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The Impact of Television, Electronic Games, and Social Technology Use on Sleep and Health in Adolescents with an Evening Circadian Preference

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Abstract

There are mixed findings when examining if technology use is harmful for adolescent sleep and health. This study builds on these mixed findings by examining the association between technology use with sleep and health in a high-risk group of adolescents. Adolescents with an evening circadian preference (N=176; 58% female, mean age=14.77, age range=10-18) completed measures over one week. Sleep was measured via actigraphy. Technology use and health were measured using ecological momentary assessment. Technology use was associated with an increase in sleep onset latency; with better emotional, social, cognitive, and physical health; and with worse behavioral health. This study offers support for technology use having some benefits and expands research on technology use to adolescents with an evening circadian preference.

Keywords

technology; sleep; ecological momentary assessment; actigraphy

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Author Contributions

NBG conceived of the study, coordinated data collection and data coding, conducted the statistical analyses, participated in the design and interpretation of the data, and drafted the manuscript; CEG participated in the design of the study, participated in the interpretation of the data, and revised the manuscript; JSS participated in the design of data collection and data coding, and revised to the manuscript; AGH conceived of the study, conceived of the larger project from which this data were drawn, participated in the interpretation of the data, and revised the manuscript. All authors read and approved the final manuscript.

Data Sharing Declaration

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Ethical Approval

The University of California, Berkeley, Committee for the Protection of Human Subjects approved all procedures and measures used in this study. The approval number for this project was 2012-02-4007.

Informed Consent

Participants received study information and consent forms prior to the beginning of the study. Signed informed consent was obtained from the legal guardian of the adolescent. Signed informed assent was obtained from adolescents who were ages 10-17 and informed consent was obtained from adolescents who were age 18.

Introduction

Adolescents have access to a wide range of technology (Rideout & Robb, 2019). A recent survey found that 95% of adolescents have access to a smartphone at home, 88% of adolescents have access to a computer at home, and 84% of adolescents have access to a videogame console at home (Anderson & Jiang, 2018). However, it remains unclear if widespread technology use has a positive or negative impact on health. Indeed, while several recent studies have found that technology use is associated with poor sleep (Bartel, Gradisar, & Williamson, 2015; Twenge, Hisler, & Krizan, 2019) and poor emotional, social, cognitive, physical, and behavioral health (Twenge, Martin, & Campbell, 2018; Vernon, Modecki, & Barber, 2018), others have found benefits to technology use (George, Russell, Piontak, & Odgers, 2018; Przybylski, Orben, & Weinstein, 2019). In light of these mixed findings, the question remains: does increased use of television, electronic games, and social technology contribute to poor sleep and poor health? The current study addresses this gap by examining the impact of technology use on sleep and health using ecological momentary assessment to evaluate these relationships in the daily life of adolescents with an evening circadian preference.

Technology use, such as watching television, playing electronic games, and social uses, is associated with worse sleep outcomes among adolescents. Many studies and a systematic review have demonstrated that watching television is associated with shorter total sleep time (Bartel et al., 2015; Hysing et al., 2015; Twenge et al., 2019), a later bedtime (Hale & Guan, 2015; Twenge et al., 2019), and a longer sleep onset latency (i.e. time to fall asleep) (Hysing et al., 2015; Twenge et al., 2019). The pattern is similar for electronic games: playing electronic games has been associated with a shorter total sleep time (Hale & Guan, 2015; Twenge et al., 2019), a later bedtime (Harbard, Allen, Trinder, & Bei, 2016), and a longer sleep onset latency (Hale & Guan, 2015; Hysing et al., 2015). Social uses, including texting and social media, are also associated with shorter total sleep time (Bartel et al., 2015; Hale & Guan, 2015), a later bedtime (Garmy & Ward, 2018; Pieters et al., 2014), and a longer sleep onset latency (Garmy & Ward, 2018; Pieters et al., 2014). This negative relationship between sleep and technology use may be driven by multiple factors, as proposed in prior theories (Bartel & Gradisar, 2017; Cain & Gradisar, 2010). First, technology use may be directly replacing sleep or other positive, sleep-promoting activities, such as physical activity. Second, technology use increases physiological arousal, which may decrease the homeostatic sleep drive and can result in difficulty relaxing. Third, technology use increases bright light exposure, which delays the circadian rhythm and suppresses melatonin production.

There is also a negative relationship between adolescent technology use—across television, electronic games, and social uses—and health across five domains: emotional, social, cognitive, physical, and behavioral. In the *emotional* health domain, technology use has been associated with symptoms of depression (Frison & Eggermont, 2016) and with suicidal ideation (Twenge et al., 2018). In the *social* health domain, technology use has been associated with decreased social connectedness and increased loneliness and aggression (Wu, Outley, Matarrita-Cascante, & Murphrey, 2015). In the *cognitive* health domain, technology use has been associated with increased problems focusing attention (Nikkelen, Valkenburg, Huizinga, & Bushman, 2014). In the *physical* health domain, technology use has been associated with decreased physical activity (Cain & Gradisar, 2010; Twenge et al., 2018). In the *behavioral* health domain, technology use has been associated with increased behavioral problems (Holtz & Appel, 2011), such as externalizing behaviors (Vernon et al., 2018). Risk across these health domains can be attributed to adolescence being a period characterized by rapid neural, hormonal, and physical development. Indeed, beginning with the onset of puberty, adolescence is characterized by development in the connectivity and maturation of brain regions responsible for emotional responsivity and impulse control (e.g. amygdala, prefrontal cortex). The rapid neural changes and, at times imbalanced immaturity of neural development, has been theorized to contribute to increased risk for engagement in emotionally-driven behaviors across all five health domains (Casey, Heller, Gee, & Cohen, 2019).

