraphy-measured sleep duration in adolescents without ADHD only. This finding was not in line with our hypotheses nor the majority of prior findings (Allen et al., 2016). It is important to consider a number of likely methodological explanations for the largely null findings for the present study in terms of technology to sleep. This study evaluated day-to-day associations over a relatively short number (i.e., at least five) of weekdays. It may be that the association between technology use and sleep occurs as a result of the cumulative effects of many nights (e.g., months or years), rather than more immediately. Although a small (N = 11) experimental study has also demonstrated negative effects of technology use on sleep (with more effects related to active technology use), that study examined effects of a very specific amount of technology use (i.e., one predetermined movie or 60 minutes of video game play), rather than a more naturalistic evaluation of day-to-day changes (Dworak et al., 2007). As such, whereas an adolescent's day-to-day variabilities in technology use and sleep may not be associated with each other, on a group level (i.e., examining the group- [i.e., ADHD, non-ADHD] or grand- rather than person-centered mean), those with greater levels of technology use overall may be experiencing poorer sleep consistently and vice versa. Conversely, it may be that youth with a biologically-based shorter sleep duration need may also be engaging in greater amounts of technology use due to having more time within their day relative to youth who require more hours of sleep. This would suggest that a latent variable may be explaining the previously-found associations between technology use and sleep in youth.

Another possible explanation for the present study's largely nonsignificant findings may be that the associations found between technology use and sleep exist only in specific groups of children, such as those with clinically elevated sleep problems or permissive/unstructured households that allow for ad libitum technology use and sleep. For instance, one study found that parental general limit-setting on children's activities is associated with reduced time watching television in pre-adolescents (i.e., ages 9-12 years; Lee et al., 2009). Conversely, results from another, multi-nation study, indicate that a controlling parenting style may be associated with *more* screen time, whereas an autonomy-supportive communication style (specifically regarding technology use) is linked with less passive and active technology use (Bjelland et al., 2015). Regardless, an adolescent's level of autonomy may relate to technology use and sleep. In addition, parenting style is known to differ between parents of youth with and without ADHD, with parents of children with ADHD employing a more authoritarian and negative style (Healey et al., 2011).

It is also important to note that the majority of studies on technology use and sleep have focused either on young children or older adolescents (Allen et al., 2016; Harbard et al., 2016; Marinelli et al., 2014). Young adolescence (specifically, middle school) is a unique developmental period in which youth begin to gain some autonomy over their schedule but are less autonomous than their high-school-aged peers (Steinberg & Silverberg, 1986). Further, there are dramatic sleep changes that occur at this time in association with pubertal development (Carskadon, 2011). As such, it may be that other factors are more salient contributors to sleep problems during this specific age.

Another important consideration when comparing the findings of this study with prior work is the relatively large number of factors controlled for in the present study. Prior studies examining the association between technology use and sleep have not always accounted for demographic and other factors that are known to impact technology use and sleep, such as sex or externalizing problems (e.g., Marinelli et al., 2014). The present study's inclusion of multiple theoretically- and empirically-linked variables is a major strength, and suggests that prior findings may have been driven at least in part by these unaccounted-for variables, rather than technology use solely. However, it is important to note that the correlations between the variables in the present study indicate that in the absence of any covariates, there are nuanced associations between different sleep parameters and technology use. Specifically, in the present study, poorer weekend but not weekend sleep quality was positively correlated with amount of passive technology use but not associated with active technology use. Conversely, sleep duration was negatively correlated with active technology use on both weekdays and weekends but not associated with passive technology use. Thus, although the included covariates in the present study may be contributing to some of the nonsignificant findings, it also appears that the more nuanced examination of sleep and technology use variables reveals a more complex pattern of associations than previously reported.

Interestingly, greater amounts of weekday television viewing were associated with *more* sleep duration among adolescents without ADHD, contradicting our hypothesis that this association would be negative overall and stronger among adolescents with ADHD. Although statistically significant, the results may not be meaningful from a clinical standpoint, as every hour of additional television viewing per weekday was associated with approximately 5 additional minutes of sleep. However, these findings may reflect the fact that for adolescents without ADHD, television viewing may be a relaxing pastime that leads to longer sleep duration. Conversely, it may be that on the evenings that adolescents without ADHD had time to watch more television, they also had more time to sleep, possibly due to reduced homework load or extra-curricular activities. Among adolescents with ADHD, this association was not significant. Prior findings that technology use was associated with sleep in youth with ADHD did not examine television viewing specifically, did not include multiple relevant covariates, and used cross-sectional and global rather than daily measures (e.g., Aishworiya et al., 2018; Bourchtein et al., 2019). The present study indicates that prior significant associations of television viewing with sleep duration among youth with ADHD may be better attributed to related variables or may not be present when examined on a daily basis.

Sleep and Subsequent Technology Use

Minimal prior research has evaluated the sleep to subsequent technology use association. Results of the present study suggest that sleep may be predictive of later technology use, and that the association may differ among various types of technology. Specifically, adolescent-reported weekday sleep quality was positively associated with next-day passive technology use but negatively associated with next-day active technology use. This means that after a poor-quality night of sleep, adolescents in this sample watched less television and played more video games. This may be explained by the use of active technology by adolescents to self-soothe after a poor night of sleep (Tavernier & Willoughby, 2014). In addition, it may be that, given the physiological effects of video game play (Wang & Perry, 2006), adolescents are using video games as a way to mitigate the daytime effects of a poor night of sleep. However, these effects, although statistically significant, were small. A 1-point decrease in sleep quality (on a 5-point Likert scale) was associated with a three-minute decrease in next-day weekday television viewing and a three-minute increase in video game play. As such, these associations may be less meaningful from a clinical standpoint.

On a positive note, these associations were not found for weekend days, which may indicate that on those days, adolescents are able to cope with poorer sleep quality in other ways. Further, objectively-assessed sleep duration was not predictive of later technology use. Prior studies that found links between sleep duration and technology use relied on parent- or self-reported estimates of sleep duration (Magee et al., 2014; Tavernier & Willoughby, 2014). The present study's use of actigraphy to assess sleep duration is a strength and suggests that it is the adolescents' *perception* of their sleep rather than objective sleep data that is associated with subsequent technology use. Finally, the association between sleep quality and consequent technology use on weekdays was not significantly different between adolescents with and without ADHD. This finding suggests that an ADHD diagnosis does not place an adolescent at additional risk for using more technology after a poor night of sleep.

Limitations and Future Directions

It is important to consider methodological limitations that may have contributed to the lack of significant findings. Specifically, the daily diary data were collected via paper diaries. Although participants were instructed to fill these out regularly and in a time-dependent manner (i.e., in the morning immediately upon waking and in the evening immediately prior to sleeping), and parents were encouraged to remind the adolescents to complete the diaries, it is conceivable that the diaries were not completed in a timely manner and may be less valid due to difficulties with recall. Studies evaluating the validity of paper diaries relative to internet-based diaries in adolescents indicate that whereas response rates are greater for paper diaries, internet-based diaries are more reliable and accurate (Krogh et al., 2016). Further, the validity of tracking daily technology use via paper measures in adolescents has not been explored. Future studies should consider utilizing technological tools, such as data-collecting phone-based applications or web-based time-stamped surveys, to increase the likelihood that data are collected in a time-dependent manner. Additionally, technology use should be assessed via objective measures, such as tracking applications that monitor screen time. Objectively-assessed technology use could also be compared to parent and adolescent diary data to determine whether parents or adolescents are more accurate reporters of technology use, and whether this varies across development.

In addition, the present study relied mostly on single-item responses, which may be more prone to measurement error (Diamantopoulos et al., 2012). Future studies may consider using validated scales to measure constructs such as sleep quality. However, given that the measures were collected on a daily basis, it was necessary to balance validity with brevity and efficiency to minimize missing data and attrition. Further, empirical studies have not always found a discernible advantage to using multiple items over single items to measure constructs, particularly when the constructs are not complex (Gardner et al., 1998; Sarstedt & Wilczynski, 2009).

The types of technology use assessed in the present study – passive (i.e., television) and active (i.e., video games) – are not all-encompassing. The landscape of technology use in adolescence is changing rapidly, with more adolescents having access to mobile devices such as smartphones (Common Sense, 2019). In addition, many students report doing their homework on desktop or laptop computers (Ma et al., 2014), which was also not examined in the present study. Future studies should consider looking at different types of technology use more broadly and including a larger variety of technology, including computers, tablets, and smartphones.

Further, the present study evaluated technology use on a daily basis. However, adolescents were asked to answer questions related to technology use via their daily diaries before bedtime, meaning that technology use in bed after "lights out" is unlikely to be captured in the present study. In addition, adolescents reported on the total quantity of passive and active technology use over the entire day. There is growing evidence to suggest that access to technology in the bedroom, technology use one hour prior to bed, and technology use in bed and/or after bedtime have significant detrimental effects on sleep, although this is not a consistent enough finding yet to warrant a clinical recommendation specifically targeting screen time before bed (Allen et al., 2016; Becker & Lienesch, 2018; Garrison et al., 2011; Lemola et al., 2015). A future examination of timing of daily technology use and its bi-directional association with sleep is therefore warranted. Additionally, future studies examining the associations between technology use and sleep should specifically account for technology used during the sleep period (e.g., when an adolescent watched television during a middle-of-the-night awakening), given its possible interference with sleep.

Although type of technology use was assessed in the present study, content of the use was not evaluated. Daytime exposure to violent media content, including movies, television, and video/computer games, has been linked to sleep problems in children across development (Garrison et al., 2011; Ivarsson et al., 2013). An experimental study involving male adolescents with no sleep difficulties at baseline found that prolonged exposure to violent video games led to reduced PSG-measured sleep quantity and self-reported sleep quality (King et al., 2013). Further, youth with ADHD or ADHD symptoms may engage in greater levels of violent media use (Beyens et al., 2018). Future studies should use experimental or longitudinal approaches to determine whether content – beyond quantity – of passive and active technology use is associated with sleep quality and duration among adolescents, and whether this differs among those with ADHD.

It must also be noted that although the present study appears adequately powered to detect effects according to guidelines for MLM (Maas & Hox, 2005), simulation studies have found that it can be hard to detect cross-level interactions using MLM when interaction effects are small (Mathieu et al., 2012). Given the lack of prior data, we were not able to determine *a priori* the strength of our proposed interactions. Therefore, it is conceivable that the present study did not have a large enough sample size to detect cross-level interactions on weekdays in addition to weekends.

Lastly, although the present study accounted for medication use, there are differential effects of medication on sleep. For instance, whereas stimulant medications that are used first-line for treating ADHD in adolescents can have deleterious effects on sleep (Kidwell et al., 2015), second- or third-line pharmacological treatment for ADHD such as clonidine are sometimes associated with better sleep outcomes (Nguyen et al., 2014). In addition, medication effects tend to be specific to the individual, with some adolescents reporting that stimulant medications have a positive effect on sleep (Stein et al., 2012). The assessment of medication in the present study does not allow for a nuanced examination of complex relations between medication and sleep. Future studies should consider examining the association between technology use and sleep in medication-naïve adolescents or using an experimental approach to isolate specific effects of different medications on this association.

Implications and Conclusion

Despite its limitations, the present study has some notable clinical implications. First, parents and healthcare providers should be mindful of the fact that the presence of an ADHD diagnosis places young adolescents at risk for greater video game use on weekdays, even when effects of race and sex are taken into account. Parents of adolescents with ADHD may consider setting specific guidelines regarding video game play on weekdays. However, the difference in weekday video game play is relatively small (i.e., 9 minutes) and may not be clinically meaningful. As such, general clinical guidelines for limiting technology use in adolescents, regardless of ADHD diagnosis, should be promoted. Second, although adolescents with ADHD are at greater risk for sleep difficulties, the present study does not support the notion that technology use accounts for this increased risk beyond the effect of other potentially relevant variables. Among adolescents without ADHD, technology use also does not appear to lead to consequent sleep difficulties, and television viewing may in fact lead to small increases in sleep duration. Incorporating other, evidence-based best-practices for adolescents who have difficulty sleeping regardless of ADHD status, such as having a consistent sleep/wake schedule, should therefore continue to be the main clinical recommendation. Third, given the present study did not find that daily technology use had an effect on consequent sleep, parents of young adolescents should be encouraged to consider other more empirically-based target areas to focus on if their child is exhibiting sleep difficulties, such as improving a child's emotional environment (e.g., reducing family stress or conflict) or ensuring developmentally-appropriate and consistent bed- and wake-times (Allen et al., 2016). Fourth, adolescents who exhibit an increase in video game play should be asked about their prior night's sleep quality, given these are inversely associated regardless of ADHD status. This can be used to spark a conversation about good sleep practice. Families should consider being proactive by encouraging adolescents to replace technology use with calming, non-screen activities, such as relaxation skills, after a night of poor sleep. Conversely, families may consider encouraging adolescents to stay active and engage in physical activity after a night of poor sleep in order to mitigate any daytime sleepiness or fatigue that may occur as a result.

In sum, the results of this longitudinal study, comprised of a relatively large and well-diagnosed sample of young adolescents with and without ADHD, extend prior findings to indicate that adolescents with ADHD engage in greater active technology use on weekdays relative to adolescents without ADHD. However, the study does not support prior findings that passive and active technology use are associated with subsequent poorer sleep outcomes, when accounting for relevant factors. Similarly, although weekday sleep quality was associated with next-day passive and active technology use, these effects were small and may not be clinically meaningful. Lastly, the presence of an ADHD diagnosis does not differentially affect the vast majority of associations between technology use and sleep or vice versa. Future studies should use experimental design to replicate these findings.

References

Acebo, C., Sadeh, A., Seifer, R., Tzischinsky, O., Wolfson, A. R., Hafer, A., & Carskadon, M. A. (1999). Estimating sleep patterns with activity monitoring in children and adolescents: how many nights are necessary for reliable measures? *Sleep*, *22*, 95–103. https://doi.org/10.1093/sleep/22.1.95

Aishworiya, R., Kiing, J. S. H., Chan, Y. H., Tung, S. S. W., & Law, E. (2018). Screen time exposure and sleep among children with developmental disabilities. *Journal of Paediatrics and Child Health*, *54*, 889–894. https://doi.org/10.1111/jpc.13918

Allen, S. L., Howlett, M. D., Coulombe, J. A., & Corkum, P. V. (2016). ABCs of SLEEPING : A review of the evidence behind pediatric sleep practice recommendations. *Sleep Medicine Reviews*, *29*, 1–14. https://doi.org/10.1016/j.smrv.2015.08.006

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

Badin, E., Haddad, C., & Shatkin, J. P. (2016). Insomnia: The sleeping giant of pediatric public health. *Current Psychiatry Reports*, *18*, 47. https://doi.org/10.1007/s11920-016-0687-0

Bartel, K. A., Gradisar, M., & Williamson, P. (2015). Protective and risk factors for adolescent sleep: A meta-analytic review. *Sleep Medicine Reviews, 21*, 72–85. https://doi.org/10.1016/j.smrv.2014.08.002

Becker, S. P., Langberg, J. M., & Byars, K. C. (2015). Advancing a biopsychosocial and contextual model of sleep in adolescence: A review and introduction to the special issue. *Journal of Youth and Adolescence*, *44*, 239–270. https://doi.org/10.1007/s10964-014-0248-y

Becker, S. P., Langberg, J. M., Eadeh, H. M., Isaacson, P. A., & Bourchtein, E. (2019). Sleep and daytime sleepiness in adolescents with and without ADHD: Differences across ratings, daily diary, and actigraphy. *Journal of Child Psychology and Psychiatry*, *60*, 1021–1031. https://doi.org/10.1111/jcpp.13061

Becker, S. P., & Lienesch, J. A. (2018). Nighttime media use in adolescents with ADHD: Links to sleep problems and internalizing symptoms. *Sleep Medicine*, *51*, 171-178. https://doi.org/doi: 10.1016/j.sleep.2018.06.021

Beyens, I., Piotrowski, J. T., & Valkenburg, P. M. (2018). Which came first? Assessing transactional relationships between children's violent media use and ADHD-related behaviors. *Communication Research*. Advance online publication. https://doi.org/10.1177/0093650218782300

Bjelland, M., Soenens, B., Bere, E., Kovács, É., Lien, N., Maes, L., Manios, Y., Moschonis, G., & Te Velde, S. J. (2015). Associations between parental rules, style of communication and children's screen time Health behavior, health promotion and society. *BMC Public Health*, *15*, 1002. https://doi.org/10.1186/s12889-015-2337-6

Börger, N., & Van Der Meere, J. (2000). Motor control and state regulation in children with ADHD: A cardiac response study. *Biological Psychology*, *51*, 247–267. https://doi.org/10.1016/S0301-0511(99)00040-X

Bourchtein, E., Langberg, J. M., Cusick, C. N., Breaux, R. P., Smith, Z. R., & Becker, S. P. (2019). Technology use and sleep in adolescents with and without attention-deficit/hyperactivity disorder. *Journal of Pediatric Psychology*, *44*, 517–526. https://doi.org/10.1093/jpepsy/jsy101

Brockmann, P. E., Diaz, B., Damiani, F., Villarroel, L., Núñez, F., & Bruni, O. (2016). Impact of television on the quality of sleep in preschool children. *Sleep Medicine*, *20*, 140–144. https://doi.org/10.1016/j.sleep.2015.06.005

Brockmann, P. E., Schlaud, M., Poets, C. F., & Urschitz, M. S. (2015). Predicting poor school performance in children suspected for sleep-disordered breathing. *Sleep Medicine*, *16*, 1077–1083. https://doi.org/10.1016/j.sleep.2015.03.021

Buckhalt, J. A., El-Sheikh, M., & Keller, P. (2007). Children's sleep and cognitive functioning: Race and socioeconomic status as moderators of effects. *Child Development*, *78*, 213–231. https://doi.org/10.1111/j.1467-8624.2007.00993.x

Cain, N., & Gradisar, M. (2010). Electronic media use and sleep in school-aged children and adolescents: A review. *Sleep Medicine*, *11*, 735–742. https://doi.org/10.1016/j.sleep.2010.02.006

Carskadon, M. A. (2011). Sleep in adolescents: The perfect storm. *Pediatric Clinics of North America*, *58*, 637–647. https://doi.org/10.1016/j.pcl.2011.03.003

Carskadon, M. A., & Dement, W. C. (2011). Monitoring and staging human sleep. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and practice of sleep medicine* (5th ed., pp. 16–26). Elsevier Saunders.