However, several recent studies have called into question whether technology use is always harmful. Indeed, multiple studies have concluded that technology use does not negatively impact sleep or health (Orben & Przybylski, 2019a, 2019b), although there are ongoing debates focused on methodological approaches (Twenge, Blake, Haidt, & Campbell, 2020; Twenge, Haidt, Joiner, & Campbell, 2020). One possible explanation is that technology use may be used as a distraction to reduce the worry and rumination that often impairs sleep (Bartel & Gradisar, 2017). Relatedly, technology use has been associated with both a reduction in same day mood and anxiety symptoms (George et al., 2018) and limited technology use (e.g. 1-2 hours) appears to be associated with better health (Przybylski et al., 2019). It is clear that additional research is needed to understand these mixed findings.

This study focuses on adolescents with an evening circadian preference, or “night owls.” These adolescents follow a delayed schedule, with a preference for a later bedtime and increased activity later in the day (Carskadon, Vieira, & Acebo, 1993). An evening circadian preference is associated with sleep problems during adolescence, most notably a delayed bedtime and insufficient total sleep time (Crowley, Wolfson, Tarokh, & Carskadon, 2018). Adolescents with an evening circadian preference are also at increased risk for a range of negative health outcomes. These include depression and anxiety in the *emotional* health domain (Fares et al., 2015), aggressive and antisocial behavior in the *social* health domain (Schlarb, Sopp, Ambiel, & Grünwald, 2014), poor academic performance in the *cognitive* health domain (Short, Gradisar, Lack, Wright, & Dohnt, 2013), obesity in the *physical* health domain (Malone et al., 2016), and substance use and impulsivity in the *behavioral* health domain (Hasler, Soehner, & Clark, 2016). Taken together, adolescents with an evening circadian preference may be particularly vulnerable to negative consequences of technology use on sleep (Crowley et al., 2018) and health (Casey et al., 2019). The extent to which technology use contributes to sleep and/or health risk for adolescents with an evening circadian preference remains unclear.

Ecological momentary assessment may be helpful to further understand the relationship between technology use and both sleep and health in daily life. Ecological momentary assessment involves the repeated sampling of an individual’s current experiences as they are in their regular environment (Stone, Hufford, & Shiffman, 2008). Ecological momentary assessment has several advantages. It maximizes ecological validity, allows for repeated assessments, permits the examination of day-by-day experiences, and minimizes retrospective recall (Stone et al., 2008). Ecological momentary assessment methods may offer new insights as prior studies have tended to rely heavily on retrospective questionnaires that ask the participant to average across time (Frison & Eggermont, 2016; Hysing et al., 2015; Orben & Przybylski, 2019b) or on parent reports of their adolescent's behavior (Orben & Przybylski, 2019a; Przybylski et al., 2019; Twenge et al., 2019).

Current Study

As the field remains mixed on if the use of television, electronic games, and social technology contribute to poor sleep and poor health, the overarching goal of the present study is to utilize ecological momentary assessment to evaluate the impact of technology use among adolescents with an evening circadian preference. The first aim is to examine the association between technology use and sleep. The hypothesis tested is that technology use at bedtime will be associated with worse sleep, operationalized as shorter total sleep time, a later bedtime, and a longer sleep onset latency. The second aim is to examine the concurrent association between technology use and the five health domains (emotional, social, cognitive, physical, behavioral). The hypothesis tested is that technology use will be associated with worse health across each of the five health domains.

Methods

Participants

Participants were 176 adolescents (mean age = 14.77, 58% female) in the United States drawn from those recruited to participate in a NICHD-funded trial designed to modify the psychosocial, behavioral, and cognitive processes that contribute to an evening circadian preference among adolescents (Harvey et al., 2018). Participants were recruited through clinician referrals and advertisements. Participant demographics are described in Table 1.

Participants were eligible if they (a) were between 10 and 18 years old, living with a parent or guardian, and attending a class/job by 9am at least three days per week, (b) were fluent in English, (c) were able and willing to give informed assent, (d) reported an evening circadian preference as demonstrated by scoring in the lowest quartile on the Children's Morningness-Eveningness Preference Scale (27 or lower), had a 7-day sleep diary showing a sleep onset time of 10:40pm or later for 10-13-year-olds, 1lpm or later for 14-16-year-olds, and 11:20pm or later for 17-18-year-olds at least three nights per week, and this pattern was present for at least three months, and (e) fell in the "at-risk" range on measures in at least one of five health domains described in greater detail in Supplement 1.