Chen, Y. L., Chen, S. H., & Gau, S. F. (2015). ADHD and autistic traits, family function, parenting style, and social adjustment for Internet addiction among children and adolescents in Taiwan: A longitudinal study. *Research in Developmental Disabilities*, *39*, 20–31. https://doi.org/10.1016/j.ridd.2014.12.025

Chorpita, B. F., Moffitt, C. E., & Gray, J. (2005). Psychometric properties of the Revised Child Anxiety and Depression Scale in a clinical sample. *Behaviour Research and Therapy*, *43*, 309–322. https://doi.org/10.1016/j.brat.2004.02.004

Common Sense. (2019). *Media Use by Tweens and Teens in 2019*. https://www.commonsensemedia.org/research/the-common-sense-census-media-use-by-tweens-and-teens-2019

Corkum, P., Moldofsky, H., Hogg-Johnson, S., Humphries, T., & Tannock, R. (1999). Sleep problems in children with attention-deficit/hyperactivity disorder: Impact of subtype, comorbidity, and stimulant medication. *Journal of the American Academy of Child and Adolescent Psychiatry*, *38*, 1285–1293. https://doi.org/10.1097/00004583-199910000-00018

Cortese, S., Brown, T. E., Corkum, P., Gruber, R., O’Brien, L. M., Stein, M., Weiss, M., & Owens, J. (2013). Assessment and management of sleep problems in youths with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, *52*, 784–796. https://doi.org/10.1016/j.jaac.2013.06.001

Cortese, S., Faraone, S. V., Konofal, E., & Lecendreux, M. (2009). Sleep in children with attention-deficit/hyperactivity disorder: Meta-analysis of subjective and objective studies. *Journal of the American Academy of Child & Adolescent Psychiatry*, *48*, 894–908. https://doi.org/10.1097/CHI.0b013e3181ac09c9

Dahl, R. E., & Lewin, D. S. (2002). Pathways to adolescent health sleep regulation and behavior. *The Journal of Adolescent Health*, *31*, 175–184. https://doi.org/10.1016/S1054-139X(02)00506-2

Daley, D., & Birchwood, J. (2010). ADHD and academic performance: Why does ADHD impact on academic performance and what can be done to support ADHD children in the classroom? *Child: Care, Health, and Development*, *36*, 455–464. https://doi.org/10.1111/j.1365-2214.2009.01046.x

Davidson, F., Rusak, B., Chambers, C., & Corkum, P. (2019). The impact of sleep restriction on daytime functioning in school-age children with and without ADHD: A narrative review of the literature. *Canadian Journal of School Psychology, 34*, 188-214. https://doi.org/10.1177/0829573518770593

de Zambotti, M., Goldstone, A., Colrain, I. M., & Baker, F. C. (2018). Insomnia disorder in adolescence: Diagnosis, impact, and treatment. *Sleep Medicine Reviews, 39*, 12–24. https://doi.org/10.1016/j.smrv.2017.06.009

Dewald, J. F., Meijer, A. M., Oort, F. J., Kerkhof, G. A., & Bögels, S. M. (2010). The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: A meta-analytic review. *Sleep Medicine Reviews, 14*, 179–189. https://doi.org/10.1016/j.smrv.2009.10.004

Diamantopoulos, A., Sarstedt, M., Fuchs, C., Wilczynski, P., & Kaiser, S. (2012). Guidelines for choosing between multi-item and single-item scales for construct measurement: a predictive validity perspective. *Journal of the Academy of Marketing Science, 40*, 434-449. https://doi.org/10.1007/s11747-011-0300-3

Diaz-Roman, A., Hita-Yáñez, E., & Buela-Casal, G. (2016). Sleep characteristics in children with attention deficit hyperactivity disorder: Systematic review and meta-analyses. *Journal of Clinical Sleep Medicine, 12,* 747–756. https://doi.org/ 10.5664/jcsm.5810

Dworak, M., Schierl, T., Bruns, T., & Struder, H. K. (2007). Impact of singular excessive computer game and television exposure on sleep patterns and memory performance of school-aged children. *Pediatrics, 120*, 978–985. https://doi.org/10.1542/peds.2007-0476

Ebesutani, C., Chorpita, B. F., Higa-Mcmillan, C. K., Nakamura, B. J., Regan, J., & Lynch, R. E. (2011). A psychometric analysis of the revised child anxiety and depression scales-parent version in a school sample. *Journal of Abnormal Child Psychology, 39*, 173–185. https://doi.org/10.1007/s10802-010-9460-8

Engelhardt, C. R., Mazurek, M. O., & Sohl, K. (2013). Media use and sleep among boys with autism spectrum disorder, ADHD, or typical development. *Pediatrics*, *132*, 1081–1089. https://doi.org/10.1542/peds.2013-2066

Fabiano, G. A., Pelham Jr, W. E., Waschbusch, D. A., Gnagy, E. M., Lahey, B. B., Chronis, A. M., Onyango, A. N., Kipp, H., Lopez-Williams, A., & Burrows-MacLean, L. (2006). A practical measure of impairment: Psychometric properties of the Impairment Rating Scale in samples of children with attention deficit hyperactivity disorder and two school-based samples. *Journal of Clinical Child and Adolescent Psychology*, *35*, 369–385. https://doi.org/10.1207/s15374424jccp3503

National Sleep Foundation (2006). *2006 Sleep in America poll*. https://www.sleepfoundation.org/sites/default/files/inline-files/2006_summary_of_findings.pdf

Gardner, D. G., Cummings, L. L., Dunham, R. B., & Pierce, J. L. (1998). Single-item versus multiple-item measurement scales: An empirical comparison. *Educational and Psychological Measurement, 58*, 898-915. https://doi.org/10.1177/0013164498058006003

Garrison, M. M., Liekweg, K., & Christakis, D. A. (2011). Media use and child sleep: The impact of content, timing, and environment. *Pediatrics*, *128*, 29–35. https://doi.org/10.1542/peds.2010-3304

Geissler, J., Romanos, M., Hegerl, U., & Hensch, T. (2014). Hyperactivity and sensation seeking as autoregulatory attempts to stabilize brain arousal in ADHD and mania? *ADHD Attention Deficit and Hyperactivity Disorders*, *6*, 159–173. https://doi.org/10.1007/s12402-014-0144-z

Gentile, D. A., Nathanson, A. I., Rasmussen, E. E., Reimer, R. A., & Walsh, D. A. (2012). Do you see what I see? Parent and child reports of parental monitoring of media. *Family Relations*, *61*, 470–487. https://doi.org/10.1111/j.1741-3729.2012.00709.x

Gul, H., Yurumez Solmaz, E., Gul, A., & Oner, O. (2018). Facebook overuse and addiction among Turkish adolescents: Are ADHD and ADHD-related problems risk factors? *Psychiatry and Clinical Psychopharmacology*, *28*, 80–90. https://doi.org/10.1080/24750573.2017.1383706

Han, D. H., Lee, Y. S., Na, C., Ahn, J. Y., Chung, U. S., Daniels, M. A., Haws, C. A., & Renshaw, P. F. (2009). The effect of methylphenidate on internet video game play in children with attention-deficit/hyperactivity disorder. *Comprehensive Psychiatry*, *50*, 251–256. https://doi.org/10.1016/j.comppsych.2008.08.011

Harbard, E., Allen, N. B., Trinder, J., & Bei, B. (2016). What's keeping teenagers up? Prebedtime behaviors and actigraphy-assessed sleep over school and vacation. *The Journal of Adolescent Health*, *58*, 426–432. https://doi.org/10.1016/j.jadohealth.2015.12.011

Healey, D. M., Flory, J. D., Miller, C. J., & Halperin, J. M. (2011). Maternal positive parenting style is associated with better functioning in hyperactive/inattentive preschool children. *Infant and Child Development*, *20*, 148–161. https://doi.org/10.1002/icd.682

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., Hazen, N., Herman, J., Katz, E. S., Kheirandish-Gozal, L., Neubauer, D. N., O'Donnell, A. E., Ohayon, M., Peever, J., Rawding, R., Sachdeva, R. C., Setters, B., Vitiello, M. V., Ware, J. C., & Adams Hillard, P. J. (2015). National Sleep Foundation's sleep time duration recommendations: Methodology and results summary. *Sleep Health*, *1*, 40–43. https://doi.org/10.1016/j.sleh.2014.12.010

Hoyle, R. H., & Gottfredson, N. C. (2015). Sample size considerations in prevention research applications of multilevel modeling and structural equation modeling. *Prevention Science*, *16*, 987–996. https://doi.org/10.1007/s11121-014-0489-8