Individuals were excluded if there was (a) an active, progressive physical illness or neurodegenerative disease directly related to the onset and course of the sleep disturbance, (b) evidence of obstructive sleep apnea, restless leg syndrome, or periodic limb movement disorder, (c) significantly impairing pervasive developmental disorder, (d) bipolar disorder, schizophrenia, or another Axis I disorder if there were risk of harm if treatment were delayed, (e) a history of substance abuse in the past six months, and (f) current suicide risk to preclude treatment on an outpatient basis. Individuals ceased taking medications that alter sleep four weeks prior to the assessment (two weeks for melatonin) or were excluded.

Measures

Sleep.—Sleep was assessed via actigraphy. The Actiwatch Spectrum (Philips Respironics, Bend, Oregon, USA) is a wrist-worn device containing an accelerometer to measure physical motion. Actigraphy is an objective measure of sleep and has been validated against polysomnography, the gold standard objective measure, in adolescents (Quante et al., 2018). For seven days, participants were asked to wear an actiwatch on their non-dominant wrist and instructed to remove the actiwatch only when showering. Activity data was logged in 30 second epochs and analyzed using the Actiware software v.6 (Philips Respironics, Bend, Oregon, USA). The scoring algorithm's sensitivity for wake/sleep detection was set to medium. The main sleep window was the longest period of sleep identified by the scoring algorithm within a 24-hour window. Following recommendations in the field, sleep diary data that was collected concurrently (Carney et al., 2012) was used to adjust the sleep window as needed (Matthews et al., 2018). The variables of interest were total sleep time, bedtime, and sleep onset latency as these have been implicated in prior studies examining technology use in adolescents (Hale & Guan, 2015; Hysing et al., 2015).

Ecological Momentary Assessment.—Health and technology use were assessed via ecological momentary assessment. Participants received calls from a trained research assistant over one week. Assessments were conducted twice on weekdays between 4pm and 9pm and four times on weekends between 11am and 9pm, for a total of up to 18 calls. Participants were instructed to turn off their cell phones during school. If a participant did not answer on the first attempt, the call was attempted again immediately and then again after 5 minutes. There were at least 30 minutes between each call. Each call consisted of a brief structured interview.

The interview delivered was based on prior research (Silk et al., 2011) and adapted to evaluate the five health domains. The coding of the ecological momentary assessments was also adapted from the methods of a prior study (Silk et al., 2011). Specifically, the interview responses were transcribed verbatim. Five coders independently coded a subset of the data (5%) with 93.21% agreement with an "expert coder" (NBG). To be a certified coder, coders had to match at over 80% accuracy with the expert coder for a minimum of 54 consecutive calls. Then each coder independently coded a subset of the data.

Health.: The five health domains were measured via ecological momentary assessment. Variables in each domain were calculated using the same method as prior research from this dataset (Dong, Gumport, Martinez, & Harvey, 2019; Harvey et al., 2018).

Emotional domain.: A short form adapted from the Positive and Negative Affect Schedule for Children (PANAS-C) (Laurent et al., 1999) was employed during each call. Four positive emotions were assessed: happy, cheerful, interested, and excited. Five negative emotions were assessed: sad, nervous, upset, angry, and bored. Positive emotions in each call were averaged to create a positive affect score. Negative emotions in each call were averaged to create a negative affect score. Adolescents were asked to rate these emotions on a 5-point Likert scale (1=not at all, 2=a little, 3=moderately, 4=quite a bit, 5=extremely).

Social domain.: Social health was measured by calculating a positivity ratio of positive affect to negative affect when adolescents reported they were alone, with family, or with friends at the time of each ecological momentary assessment call. In addition to reporting their emotions (see emotional domain above), adolescents reported they were with at a given call (“At the moment the phone rang, was anyone else with you?”). These responses were binned into being alone, with a family member, or with a friend.

Cognitive domain.: Cognitive health was assessed by examining ratings of adolescents’ difficulty with concentration (“To what extent was it difficult for you to concentrate on the task?”), getting distracted (“To what extend were you distracted?”), and ability to focus attention (“To what extent were you able to focus your attention?”) on their current activity during each call. Adolescents were asked to rate each of these items on a 5-point Likert scale (1=not at all, 2=a little, 3=moderately, 4=quite a bit, 5=extremely). A composite score of all three items was also created.

Physical domain.: Physical health was assessed as a binary variable (1=active, 2=inactive) derived by questions from prior research (Kanning & Schlicht, 2010). Physical activity was assessed only in the final ecological momentary assessment call each day by asking “Were you physically active today?” and “What activities did you do?”

Behavioral domain.: Behavioral health was calculated by creating a composite score of the consumption of junk food, caffeine use, alcohol use, tobacco use, and other substance use during each call.

Technology Use.: Technology use was measured using the same ecological momentary assessment procedures described above. During each call, participants responded to the question, “At the moment the phone rang, what were you doing?” Responses were coded and technology use was identified. The type of technology use was categorized into one of three categories: television, electronic games (e.g., video games, computer games), or social uses (e.g., social media, texting).

Procedure

Participants completed ecological momentary assessment measures to assess health and technology use and wore an actiwatch concurrently over one week. These data were collected prior to any participant received treatment as part of the broader clinical trial (Harvey et al., 2018). Data were collected in 2013-2016.

All procedures were approved by the Institutional Review Board. All participants provided informed assent or consent.