Hysing, M., Lundervold, A. J., Posserud, M.-B., & Sivertsen, B. (2016). Association between sleep problems and symptoms of attention deficit hyperactivity disorder in adolescence: Results from a large population-based study. *Behavioral Sleep Medicine*, *14*, 550–564. https://doi.org/10.1080/15402002.2015.1048448

Ivarsson, M., Anderson, M., Akerstedt, T., & Lindblad, F. (2013). The effect of violent and nonviolent video games on heart rate variability, sleep, and emotions in adolescents with different violent gaming habits. *Psychosomatic Medicine*, *75*, 390–396. https://doi.org/10.1097/PSY.0b013e3182906a4c

Jensen, P. S., Hoagwood, K. E., Roper, M., Arnold, L. E., Odbert, C., Crowe, M., Molina, B. S. G., Hechtman, L., Hinshaw, S. P., Hoza, B., Newcorn, J., Swanson, J., & Wells, K. (2004). The services for children and adolescents-parent interview: Development and performance characteristics. *Journal of the American Academy of Child and Adolescent Psychiatry*, *43*, 1334–1344. https://doi.org/10.1097/01.chi.0000139557.16830.4e

Johnson, E. O., Roth, T., Schultz, L., & Breslau, N. (2006). Epidemiology of DSM-IV insomnia in adolescence: Lifetime prevalence, chronicity, and an emergent gender difference. *Pediatrics*, *117*, e247–e256. https://doi.org/10.1542/peds.2004-2629

Kidwell, K. M., Van Dyk, T. R., Lundahl, A., & Nelson, T. D. (2015). Stimulant medications and sleep for youth with ADHD: A meta-analysis. *Pediatrics*, *136*, 1144–1153. https://doi.org/10.1542/peds.2015-1708

King, D. L., Gradisar, M., Drummond, A., Lovato, N., Wessel, J., Micic, G., Douglas, P., & Delfabbro, P. (2013). The impact of prolonged violent video-gaming on adolescent sleep:

An experimental study. *Journal of Sleep Research*, *22*, 137–143. https://doi.org/10.1111/j.1365-2869.2012.01060.x

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*, 937–943. https://doi.org/10.1001/archpediatrics.2009.159

Kowalski, R. M., Giumetti, G. W., & Cox, H. (2019). Differences in technology use among demographic groups. In G. W. Giumetti & R. M. Kowalski (Eds.), *Cyberbullying in schools, workplaces, and romantic relationships: The many lenses and perspectives of electronic mistreatment*. Routledge.

Krogh, A. B., Larsson, B., Salvesen, Ø., & Linde, M. (2016). A comparison between prospective internet-based and paper diary recordings of headache among adolescents in the general population. *Cephalalgia*, *36*, 335–345. https://doi.org/10.1177/0333102415591506

Kwok, O., Underhill, A. T., Berry, J. W., Luo, W., Elliott, T. R., & Yoon, M. (2008). Analyzing longitudinal data with multilevel models: An example with individuals living with lower extremity intra-articular fractures. *Rehabilitation Psychology*, *53*, 370–386. https://doi.org/10.1037/a0012765

Langberg, J. M., Breaux, R. P., Cusick, C. N., Green, C. D., Smith, Z. R., Molitor, S. J., & Becker, S. P. (2019). Intraindividual variability of sleep/wake patterns in adolescents with and without attention-deficit/hyperactivity disorder. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *60*, 1219–1229. https://doi.org/10.1111/jcpp.13082

Langberg, J. M., Molina, B. S. G., Arnold, L. E., Epstein, J. N., Altaye, M., Hinshaw, S. P., Swanson, J. M., Wigal, T., & Hechtman, L. (2011). Patterns and predictors of adolescent academic achievement and performance in a sample of children with attention-deficit/hyperactivity disorder. *Journal of Clinical Child & Adolescent Psychology*, *40*, 519–531. https://doi.org/10.1080/15374416.2011.581620

Lange, K., Cohrs, S., Skarupke, C., Görke, M., Szagun, B., & Schlack, R. (2017). Electronic media use and insomnia complaints in German adolescents: Gender differences in use patterns and sleep problems. *Journal of Neural Transmission*, *124*, S79–S87. https://doi.org/10.1007/s00702-015-1482-5

LeBourgeois, M. K., Avis, K., Mixon, M., Olmi, J., & Harsh, J. (2004). Snoring, sleep quality, and sleepiness across attention-deficit/hyperactivity disorder subtypes. *Sleep*, *27*, 520–525. https://doi.org/10.1093/sleep/27.3.520

Lee, K. A., McEnany, G., & Weekes, D. (1999). Gender differences in sleep patterns for early adolescents. *The Journal of Adolescent Health*, *24*, 16–20. https://doi.org/10.1016/S1054-139X(98)00074-3

Lee, S. J., Bartolic, S., & Vandewater, E. A. (2009). Predicting children's media use in the USA: Differences in cross-sectional and longitudinal analysis. *British Journal of Developmental Psychology*, *27*, 123–143. https://doi.org/10.1348/026151008X401336

Lemola, S., Perkinson-Gloor, N., Hagmann-von Arx, P., Brand, S., Holsboer-Trachsler, E., Grob, A., & Weber, P. (2015). Morning cortisol secretion in school-age children is related to the sleep pattern of the preceding night. *Psychoneuroendocrinology*, *52*, 297–301. https://doi.org/10.1016/j.psyneuen.2014.12.007

Lenhart, A., Duggan, M., Perrin, A., Stepler, R., Rainie, H., & Parker, K. (2015). *Teens, social media & technology overview 2015*. http://www.pewinternet.org/2015/04/09/teens-social-media-technology-2015

Lowry, R., Wechsler, H., Galuska, D. A., Fulton, J. E., & Kann, L. (2002). Television viewing and its associations with overweight, sedentary lifestyle, and insufficient consumption of fruits and vegetables among US high school students: Differences by race, ethnicity, and gender. *Journal of School Health*, *72*, 413–421. https://doi.org/10.1111/j.1746-1561.2002.tb03551.x

Lunsford-Avery, J. R., Krystal, A. D., & Kollins, S. H. (2016). Sleep disturbances in adolescents with ADHD: A systematic review and framework for future research. *Clinical Psychology Review*, *50*, 159–174. https://doi.org/10.1016/j.cpr.2016.10.004

Ma, W., Adesope, O. O., Nesbit, J. C., & Liu, Q. (2014). Intelligent tutoring systems and learning outcomes: A meta-analysis. *Journal of Educational Psychology, 106*, 901–918. https://doi.org/10.1037/a0037123

Maas, C. J. M., & Hox, J. J. (2005). Sufficient sample sizes for multilevel modeling. *Methodology*, *1*, 86–92. https://doi.org/10.1027/1614-1881.1.3.86

Maddison, R., Mhurchu, C. N., Jull, A., Prapavessis, H., & Rodgers, A. (2007). Energy expended playing video console games: An opportunity to increase children's physical activity? *Pediatric Exercise Science*, *19*, 334–343. https://doi.org/10.1123/pes.19.3.334

Magee, C. A., Lee, J. K., & Vella, S. A. (2014). Bidirectional relationships between sleep duration and screen time in early childhood. *JAMA Pediatrics*, *168*, 465–470. https://doi.org/10.1001/jamapediatrics.2013.4183

Marinelli, M., Sunyer, J., Alvarez-Pedrerol, M., Iniguez, C., Torrent, M., Vioque, J., Turner, M. C., & Julvez, J. (2014). Hours of television viewing and sleep duration in children: A multicenter birth cohort study. *JAMA Pediatrics, 168*, 458–464. https://doi.org/10.1001/jamapediatrics.2013.3861

Mathieu, J. E., Aguinis, H., Culpepper, S. A., & Chen, G. (2012). Understanding and estimating the power to detect cross-level interaction effects in multilevel modeling. *Journal of Applied Psychology*, *97*, 951–966. https://doi.org/10.1037/a0028380

Matricciani, L. (2013). Subjective reports of children’s sleep duration: Does the question matter? A literature review. *Sleep Medicine*, *14*, 303–311. https://doi.org/10.1016/j.sleep.2013.01.002

Matthews, K. A., Hall, M., & Dahl, R. E. (2014). Sleep in healthy black and white adolescents. *Pediatrics*, *133*, e1189-96. https://doi.org/10.1542/peds.2013-2399

Mazurek, M. O., & Engelhardt, C. R. (2013). Video game use in boys with autism spectrum disorder, ADHD, or typical development. *Pediatrics*, *132*, 260–266. https://doi.org/10.1542/peds.2012-3956

McQuade, J. D., & Breaux, R. P. (2017). Are elevations in ADHD symptoms associated with physiological reactivity and emotion dysregulation in children? *Journal of Abnormal Child Psychology*, *45*, 1091–1103. https://doi.org/10.1007/s10802-016-0227-8

Meltzer, L. J., & Mindell, J. A. (2006). Sleep and sleep disorders in children and adolescents. *The Psychiatric Clinics of North America*, *29*, 1059–1076. https://doi.org/10.1016/j.psc.2006.08.004

Moorman, J. D., Morgan, P., & Adams, T. L. (2019). The implications of screen media use for the sleep behavior of children ages 0-5: A systematic review of the literature. *Current Sleep Medicine Reports*, *5*, 164–172. https://doi.org/10.1007/s40675-019-00151-0

Morgenthaler, T. I., Owens, J. A., Alessi, C., Boehlecke, B., Brown, T., Coleman, J. A. J., Friedman, L., Kapur, V. K., Lee-Chiong, T., Pancer, J., & Swick, T. J. (2006). Practice parameters for behavioral treatment of bedtime problems and night wakings in infants and young children. *Sleep*, *29*, 1277–1281. https://doi.org/10.1093/sleep/29.10.1277

Musser, E. D., Backs, R. W., Schmitt, C. F., Ablow, J. C., Measelle, J. R., & Nigg, J. T. (2011). Emotion regulation via the autonomic nervous system in children with attention-deficit/hyperactivity disorder (ADHD). *Journal of Abnormal Child Psychology*, *39*, 841–852. https://doi.org/10.1007/s10802-011-9499-1

Neumann, M. M. (2015). Young children and screen time: Creating a mindful approach to digital technology. *Australian Educational Computing*, *30*(2). http://journal.acce.edu.au/index.php/AEC/article/view/67

Nguyen, M., Tharani, S., Rahmani, M., & Shapiro, M. (2014). A review of the use of clonidine as a sleep aid in the child and adolescent population. *Clinical Pediatrics*, *53*, 211–216. https://doi.org/10.1177/0009922813502123

Paquet, J., Kawinska, A., & Carrier, J. (2007). Wake detection capacity of actigraphy during sleep. *Sleep*, *30*, 1362–1369. https://doi.org/10.1093/sleep/30.10.1362

Petersen, A. C., Crockett, L., Richards, M., & Boxer, A. (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of Youth and Adolescence*, *17*, 117–133. https://doi.org/10.1007/BF01537962

Pieters, D., De Valck, E., Vandekerckhove, M., Pirrera, S., Wuyts, J., Exadaktylos, V., Haex, B., Michiels, N., Verbraecken, J., & Cluydts, R. (2014). Effects of pre-sleep media use on sleep/wake patterns and daytime functioning among adolescents: The moderating role of parental control. *Behavioral Sleep Medicine*, *12*, 427–443. https://doi.org/10.1080/15402002.2012.694381

Reale, L., Bartoli, B., Cartabia, M., Zanetti, M., Costantino, M. A., Canevini, M. P., Termine, C., Bonati, M., & Lombardy ADHD Group. (2017). Comorbidity prevalence and treatment outcome in children and adolescents with ADHD. *European Child & Adolescent Psychiatry*, *26*, 1443-1457. https://doi.org/10.1007/s00787-017-1005-z

Rideout, V., Pai, S., Saphir, M., Pritchett, J., & Rudd, A. (2015). *The common sense census: Media use by tweens and teens*. Common Sense Media. https://www.commonsensemedia.org/sites/default/files/uploads/research/census_researchreport.pdf

Roberts, R. E., Roberts, C. R., & Duong, H. T. (2009). Sleepless in adolescence: Prospective data on sleep deprivation, health and functioning. *Journal of Adolescence*, *32*, 1045–1057. https://doi.org/10.1016/j.adolescence.2009.03.007

Sadeh, A, Pergamin, L., & Bar-haim, Y. (2006). Sleep in children with attention-deficit hyperactivity disorder: A meta-analysis of polysomnographic studies. *Sleep Medicine Reviews*, *10*, 381–398. https://doi.org/10.1016/j.smrv.2006.03.004

Sadeh, A, Sharkey, K. M., & Carskadon, M. A. (1994). Activity-based sleep-wake identification: An empirical test of methodological issues. *Sleep*, *17*, 201–207. https://doi.org/10.1093/sleep/17.3.201

Sadeh, A. (2011). The role and validity of actigraphy in sleep medicine: An update. *Sleep Medicine Reviews*, *15*, 259–267. https://doi.org/10.1016/j.smrv.2010.10.001

Sarstedt, M., & Wilczynski, P. (2009). More for less? A comparison of single-item and multi-item measures. *Die Betriebswirtschaft*, *69*, 211-227.

Short, M. A., Gradisar, M., Lack, L. C., Wright, H., & Carskadon, M. A. (2012). The discrepancy between actigraphic and sleep diary measures of sleep in adolescents. *Sleep Medicine*, *13*, 378–384. https://doi.org/10.1016/j.sleep.2011.11.005

Smaldone, A., Honig, J. C., & Byrne, M. W. (2007). Sleepless in America: Inadequate sleep and relationships to health and well-being of our nation's children. *Pediatrics*, *119*, S29-37. https://doi.org/10.1542/peds.2006-2089F

Stein, M. A., Weiss, M., & Hlavaty, L. (2012). ADHD treatments, sleep, and sleep problems: Complex associations. *Neurotherapeutics*, *9*, 509–517. https://doi.org/10.1007/s13311-012-0130-0

Steinberg, L., & Silverberg, S. B. (1986). The vicissitudes of autonomy in early adolescence. *Child Development*, *57*, 841–851. https://doi.org/10.2307/1130361

Sweetser, P., Johnson, D., Ozdowska, A., & Wyeth, P. (2012). Active versus passive screen time for young children. *Australian Journal of Early Childhood*, *37*, 94–98. https://doi.org/10.1177/183693911203700413

Szatmari, P., Offord, D. R., & Boyle, M. H. (1989). Ontario Child Health Study: Prevalence of attention deficit disorder with hyperactivity. *Journal of Child Psychology and Psychiatry*, *30*, 219–223. https://doi.org/10.1111/j.1469-7610.1989.tb00236.x

Tabachnik, B. G., & Fidell, L. S. (2013). *Using Multivariate Statistics* (6th ed.). Pearson Education Inc.

Tambalis, K. D., Panagiotakos, D. B., Psarra, G., & Sidossis, L. S. (2018). Insufficient sleep duration is associated with dietary habits, screen time, and obesity in children. *Journal of Clinical Sleep Medicine*, *14*, 1689–1696. https://doi.org/10.5664/jcsm.7374

Tavernier, R., & Willoughby, T. (2014). Sleep problems: Predictor or outcome of media use among emerging adults at university? *Journal of Sleep Research*, *23*, 389–396. https://doi.org/10.1111/jsr.12132

Turel, O., Romashkin, A., & Morrison, K. M. (2017). A model linking video gaming, sleep quality, sweet drinks consumption and obesity among children and youth. *Clinical Obesity*, *7*, 191–198. https://doi.org/10.1111/cob.12191

Van den Bulck, J. (2004). Television viewing, computer game playing, and internet use and self-reported time to bed and time out of bed in secondary-school children. *Sleep, 27*, 101–104. https://doi.org/10.1093/sleep/27.1.101

Visser, S. N., Blumberg, S. J., Danielson, M. L., Bitsko, R. H., & Kogan, M. D. (2013). State-based and demographic variation in parent-reported medication rates for attention-deficit/hyperactivity disorder, 2007-2008. *Preventing Chronic Disease*, *10*, E09. https://doi.org/10.5888/pcd9.120073

Wang, L. P., & Maxwell, S. E. (2015). On disaggregating between-person and within-person effects with longitudinal data using multilevel models. *Psychological Methods, 20*, 63–83. https://doi.org/10.1037/met0000030

Wang, X., & Perry, A. C. (2006). Metabolic and physiologic responses to video game play in 7- to 10-year-old boys. *Archives of Pediatrics and Adolescent Medicine*, *160*, 411–415. https://doi.org/10.1001/archpedi.160.4.411

Wechsler, D. (2011). *Wechsler Abbreviated Scale of Intelligence -- Second Edition (WASI-II)*. NCS Pearson.

Weller, E. B., Weller, R. A., Fristad, M. A., Rooney, M. T., & Schecter, J. (2000). Children's interview for psychiatric syndromes (ChIPS). *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*, 76–84. https://doi.org/10.1097/00004583-200001000-00019

Wiggs, L., Montgomery, P., & Stores, G. (2005). Actigraphic and parent reports of sleep patterns and sleep disorders in children with subtypes of attention-deficit hyperactivity disorder. *Sleep*, *28*, 1437–1445. https://doi.org/10.1093/sleep/28.11.1437