Data Analysis

Data analyses were conducted in Statal5. Hierarchical linear modeling using maximum likelihood estimation was used to address the aims of this study. This statistical method can account for the associations between repeated measurements and does not have the same missing data restrictions of traditional regression analyses. Sleep and health variables were standardized. Standardized coefficients were calculated, as these are interpretable as effect sizes (Lorah, 2018).

The first aim of this study only included technology use during the final ecological momentary assessment call of each day in the analyses in order to evaluate the relationship between technology use and sleep as closely as possible. To verify that we assessed the relationship between technology use and sleep as directly as possible, we examined the timing of ecological momentary assessment calls. The average ecological momentary assessment call was at 19.66 decimal hours (SD = 2.61), or 7:40 PM. The average distance between the final call of the day and an adolescent's bedtime was 4.09 decimal hours (SD = 2.82). In order to increase temporal accuracy between technology use and bedtime, this study only included calls that were within one standard deviation from the mean, or within 1.27 decimal hours of an adolescent's bedtime. This reduced the sample size for the first aim to 68 data points drawn from 39 participants. The second aim of this study included all calls.

For the first aim of this study, previous night's sleep (total sleep time, bedtime, and sleep onset latency), age, sex, Children's Morningness-Eveningness Preference Scale score, and a dummy variable indicating if the night assessed was a weekday or weekend were included as covariates in the fixed part of the model. For the second aim of this study, age and sex were included as covariates in the fixed part of the model. The random part of all models included a random intercept for participant, assumed to have a bivariate normal distribution with a mean of zero and an unstructured covariance matrix. A significance level of 0.05 was used throughout.

Missing Data

The average number of EMA calls per participant was 9.24 (SD = 5.11). Data was assumed to be missing at random and multilevel models as used in the present study can account for missing data. All available data was used in the present study.

Results

Table 2 presents the descriptive statistics for the study variables. The average total sleep time was 448.29 minutes (SD = 10.13 minutes), the average bedtime was 22.21 decimal hours, or 10:12pm (SD = 0.14 decimal hours), and the average sleep onset latency was 33.46 minutes (SD = 6.64 minutes). For the emotional health domain, positive affect was rated on average as a little to moderate (mean = 2.54, SD = 0.02) and negative affect was rated on average as very slightly/not at all to a little (mean = 1.42, SD = 0.01). For the health social domain, the average positivity ratio ranged as very slightly to moderately (mean = 1.83-2.51, SD = 0.03-0.06). For cognitive health domain, overall cognitive problems were rated on average as a little to moderately challenging (mean = 2.31, SD = 0.01). For the physical health domain, adolescents were on average more active than not (mean = 1.47, SD = 0.02). For the behavioral health domain, adolescents reported few behavioral problems (mean = 0.08, SD = 0.00). Table 3 presents correlations between all the sleep and health outcome variables.

Technology Use and Sleep

As evident in Table 4, technology use was associated with an increased sleep onset latency ($\beta = 0.65$, $p < 0.01$) with a medium effect size. Technology use was not associated with total sleep time or bedtime.

Technology Use and Health

The results are presented in Table 5. Technology use was associated with better health in the emotional domain. Television and electronic game use were significantly associated with increased positive affect ($\beta = 0.10\text{-}0.44$, $p = 0.00\text{-}0.01$) and lower negative affect ($\beta = -0.31\text{-}0.21$, $p < 0.001$). Also, television use was significantly associated with an increase in ratings of happy and interested and with a decrease in ratings of sad, upset, and bored. Electronic game use was significantly associated with higher ratings of happy, cheerful, interested, and excited, and with lower ratings of sad and bored. While social uses were not significantly associated with positive affect and negative affect, social uses were associated with lower ratings of excited, interested, and nervous.

Technology use was associated with better health in the social domain. Specifically, television use was significantly associated with a higher positivity ratio among adolescents when they were alone ($\beta = 0.31$, $p < 0.001$), but not when adolescents were with family or with friends. Electronic game use was significantly associated with higher positivity ratios when adolescents were alone, with family, and with friends ($\beta = 0.51\text{-}0.57$, $p = 0.00\text{-}0.04$). Social uses were not associated with the positivity ratio when adolescents were alone, with family, or with friends.

Technology use was significantly associated with better health in the cognitive domain ($\beta = 0.62$, $p = 0.01$). In particular, television use was significantly associated with less difficulty concentrating and with being less distracted. Electronic game use was associated with less difficulty concentrating and less difficulty focusing attention. Social uses were significantly associated with less difficulty concentrating and with being less distracted.

Technology use was associated with better health in the physical domain. Specifically, electronic game use was significantly associated with increased physical activity ($\beta = 0.30$, $p = 0.04$). Television and social uses were not associated with physical health.

Finally, technology use was associated with worse health in the behavioral domain. Specifically, television use was associated with increased behavioral problems ($\beta = 0.26$, $p < 0.001$). Electronic game use and social uses were not associated with behavioral health.

Sensitivity Analyses

Alternative models were explored as a part of sensitivity analyses. First, we examined if technology use was associated with subsequent sleep using the last call of the day within the entire sample regardless of how close the final call was to bedtime. Results displayed a similar pattern to the reported findings, although they were not significant (total sleep time: $\beta = 0.13$, $p = 0.38$; bedtime: $\beta = 0.05$, $p = 0.63$; sleep onset latency: $\beta = 3.58$, $p = 0.18$). Second, we examined if any technology use was associated with concurrent health, collapsing across all three categories of technology use. No other analyses were conducted and we have reported all decisions for excluding participants in the Methods section.