Table 1

Sample Characteristics

Variable	Total sample (N = 302)	ADHD group (n = 162)	Comparison group (n = 140)	Group differences
	$M \pm SD$	$M \pm SD$	$M \pm SD$	
Age	13.17 ± 0.40	13.17± 0.41	13.18 ± 0.40	t = 0.26, p = .80
Estimated IQ	107.03 ± 13.39	104.75 ± 13.89	109.67 ± 12.31	t = 3.23, p = .001
Pubertal development				
Female	3.07 ± 0.62	3.11 ± 0.57	3.05 ± 0.66	t = 0.60, p = .55
Male	2.34 ± 0.58	2.31 ± 0.56	2.39 ± 0.61	t = 0.86, p = .39
	N (%)	N (%)	N (%)	
Female	135 (44.7)	57 (35.2)	78 (55.7)	X^2 = 12.80, p < .001
Race				X^2 = 9.17, p = .06
White	247 (81.8)	129 (79.6)	118 (84.3)	
Black	16 (5.3)	12 (7.4)	4 (2.9)	
Asian	14 (4.6)	4 (2.5)	10 (7.1)	
American Indian/Alaskan	1 (0.3)	1 (0.6)	0 (0)	
Bi/Multiracial	24 (7.9)	16 (9.9)	8 (5.7)	
Hispanic/Latinx	14 (4.6)	7 (4.3)	7 (5.0)	X^2 = 0.08, p = .78
Medication use	120(39.7)	105 (64.8)	15 (10.7)	X^2 = 91.79, p < .001
Comorbid mental health diagnosis	107 (35.4)	74 (45.7)	33 (23.6)	X^2 = 16.04, p < .001
ODD/CD	41 (13.6)	35 (21.6)	6 (4.3)	X^2 = 19.20, p < .001
Any anxiety	73 (24.2)	46 (28.4)	27 (19.3)	X^2 = 3.40, p = .07
Any depression	24 (7.9)	16 (9.9)	8 (5.7)	X^2 = 1.78, p = .18

Note. Presence of comorbid mental health diagnosis based on parent or adolescent report (only parents were administered ODD and PTSD modules). ADHD = attention-deficit/hyperactivity disorder. ODD/CD = oppositional defiant disorder/conduct disorder. Any anxiety = presence of generalized anxiety disorder, social phobia, obsessive-compulsive disorder, and/or posttraumatic stress disorder (PTSD). Any depression = presence of major depression.

Table 2

Variable Summary Information

Variable	Total sample (N = 302)		ADHD group (n = 162)		Comparison group (n = 140)	
	Weekdays $M \pm SD$	Weekend days $M \pm SD$	Weekdays $M \pm SD$	Weekend days $M \pm SD$	Weekdays $M \pm SD$	Weekend days $M \pm SD$
Passive technology use (min.)	48.60 ± 57.87	58.79 ± 60.27	51.05 ± 59.25	62.64 ± 63.12	46.38 ± 56.44	55.70 ± 56.82
Active technology use (min.)	26.20 ± 47.38	36.64 ± 57.94	33.05 ± 53.92	42.20 ± 60.67	20.13 ± 39.51	32.78 ± 55.74
Sleep quality	2.26 ± 0.95	2.01 ± 0.92	2.30 ± 1.00	2.02 ± 0.96	2.21 ± 0.89	2.02 ± 0.90
Sleep duration (min.)	469.86 ± 71.78	519.19 ± 88.10	464.91 ± 74.65	516.42 ± 91.57	475.36 ± 68.05	522.12 ± 84.26

Note. Sleep quality is coded on a 5-point Likert scale, with greater values indicating poorer sleep quality. ADHD = attention-deficit/hyperactivity disorder; SD = standard deviation; min. = minutes.

Table 3

Bivariate Correlations between Study Variables

Variable	Passive technology use	Active technology use	Sleep quality	Sleep duration
Passive technology use	--	.07**	.01	-.03
Active technology use	.09**	--	.02	-.07**
Sleep quality	.06*	.00	--	-.17**
Sleep duration	-.01	-.08*	-.14**	--

Note. Correlations above the above the diagonal reflect weekdays, correlations below the diagonal reflect weekend days. Greater values of sleep quality indicate poorer sleep quality.

** $p < .01$; * $p < .05$

Table 4

Differences in Passive Technology Use Between Adolescents with and without ADHD

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	53.87 (4.88)	44.27, 63.47	11.05 (271.34)	<.001	69.04 (5.59)	58.04, 80.05	12.35 (261.76)	<.001
ADHD status	-5.61 (4.90)	-15.26, 4.04	1.15 (270.08)	.253	-8.71 (5.59)	-19.71, 2.29	1.56 (257.50)	.120
Sex	-5.47 (4.96)	-15.24, 4.30	1.10 (270.56)	.271	-9.16 (5.66)	-20.31, 2.00	1.62 (257.60)	.107
Race	7.45 (6.55)	-5.44, 20.33	1.14 (280.42)	.256	2.45 (7.50)	-12.31, 17.21	0.33 (261.13)	.744

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; SE = standard error.

Table 5

Differences in Active Technology Use Between Adolescents with and without ADHD

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	17.87 (4.03)	9.94, 25.80	4.44 (271.51)	<.001	19.50 (5.57)	8.53, 30.48	3.50 (262.84)	.001
ADHD status	-9.39 (4.01)	-17.30, -1.49	2.34 (267.89)	.020	-2.93 (5.51)	-13.79, 7.93	0.53 (257.29)	.596
Sex	25.53 (4.07)	17.52, 33.55	6.27 (268.20)	<.001	33.72 (5.59)	22.72, 44.72	6.04 (257.12)	<.001
Race	0.49 (5.34)	-10.03, 11.01	0.09 (272.51)	.927	6.52 (7.26)	-7.78, 20.83	0.90 (260.74)	.370

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; SE = standard error.

Table 6

Association Between Passive Technology Use and Sleep Quality Moderated by ADHD Status

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	1.73 (0.22)	1.29, 2.16	7.85 (270.87)	<.001	1.63 (0.24)	1.17, 2.10	6.90 (246.28)	<.001
ADHD status	-0.09 (0.09)	-0.26, 0.09	0.95 (271.24)	.342	-0.02 (0.10)	-0.21, 0.17	0.22 (251.21)	.830
Passive tech. use	0.00 (0.09)	-0.26, 0.09	0.17 (2656.13)	.862	0.00 (0.00)	0.00, 0.00	1.44 (1042.90)	.152
ADHD*Passive tech. use	0.00 (0.00)	0.00, 0.00	0.79 (2643.26)	.429	0.00 (0.00)	0.00, 0.00	0.21 (1022.34)	.838
Sex	-0.09 (0.09)	-0.26, 0.08	1.01 (268.97)	.311	-0.11 (0.09)	-0.29, 0.07	1.19 (248.18)	.236
Race	-0.11 (0.10)	-0.30, 0.09	1.09 (279.48)	.276	-0.07 (0.11)	-0.28, 0.14	0.63 (255.18)	.531
Medication use	0.00 (0.09)	-0.18, 0.17	0.04 (269.00)	.965	-0.04 (0.10)	-0.23, 0.15	0.44 (250.80)	.660
Externalizing dx.	0.03 (0.11)	-0.19, 0.24	0.23 (273.88)	.821	0.07 (0.12)	-0.17, 0.30	0.56 (257.82)	.573
Internalizing sx.	0.58 (0.09)	0.40, 0.76	6.47 (275.88)	<.001	0.43 (0.10)	0.24, 0.62	4.43 (251.42)	<.001
Pubertal development	0.12 (0.06)	0.00, 0.24	1.99 (266.69)	.047	0.08 (0.06)	-0.05, 0.21	1.27 (250.14)	.207

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for ADHD*Passive tech. use variable is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. Medication use is dichotomized into presence/absence of psychotropic medication use; reference group for medication use is presence of medication use. Reference group for externalizing diagnosis is presence of an externalizing diagnosis (i.e., oppositional defiant disorder and/or conduct disorder). ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; dx = diagnosis; SE = standard error; sx = symptoms; tech. = technology.

Table 7

Association Between Passive Technology Use and Sleep Duration Moderated by ADHD Status

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	505.60 (16.67)	472.76, 538.43	30.32 (263.80)	<.001	531.02 (20.67)	490.30, 571.74	25.69 (229.28)	<.001
ADHD status	9.42 (6.84)	-4.06, 22.89	1.38 (262.85)	.170	-6.65 (8.69)	-23.77, 10.48	0.77 (237.49)	.445
Passive tech. use	-0.02 (0.04)	-0.09, 0.05	0.53 (2309.12)	.599	0.04 (0.08)	-0.12, 0.20	0.54 (924.05)	.592
ADHD*Passive tech. use	0.11 (0.06)	0.01, 0.22	2.07 (2304.41)	.038	-0.01 (0.12)	-0.25, 0.22	0.12 (889.50)	.903
Sex	-3.32 (6.51)	-16.15, 9.51	0.51 (259.20)	.611	-23.12 (8.19)	-39.26, -6.98	2.82 (233.59)	.005
Race	-9.49 (7.58)	-24.41, 5.43	1.25 (271.94)	.211	-20.73 (9.53)	-39.51, -1.95	2.18 (225.09)	.031
Medication use	2.47 (6.65)	-10.63, 15.57	0.37 (260.65)	.710	7.50 (8.37)	-8.99, 24.00	0.90 (232.68)	.371
Externalizing dx.	-10.96 (8.35)	-27.40, 5.48	1.31 (269.06)	.190	-6.16 (10.66)	-27.16, 14.84	0.58 (242.39)	.564
Internalizing sx.	-18.96 (6.74)	-32.23, -5.69	2.81 (266.00)	.005	-6.64 (8.46)	-23.31, 10.04	0.78 (233.35)	.434
Pubertal development	-7.17 (4.56)	-16.15, 1.81	1.57 (254.15)	.117	4.46 (5.65)	-6.68, 15.60	0.79 (226.47)	.431

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for ADHD*Passive tech. use variable is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. Medication use is dichotomized into presence/absence of psychotropic medication use; reference group for medication use is presence of medication use. Reference group for externalizing diagnosis is presence of an externalizing diagnosis (i.e., oppositional defiant disorder and/or conduct disorder). ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; dx = diagnosis; SE = standard error; sx = symptoms; tech. = technology.