Discussion

The literature on the impact of technology use on adolescent sleep and health is mixed – at times, technology use has been found not to have an impact on adolescent sleep and health (e.g., Orben & Przybylski, 2019a, 2019b), while at other times it has been shown to be harmful (e.g., Twenge et al., 2019; Vernon et al., 2018) or helpful (e.g., George et al., 2018). One possibility for these disparate findings is the measurement of technology use, as existing studies have relied on parent-report of adolescent behavior or on retrospective averages. The impact of technology use in adolescents with an evening circadian preference, a group of adolescents at increased risk for a range of problematic outcomes across several domains of adolescent health, is not yet known. To address prior methodological concerns and examine technology use in this high risk sample, the goal of the present study was to use ecological momentary assessment to examine the impact of technology use on both sleep and health in adolescents with an evening circadian preference.

The first aim was to examine if technology use predicted worse sleep among adolescents with an evening circadian preference. In partial support of the hypothesis, technology use was associated with an increase in sleep onset latency. This finding is consistent with prior literature demonstrating that technology use increases sleep onset latency (Hale & Guan, 2015; Hysing et al., 2015). Notably, the findings (*Unstandardized* β = 35.87 minutes) suggest that technology use had a clinically-relevant impact on sleep onset latency, as a sleep onset latency of 30 minutes is often considered to serve as a cut-off for clinical significance (Hysing, Pallesen, Stormark, Lundervold, & Sivertsen, 2013). Contrary to the hypothesis, technology use was not associated with total sleep time or bedtime. These findings contribute to the mixed findings on the relationship between technology use adolescent sleep (Hale & Guan, 2015; Orben & Przybylski, 2019a).

The second aim was to examine the association between adolescent technology use and health. In partial support, technology use—specifically watching television—was associated with worse health in the behavioral domain. This finding is congruous with prior research demonstrating that watching television is associated with increased behavioral difficulties among adolescents (Vernon et al., 2018). Contrary to the hypothesis, and consistent with the recently debated research reporting that technology use is not harmful to adolescent health (Orben & Przybylski, 2019a, 2019b), technology use was associated with better health in the emotional, social, cognitive, and physical domains. Specifically, in the emotional and social domains, watching television (when alone) and playing electronic games (alone, with family and with friends) were associated with higher positive affect and lower negative affect. The results are also consistent with research demonstrating that technology use can improve mood symptoms (George et al., 2018) and with research showing that playing electronic games can foster an increased sense of social connectedness and community (Trepte, Reinecke, & Juechems, 2012), which may reduce negative emotion. Furthermore, in the cognitive domain, television, electronic games, and social uses were all associated with higher cognitive functioning, which is not consistent with prior research (Nikkelen et al., 2014). This finding is unexpected. Perhaps adolescents are poor reporters of their concentration or perhaps they were reporting how focused they were on their current technology use, as adolescents often underestimate the effects of their multitasking while using technology (e.g., technology plus another activity or multiple technologies at once, May & Elder, 2018). In the physical domain, the findings that electronic games use was associated with increased physical activity is not consistent with theory (Cain & Gradisar, 2010), although is in line with research about the benefits of physically active video game use (Gao, Chen, Pasco, & Pope, 2015). As technology use may take up time that would otherwise be used to engage in other recreational activities (Cain & Gradisar, 2010; Twenge et al., 2019), future research should explore the function of technology use (e.g., to socialize with friends, to be physically active, to escape or cope with negative emotions).

Technology use for social uses (e.g., social media) had no negative effects on adolescent health. These findings are inconsistent with studies highlighting problems with social media use among adolescents, specifically that social media is associated with increased anxiety, depression, and loneliness as well as with lower self-esteem (Woods & Scott, 2016). However, the findings from the present study are consistent with recent literature that has demonstrated that social media use does not negatively impact adolescent health (Orben, Dienlin, & Przybylski, 2019). There are at least possible interpretations. First, the statistical analyses conducted for the present study did not examine the health domain in which each adolescent was “at-risk” as most adolescents were at risk in multiple health domains and this would add many more comparisons. Therefore, perhaps risk in a particular health domain or combination of health domains may render adolescents more susceptible to problems with technology for social uses, and this is an important domain for future research. Second, perhaps social uses are helpful or harmful based on the function of using technology itself (i.e. what is the function of the behavior of using social media?). For example, social media used to distract oneself to reduce anxiety by looking at cute animal pictures/videos may prove helpful. In contrast, looking at pictures from a party that an adolescent was not invited to may be harmful. Hence, future studies examining the reasons why adolescents use technology in a given moment and the association with health would be beneficial.

Several limitations should be noted. First, as technology use and health were assessed concurrently during each ecological momentary assessment call, we are unable to establish the temporal relationship between technology use and the health domains. Perhaps technology use and health have a bidirectional relationship. This should be explored in future studies. Second, this sample was comprised of adolescents with an evening circadian preference, a group of adolescents who are particularly at-risk for negative sleep and health outcomes (Fares et al., 2015; Hasler et al., 2016). Future research is needed with other groups of adolescents (e.g., those with a morning circadian preference) or in individuals who are not experiencing health risk in order to increase the generalizability of the findings. However, as 40% of adolescents experience an evening circadian preference, the present findings seem likely to apply to a large swath of adolescents (Carskadon et al., 1993). Third, due to the variability in the timing of the ecological momentary assessment calls, the sample was small for the first aim (n = 39 participants, n = 68 calls), which evaluated the relationship between technology use and sleep. However, this subsample was representative of the larger sample (mean age = 14.74 years old, mean Children’s

Morningness-Eveningness Preference Scale score = 22). Future studies should carefully time assessments in order to more accurately capture adolescent's technology use at bedtime with a larger sample. Fourth, daily physical activity was only measured in one call each day and was measured as a binary variable. Thus, this variable may not capture all of the various metrics that can contribute to physical wellbeing. Fifth, a measure of pubertal development was not included, although age and sex are correlates of pubertal status. Future studies could include a measure of pubertal status. Sixth, multiple comparisons were used. Corrections for multiple comparisons further reduce power, increase the probability of a Type II error, and contribute to publication bias (Nakagawa & Cuthill, 2007). Hence, we included effect sizes as suggested by Nakagawa and Cuthill (2007). Standardized coefficients, as presented, are interpretable as effect sizes (Lorah, 2018). Seventh, data were collected in 2013-2016. As technology is rapidly advancing, these findings may not reflect all of today's available technology. Eighth, the measures used do not allow for reliability analyses. Ninth, we did not assess why adolescents chose to use technology at bedtime. For example, bedtime procrastination has been associated with an evening circadian preference and may contribute to increased technology use (Kadzikowska-Wrzosek, 2018). Future studies should assess contributors to bedtime technology use. Finally, while the selection of items to include in the health measures was adapted from a prior interview (Silk et al., 2011), this measure has not yet been validated.

Conclusion

Research and theory have identified that technology use may contribute to problems with adolescent sleep and health. However, much of this work has relied on parent reports of adolescent behavior or retrospective reports. To this end, the present study sought to use ecological momentary assessment to examine the impact of three types of technology use – television, electronic games, and social uses – on sleep and health in adolescents with an evening circadian preference. The current study provides evidence that technology use among adolescents with an evening circadian preference is associated with increased sleep onset latency (i.e., time to fall asleep) and negatively impacts behavioral health, yet also provides support for technology use positively impacting emotional, social, physical, and cognitive health domains. These findings expand prior research on technology use to a novel, high-risk group – adolescents with an evening circadian preference – and provide additional support for a possible negative association between technology use and sleep. Moreover, these findings add to a growing debate about the nuanced impact of technology use on health and future studies are needed to further understand the mixed findings around the function of technology use and how it impacts health across a wide range of domains. The present study offers evidence that the function of technology use needs to be assessed before selecting it as a treatment target for improving health, especially in the emotional, social, cognitive, or physical domains.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix.: Inclusion criteria operationalizing 'at risk' for the five health domains (from Harvey et al., 2018)

Risk Domain	Criteria for Inclusion
Emotional	≥ 4 on any of the following items on the CDRS: Difficulty Having Fun, Social Withdrawal, Irritability, Depressed Feelings, Excessive Weeping, *or* a T-score of 61 or above on the MASC-10, based on age group (10-11 years, 12-15 year, 16-19 years) using the MASC-10 Profile.
Behavioral	A SSS score greater than 3.93 for males aged 10-13, greater than 3.19 for females aged 10-13, greater than 4.07 for males aged 14-18, or greater than 3.19 for females aged 14-18 *or* taking ADHD medication or the KSADS indicating a diagnosis of ADHD *or* current alcohol or substance abuse assessed with the KSADS.
Social	A parent rating their child as "worse" than others the participants age on one or more of the social behavior items (Section VI) from the CBCL.
Cognitive	A parent rating their child as "failing" in one or more academic class from CBCL Section VII.
Physical	A score of 4 or above on the PHQ-15, six or more days of school absences, or a BMI above the 85th percentile for the participan's sex and age.

Note. CDRS = Child Depression Rating Scale (Poznanski et al., 1984), the cutoff is commensurate with "clinical symptoms." MASC-10 = Multidimensional Anxiety Scale for Children, the cutoff T-score was selected to capture the 'slightly elevated' through to the 'very elevated' range (March, Sullivan, & Parker, 1999). SSS = Sensation Seeking Scale (Russo et al., 1993), the cutoff correspond to at or above one standard deviation over the normative average (Stephenson, Hoyle, Palmgreen, & Slater, 2003). K-SADS = Schedule for Affective Disorders and Schizophrenia for School-Age Children (Kaufman et al., 1997). CBCL = Child Behavior Checklist (Becker, Ramsey, & Byars, 2015), which asks the parent if their child does "worse", "average", or "better" than other teens their age or if the teen is "failing", "below average", " average" or "above average". PHQ-15 = Physical Health Questionnaire-15, the cutoff corresponds to 'minimal somatic symptom severity' through to the 'high somatic symptom severity' range (Kroenke, Spitzer, & Williams, 2002). BMI = Body Mass Index, the cutoff corresponds to 1 standard deviation above the mean.