Table 8

Association Between Active Technology Use and Sleep Quality Moderated by ADHD Status

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	1.74 (0.22)	1.31, 2.17	7.94 (267.76)	<.001	1.50 (0.24)	1.02, 1.97	6.23 (244.98)	<.001
ADHD status	-0.09 (0.09)	-0.27, 0.09	0.99 (269.79)	.321	-0.04 (0.10)	-0.24, 0.16	0.40 (249.87)	.687
Active tech. use	0.00 (0.00)	0.00, 0.00	0.22 (2534.89)	.828	0.00 (0.00)	0.00, 0.00	1.83 (1014.89)	.067
ADHD*Active tech. use	0.00 (0.00)	0.00, 0.00	1.14 (2554.33)	.255	0.00 (0.00)	0.00, 0.00	1.19 (1011.84)	.233
Sex	-0.09 (0.09)	-0.26, 0.08	0.99 (266.32)	.323	-0.08 (0.10)	-0.27, 0.11	0.82 (245.93)	.416
Race	-0.10 (0.10)	-0.29, 0.09	1.02 (271.56)	.309	-0.04 (0.11)	-0.25, 0.18	0.33 (256.39)	.741
Medication use	-0.02 (0.09)	-0.19, 0.15	0.22 (268.27)	.825	-0.03 (0.10)	-0.22, 0.16	0.31 (247.78)	.756
Externalizing dx.	0.05 (0.11)	-0.17, 0.27	0.43 (273.56)	.668	0.13 (0.12)	-0.11, 0.37	1.07 (261.99)	.286
Internalizing sx.	0.57 (0.09)	0.39, 0.74	6.32 (275.86)	<.001	0.41 (0.10)	0.21, 0.61	4.12 (257.81)	<.001
Pubertal development	0.12 (0.06)	0.00, 0.24	1.96 (265.42)	.051	0.11 (0.07)	-0.02, 0.24	1.66 (249.17)	.099

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for ADHD*Active tech. use variable is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. Medication use is dichotomized into presence/absence of psychotropic medication use; reference group for medication use is presence of medication use. Reference group for externalizing diagnosis is presence of an externalizing diagnosis (i.e., oppositional defiant disorder and/or conduct disorder). ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; dx = diagnosis; SE = standard error; sx = symptoms; tech. = technology.

Table 9

Association Between Active Technology Use and Sleep Duration Moderated by ADHD Status

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	504.91 (16.56)	472.31, 537.51	30.50 (263.49)	<.001	531.34 (19.94)	492.04, 570.63	26.65 (220.89)	<.001
ADHD status	7.08 (6.81)	-6.33, 20.49	1.04 (263.72)	.299	-6.93 (8.41)	-23.50, 9.64	0.82 (228.92)	.411
Active tech. use	0.03 (0.04)	-0.06, 0.11	0.63 (2210.80)	.532	-0.16 (0.09)	-0.34, 0.01	1.80 (830.20)	.073
ADHD*Active tech. use	-0.13 (0.07)	-0.28, 0.01	1.83 (2251.30)	.068	0.11 (0.13)	-0.15, 0.37	0.82 (790.73)	.415
Sex	-4.80 (6.51)	-17.61, 8.02	0.74 (259.68)	.462	-20.62 (8.00)	-36.38, -4.86	2.58 (224.06)	.011
Race	-9.96 (7.51)	-24.75, 4.84	1.33 (266.19)	.186	-16.10 (9.11)	-34.06, 1.86	1.77 (214.27)	.079
Medication use	2.23 (6.62)	-10.80, 15.27	0.34 (262.50)	.736	9.15 (8.07)	-6.76, 25.05	1.13 (220.50)	.258
Externalizing dx.	-9.29 (8.30)	-25.62, 7.05	1.12 (271.70)	.264	-5.79 (10.37)	-26.22, 14.63	0.56 (236.46)	.577
Internalizing sx.	-18.95 (6.71)	-32.17, -5.73	2.82 (270.37)	.005	-4.41 (8.28)	-20.71, 11.90	0.53 (233.66)	.595
Pubertal development	-6.81 (4.54)	-15.75, 2.12	1.50 (255.23)	.134	3.02 (5.52)	-7.86, 13.89	0.55 (217.96)	.585

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for ADHD*Active tech. use variable is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. Medication use is dichotomized into presence/absence of psychotropic medication use; reference group for medication use is presence of medication use. Reference group for externalizing diagnosis is presence of an externalizing diagnosis (i.e., oppositional defiant disorder and/or conduct disorder). ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; dx = diagnosis; SE = standard error; sx = symptoms; tech. = technology.

Table 10

Association Between Sleep Quality and Passive Technology Use Moderated by ADHD Status

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	49.15 (15.62)	18.39, 79.90	3.15 (262.86)	.002	99.09 (16.54)	66.52, 131.66	5.99 (253.89)	<.001
ADHD status	-5.99 (6.44)	-18.68, 6.69	0.93 (264.77)	.353	-3.25 (6.76)	-16.57, 10.06	0.48 (253.12)	.631
Sleep quality	-2.93 (1.54)	-5.95, 0.10	1.90 (2481.75)	.058	3.82 (2.95)	-1.97, 9.61	1.30 (1054.42)	.195
ADHD*Sleep quality	4.10 (2.33)	-0.48, 8.67	1.76 (2483.25)	.079	-2.72 (4.27)	-11.11, 5.66	0.64 (1012.27)	.524
Sex	-5.72 (6.13)	-17.79, 6.36	0.93 (261.50)	.352	-12.07 (6.48)	-24.82, 0.69	1.86 (253.52)	.064
Race	9.48 (7.04)	-4.39, 23.35	1.35 (267.46)	.179	-1.20 (7.58)	-16.12, 13.72	0.16 (255.83)	.874
Medication use	1.76 (6.26)	-10.57, 14.09	0.28 (262.91)	.779	-4.67 (6.58)	-17.64, 8.29	0.71 (250.02)	.479
Externalizing dx.	-0.60 (7.87)	-16.10, 14.91	0.08 (266.27)	.940	-17.84 (8.40)	-34.38, -1.30	2.12 (262.07)	.035
Internalizing sx.	0.45 (6.34)	-12.03, 12.92	0.07 (267.82)	.944	1.72 (6.79)	-11.66, 15.06	0.25 (251.20)	.800
Pubertal development	1.08 (4.28)	-7.35, 9.51	0.25 (260.65)	.801	-3.50 (4.52)	-12.40, 5.40	0.77 (254.33)	.440

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for ADHD*Sleep quality variable is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. Medication use is dichotomized into presence/absence of psychotropic medication use; reference group for medication use is presence of medication use. Reference group for externalizing diagnosis is presence of an externalizing diagnosis (i.e., oppositional defiant disorder and/or conduct disorder). ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; dx = diagnosis; SE = standard error; sx = symptoms.

Table 11

Association Between Sleep Duration and Passive Technology Use Moderated by ADHD Status

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	49.30 (15.97)	17.85, 80.75	3.09 (259.62)	.002	96.39 (17.04)	62.81, 129.97	5.66 (234.45)	<.001
ADHD status	-5.94 (6.59)	-18.91, 7.03	0.90 (262.25)	.368	0.29 (7.23)	-13.95, 14.53	0.04 (255.30)	.968
Sleep duration	0.04 (0.02)	0.00, 0.08	1.78 (2166.93)	.075	0.00 (0.03)	-0.05, 0.06	0.14 (729.52)	.890
ADHD*Sleep duration	-0.05 (0.03)	-0.11, 0.01	1.57 (2162.03)	.116	0.03 (0.04)	-0.05, 0.12	0.81 (768.25)	.420
Sex	-3.17 (6.26)	-15.50, 9.15	0.51 (255.94)	.613	-6.77 (6.71)	-19.99, 6.46	1.01 (238.27)	.315
Race	9.82 (7.28)	-4.50, 24.15	1.35 (263.91)	.178	-6.79 (7.89)	-22.35, 8.76	0.86 (227.04)	.390
Medication use	1.32 (6.38)	-11.25, 13.89	0.21 (258.55)	.837	-9.05 (6.84)	-22.52, 4.41	1.32 (232.80)	.187
Externalizing dx.	-3.89 (7.98)	-19.60, 11.82	0.49 (263.81)	.626	-18.07 (8.71)	-35.23, -0.91	2.07 (252.68)	.039
Internalizing sx.	1.74 (6.44)	-10.94, 14.42	0.27 (262.29)	.787	3.84 (6.93)	-9.81, 17.50	0.56 (229.57)	.580
Pubertal development	1.37 (4.39)	-7.26, 10.01	0.31 (253.33)	.754	-4.71 (4.63)	-13.84, 4.42	1.02 (229.73)	.310

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for ADHD*Sleep quality variable is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. Medication use is dichotomized into presence/absence of psychotropic medication use; reference group for medication use is presence of medication use. Reference group for externalizing diagnosis is presence of an externalizing diagnosis (i.e., oppositional defiant disorder and/or conduct disorder). ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; dx = diagnosis; SE = standard error; sx = symptoms.