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Table 1

Participant Demographics

Characteristic	***N***	**%**
Female	102	57.95
Race		
Caucasian	114	64.77
African-American or Black	12	6.82
Asian	18	10.23
Native Hawaiian or Other Pacific Islander	2	1.14
Mixed Race	30	17.05
Ethnicity		
Hispanic or Latino	27	15.34
Not Hispanic or Latino	149	84.66
Family Annual Income ($)		
≤ 20,000	6	3.41
20,001-50,000	21	11.93
50,001-100,000	42	23.86
100,000	102	57.95
Refused to answer/missing	5	2.84
Current Grade		
5	5	2.84
6	7	3.98
7	14	7.95
8	25	14.20
9	28	15.91
10	46	26.14
11	25	14.20
12	25	14.20
College	1	0.57
	Mean	*SD*
Age (years)	14.77	1.84

Note. N = 176.

Table 2

Descriptive Statistics of Study Variables

Measure	Mean	SD	Range
Sleep Measures			
Total sleep time	448.29	10.13	343.00-690.50
Bedtime	22.21	0.14	17.41-24.18
Sleep onset latency	33.46	6.64	0-276
Health Measures			
Emotional			
Positive Affect	2.54	0.02	1.00-5.00
Happy	3.07	0.02	1.00-5.00
Cheerful	2.43	0.02	1.00-5.00
Interested	2.53	0.02	1.00-5.00
Excited	2.11	0.02	1.00-5.00
Negative Affect	1.42	0.01	1.00-5.00
Sad	1.34	0.01	1.00-5.00
Nervous	1.36	0.02	1.00-5.00
Upset	1.30	0.01	1.00-5.00
Angry	1.24	0.01	1.00-5.00
Bored	1.84	0.02	1.00-5.00
Social			
Alone	1.83	0.03	0.26-5.00
Family	2.17	0.05	0.24-5.00
Friend	2.51	0.06	0.67-5.00
Cognitive	2.31	0.01	0.67-5.00
Hard to Concentrate	1.67	0.02	1.00-5.00
Getting Distracted	1.77	0.02	1.00-5.00
Difficulty Focusing Attention	3.48	0.03	1.00-5.00
Physical	1.47	0.02	1.00-2.00
Behavioral	0.08	0.00	0.00-2.00

Note. SD = Standard Deviation.

Table 3

ns between Outcome Variables

	Correlations		
	1	2	3
o	-		
	−0.40**	-	
et	−0.30	−0.55***	-

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
re ct	-																			
y	0.82***	-																		
al	0.86***	0.71***	-																	
d	0.72***	0.43***	0.43***	-																
d	0.83***	0.57***	0.66***	0.48***	-															
re ct	−0.14***	−0.19***	−0.13	0.60***	−0.07***	-														
d	−0.08***	−0.13***	−0.10***	−0.02	−0.04	0.72***	-													
s	0.09***	0.02***	0.07***	0.09***	0.13***	0.60***	0.33***	-												
et	−0.08***	−0.16***	−0.12***	0.02	−0.03	0.74***	0.56***	0.39***	-											
y	−0.07**	−0.14***	−0.10***	0.02	−0.01	0.65***	0.49***	0.29***	0.63***	-										
d	−0.28***	−0.21***	0.13***	−0.27***	−0.23***	0.56***	0.24***	0.13***	0.17***	0.11***	-									
	0.82***	0.70***	0.70***	0.56***	0.67***	−0.54***	−0.38***	−0.25***	−0.36***	−0.32***	0.51***	-								
	0.85***	0.73***	0.71***	0.61***	0.70***	−0.57***	−0.33***	−0.23***	−0.35***	−0.33***	−0.51***	+	-							
	0.79***	0.68***	0.66***	0.46***	0.64***	−0.61***	−0.36***	−0.34***	−0.46***	−0.35***	−0.41***	+	+	-						

	Correlations																		
e	0.15***	0.13***	0.11***	0.15***	0.08***	0.21***	0.13***	0.18***	0.11***	0.10***	0.15***	−0.03	0.06	0.08	-				
	−0.06*	−0.07**	−0.06**	−0.04*	−0.04*	0.25***	0.18***	0.16***	0.13***	0.14***	0.21***	−0.18***	−0.17***	−0.11	0.72	-			
	−0.03	−0.02	−0.03	−0.00	−0.02	0.27***	0.17***	0.22***	0.14***	0.12***	0.23***	−0.19***	−0.19***	−0.14*	0.61***	0.47***	-		
y																			
	0.29***	0.27***	0.24***	0.26***	0.18***	−0.14***	−0.11***	−0.06**	−0.08***	−0.08***	−0.16***	0.28***	0.36***	0.33***	0.32***	−0.26***	−0.32***	-	
	−0.06*	−0.0[illegible]	−0.06	−0.04	−0.06	−0.03	0.00	−0.04	−0.02	−0.05	−0.02	−0.03	0.01	0.19	−0.02	−0.01	−0.01	−0.00	-
l	−0.06**	0.07***	0.03	0.07***	0.04*	0.02	−0.00	−0.03	−0.02	−0.00	−0.02	0.04	0.10*	−0.03	0.05**	0.02	0.05**	0.01	−0.01*	-

os do not overlap so cannot calculate correlations between them.

Table 4.

Coefficients from hierarchical linear models examining the association between technology use and sleep

Sleep Outcome	*Beta*	*SE*	*P*	95% CI
Total sleep time	0.14	0.36	0.69	−.56, 0.85
Bedtime	−0.20	0.37	0.42	−0.67, 0.28
Sleep onset latency	0.65	0.24	0.01**[a]	0.17, 1.23

Note. Calls are nested within participants. Analyses examine technology use predicting the subsequent night's sleep. We took the last call per day for each participant, for up to 7 calls per participant. Models included participants' age, sex, previous night's sleep (total sleep time, bedtime, sleep onset latency , respectively), Children's Morningness-Eveningness Preference Scale score, and if the night assessed was a weekday versus weekend as covariates. 68 calls total, 39 participants, range of 1-4 calls per participant, average of 1.7 calls per participant included. All sleep outcome variables are standardized with a mean of 0 and standard deviation of 1.

[*] $p < 0.01$.

[a] Value is 0.008, which rounds to 0.01.

Table 5.

Coefficients from hierarchical linear models examining the association between technology use and the health domains

Health Outcome	Television				Electronic Games				Social Uses			
	Beta	**SE**	**p**	**95% CI**	**Beta**	**SE**	**p**	**95% CI**	**Beta**	**SE**	**p**	**95% CI**
Emotional												
Positive Affect	0.10	0.04	0.01 *	0.02, 0.20	0.44	0.08	0.000 ***	0.29, 0.60	−0.09	0.05	0.07	−0.19, 0.01
Happy	0.14	0.05	0.003 **	0.05, 0.23	0.32	0.08	0.000 ***	0.16, 0.48	−0.10	0.05	0.06	−0.21, 0.00
Cheerful	0.08	0.04	0.07	−0.01, 0.17	0.25	0.08	0.002 **	0.10, 0.41	−0.15	0.05	0.005 **	−0.25, −0.05
Interested	0.19	0.05	0.000 ***	0.09, 0.29	0.63	0.09	0.000 ***	0.45, 0.81	0.10	0.06	0.10	−0.02, 0.21
Excited	−0.03	0.05	0.48	−0.13, 0.06	0.26	0.09	0.003 **	0.09, 0.43	−0.16	0.06	0.005 **	−0.27, −0.05
Negative Affect	−0.21	0.05	0.000 ***	−0.31, −0.12	−0.31	0.09	0.000 ***	−0.48,-0.14	0.08	0.06	0.18	−0.03, 0.19
Sad	−0.13	0.05	0.01 *	−0.23, −0.03	−0.20	0.09	0.03 *	−0.38, −0.02	0.02	0.06	0.53	−0.08, 0.15
Nervous	−0.10	0.05	0.05	−0.20, 0.00	−0.10	0.09	0.28	−0.28, 0.08	−0.13	0.06	0.02 *	−0.25, −0.02
Upset	−0.18	0.05	0.001 **	−0.28, −0.07	−0.14	0.10	0.14	−0.34, 0.05	0.12	0.06	0.06	−0.01, 0.24
Angry	−0.08	0.06	0.13	−0.19, 0.03	0.08	0.10	0.45	−0.12, 0.27	0.07	0.06	0.29	−0.06, 0.19
Bored	−0.18	0.05	0.001 **	−0.29, −0.08	−0.49	0.10	0.000 ***	−0.67, −0.29	0.05	0.06	0.45	−0.07, 0.17
Social												
Alone	0.31	0.06	0.000 ***	0.19, 0.43	0.57	0.12	0.000 ***	0.35, 0.78	0.01	0.06	0.85	−0.11, 0.14
Family	0.13	0.10	0.18	−0.06, 0.32	0.51	0.22	0.02 *	0.07, 0.94	0.13	0.18	0.46	−0.22, 0.49
Friend	0.00	0.19	0.99	−0.36, 0.37	0.52	0.26	0.04 *	0.02, 1.02	−0.45	0.26	0.09	−0.96, 0.06
Cognitive	−0.14	0.05	0.007 **	−0.24, −0.04	−0.17	0.06	0.09	−0.36, 0.01	−0.20	0.06	0.001 **	−0.32, −0.08
Hard to Concentrate	−0.22	0.06	0.000 ***	−0.33, −0.11	−0.32	0.10	0.002 **	−0.52, −0.12	−0.23	0.07	0.001 **	−0.35, −0.10
Getting Distracted	−0.11	0.05	0.04 *	−0.22, −0.01	−0.25	0.10	0.01 *	−0.44, −0.06	−0.14	0.06	0.03 *	−0.26, −0.01
Difficulty Focusing Attention	0.09	0.05	0.08	−0.01, 0.18	0.26	0.09	0.003 **	0.09, 0.44	0.02	0.06	0.71	−0.09, 0.13
Physical	0.09	0.08	0.28	−0.07, 0.25	0.30	0.15	0.04 *	0.01, 0.59	0.14	0.09	0.15	−0.05, 0.32
Behavioral	0.26	0.07	0.000 ***	0.13, 0.39	−0.02	0.12	0.90	−0.26, 0.22	0.01	0.08	0.88	−0.14, 0.16

Note. Social uses comprises social media, internet surfing, and texting. Models include age and sex as covariates. All health outcome variables are standardized with a mean of 0 and standard deviation of 1.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.