Table 12

Association Between Sleep Quality and Active Technology Use Moderated by ADHD Status

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	28.00 (12.25)	3.88, 52.11	2.29 (264.09)	.023	31.54 (17.63)	-3.19, 66.28	1.79 (229.95)	.075
ADHD status	-1.29 (5.06)	-11.25, 8.67	0.26 (267.45)	.799	-9.90 (7.21)	-24.11, 4.32	1.37 (225.94)	.171
Sleep quality	2.80 (1.30)	0.26, 5.35	2.16 (2354.71)	.031	-2.23 (2.55)	-7.23, 2.77	0.87 (959.12)	.383
ADHD*Sleep quality	-2.11 (1.94)	-5.92, 1.69	1.09 (2358.80)	.277	-0.11 (3.60)	-7.18, 6.96	0.03 (917.90)	.976
Sex	22.77 (4.83)	13.26, 32.27	4.72 (264.19)	<.001	28.00 (6.95)	14.32, 41.69	4.03 (228.17)	<.001
Race	0.32 (5.52)	-10.56, 11.19	0.06 (269.05)	.954	11.81 (7.97)	-3.89, 27.50	1.48 (230.06)	.140
Medication use	-10.29 (4.92)	-19.97, -0.61	2.09 (265.40)	.037	-2.83 (7.05)	-16.72, 11.05	0.40 (225.66)	.688
Externalizing dx.	9.36 (6.19)	-2.83, 21.55	1.51 (271.38)	.132	7.60 (8.95)	-10.04, 25.24	0.85 (234.95)	.397
Internalizing sx.	3.56 (4.99)	-6.27, 13.40	0.71 (273.35)	.476	2.51 (7.30)	-11.87, 16.89	0.34 (230.68)	.731
Pubertal development	-6.14 (3.36)	-12.77, 0.48	1.83 (264.13)	.069	-4.35 (4.83)	-13.86, 5.16	0.90 (228.90)	.368

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for ADHD*Sleep quality variable is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. Medication use is dichotomized into presence/absence of psychotropic medication use; reference group for medication use is presence of medication use. Reference group for externalizing diagnosis is presence of an externalizing diagnosis (i.e., oppositional defiant disorder and/or conduct disorder). ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; dx = diagnosis; SE = standard error; sx = symptoms.

Table 13

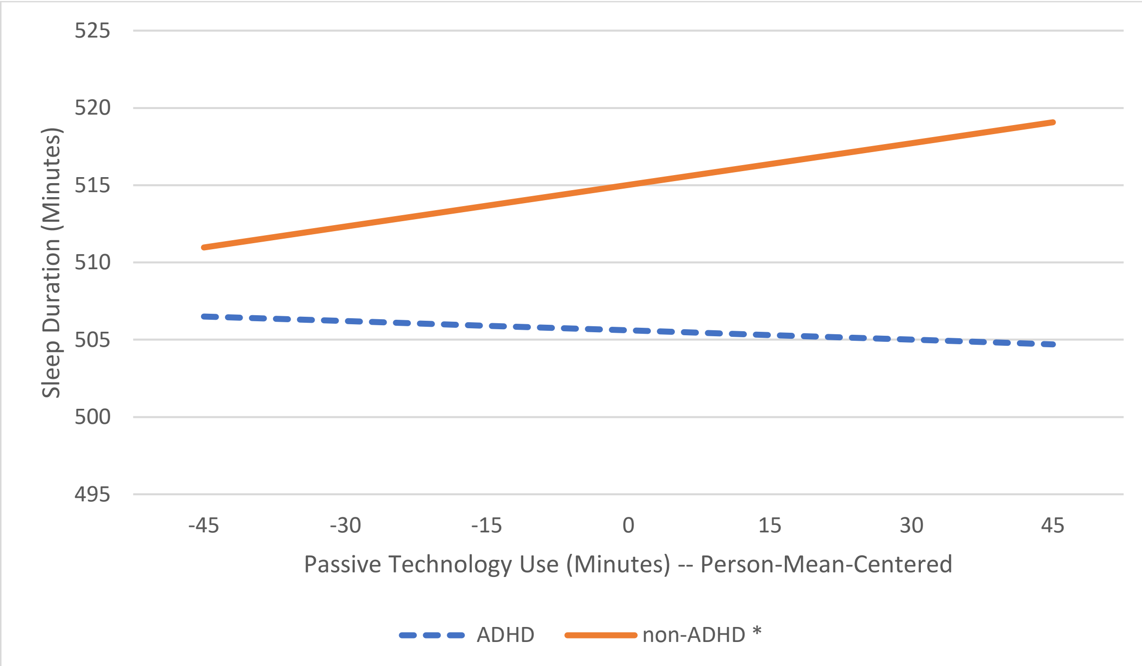
Association Between Sleep Duration and Active Technology Use Moderated by ADHD Status

Variable	Weekdays				Weekend days			
	B (*SE*)	95% CI	*t* (df)	*p*-value	*B* (*SE*)	95% CI	*t* (df)	*p*-value
Intercept	31.43 (11.83)	8.14, 54.72	2.66 (259.02)	.008	29.43 (17.47)	-5.00, 63.86	1.69 (217.98)	.094
ADHD status	-2.45 (4.88)	-12.06, 7.16	0.50 (262.80)	.616	-11.05 (7.83)	-25.60, 3.50	1.50 (230.36)	.136
Sleep duration	0.00 (0.02)	-0.03, 0.04	0.25 (2104.02)	.803	-0.01 (0.03)	-0.06, 0.04	0.48 (665.64)	.630
ADHD*Sleep duration	0.02 (0.03)	-0.03, 0.07	0.89 (2052.62)	.375	0.00 (0.04)	-0.07, 0.07	0.04 (714.21)	.970
Sex	22.00 (4.65)	12.84, 31.16	4.73 (256.63)	<.001	29.12 (6.93)	15.46, 42.77	4.20 (218.49)	<.001
Race	-2.64 (5.38)	-13.22, 7.95	0.49 (262.72)	.625	6.77 (8.02)	-9.05, 22.58	0.84 (210.85)	.400
Medication use	-9.43 (4.73)	-18.75, -0.12	1.99 (258.97)	.047	-4.49 (7.04)	-18.37, 9.39	0.64 (215.71)	.525
Externalizing dx.	7.05 (5.93)	-4.61, 18.72	1.19 (267.46)	.235	6.99 (8.85)	-10.46, 24.44	0.79 (229.87)	.431
Internalizing sx.	4.99 (4.79)	-4.45, 14.43	1.04 (266.72)	.299	3.60 (7.17)	-10.53, 17.72	0.50 (214.40)	.616
Pubertal development	-6.93 (3.25)	-13.33, -0.53	2.13 (254.02)	.034	-2.83 (4.79)	-12.27, 6.61	0.59 (213.55)	.555

Note. Reference group for ADHD status is presence of ADHD diagnosis. Reference group for ADHD*Sleep duration variable is presence of ADHD diagnosis. Reference group for sex is female. Race is dichotomized into White and non-White adolescents; reference group for race is non-White adolescents. Medication use is dichotomized into presence/absence of psychotropic medication use; reference group for medication use is presence of medication use. Reference group for externalizing diagnosis is presence of an externalizing diagnosis (i.e., oppositional defiant disorder and/or conduct disorder). ADHD = attention-deficit/hyperactivity disorder; CI = confidence interval; df = degrees of freedom; dx = diagnosis; SE = standard error; sx = symptoms.

Figure 1

Association between Weekday Passive Technology Use and Actigraphy-Measured Sleep Duration Moderated by ADHD Status



Note. This figure demonstrates the association between person-mean-centered weekday passive technology use and subsequent sleep duration as moderated by ADHD status. Sex, race, pubertal development, medication status, internalizing symptoms, and externalizing diagnoses are included as covariates in the model. ADHD = attention-deficit/hyperactivity disorder.

* $p < .05$ for simple slope

Vita

Elizaveta Bourchtein was born on August 13, 1988, in Moscow, Russia, and is a United States citizen. She graduated from Scotch Plains-Fanwood High School in Scotch Plains, New Jersey, in 2006. She graduated with her Bachelor of Arts degree in Psychology from Wesleyan University, Middletown, Connecticut, in 2010. She subsequently worked at Tufts Medical Center in Boston, Massachusetts, from 2010 to 2011, and Queens College, the City University of New York, Queens, New York, from 2011 to 2014. She received a Master of Science in Clinical Psychology from Virginia Commonwealth University, Richmond, Virginia, in 2016. She is currently completing her pre-doctoral internship at Penn State Hershey College of Medicine, Hershey, Pennsylvania, and will graduate with her Doctor of Philosophy in Clinical Psychology, Child/Adolescent concentration, from Virginia Commonwealth University in 2020.