Published in final edited form as:

Sleep Health. 2017 August ; 3(4): 276–283. doi:10.1016/j.sleh.2017.04.005.

Adolescents' Technology and Face-to-Face Time Use Predict Objective Sleep Outcomes

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Abstract

Objectives—The present study examined both within- and between-person associations between adolescents' time use (technology-based activities and face-to-face interactions with friends and family) and sleep behaviors. We also assessed whether age moderated associations between adolescents' time use with friends and family and sleep.

Design—Adolescents wore an actigraph monitor and completed brief evening surveys daily for 3 consecutive days.

Participants—Adolescents (*N* = 71; *Mean age* = 14.50 years old, SD = 1.84; 43.7% female) were recruited from 3 public high schools in the Midwest.

Measures—We assessed 8 technology-based activities (e.g., texting, working on computer), as well as time spent engaged in face-to-face interactions with friends and family via questions on adolescents' evening surveys. Actigraph monitors assessed three sleep behaviors: sleep latency, sleep hours, and sleep efficiency.

Results—Hierarchical linear models indicated that texting and working on the computer were associated with shorter sleep, whereas time spent talking on the phone predicted longer sleep. Time spent with friends predicted shorter sleep latencies, while family time predicted longer sleep latencies. Age moderated the association between time spent with friends and sleep efficiency, as well as between family time and sleep efficiency. Specifically, longer time spent interacting with friends was associated with higher sleep efficiency but only among younger adolescents. Furthermore, longer family time was associated with higher sleep efficiency but only for older adolescents.

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Conclusion—Findings are discussed in terms of the importance of regulating adolescents' technology use and improving opportunities for face-to-face interactions with friends, particularly for younger adolescents.

Keywords

technology; peer relationships; family relationships; actigraphy; adolescent sleep

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Advancements in technology have led to an increase in the availability of mobile devices, such as smartphones, which provide constant opportunities to connect with others via mobile screens (1). In the U.S, over 90% of 13–17 year olds report daily online activity and 24% report being constantly connected to some form of technology (2). Adolescents' technology use may facilitate the accomplishment of developmental tasks by providing opportunities for identity development and social interactions (3). However, despite these benefits, there is concern over the implications of widespread technology use on adolescent functioning. Specifically, researchers have proposed three specific domains of adolescent development that may be implicated in adolescents' technology use: identity, intimacy and sexual development (4). Another domain of adolescent development that researchers believe may be associated with technology use is sleep (5). There is increased concern regarding the potential negative impact of technology use on adolescent sleep-wake patterns (5–7), particularly because of the important developmental changes in sleep that take place during the transition from childhood to adolescence (8). The present study adds to the available literature by examining whether adolescents' time spent using technology, as compared to face-to-face interactions with friends and family, are associated with three objectively-measured sleep behaviors. Uniquely, in addition to examining individual differences in adolescents' time use and sleep (i.e., between-person asociations), we examined whether day-to-day changes in technology use and face-to-face interactions were associated with corresponding day-to-day changes in sleep across 3 days (i.e., within-person associations).

Adolescence is a sensitive age period for changes in sleep-wake patterns. Adolescents experience a biological shift in circadian timing, which leads to an increased eveningness preference (9, 10). Furthermore, psychosocial factors, such as early class start times, rigorous academic and extracurricular commitments, as well as increased opportunities to engage in late-night activities with friends, contribute to changes in adolescents' sleep behaviors (11). Although the National Sleep Foundation recommends that 14–17 year olds get between 8 and 10 hours of sleep each night (12), the reality is that many adolescents consistently get below the recommended amount of sleep and subsequently experience significant sleep debt (5, 13). For example, Winsler and colleagues (14) found that adolescents, on average, reported getting 1.5 hours less than the minimal recommended amount of sleep. Similarly, Polos and colleagues (5) found that over 70% of their sample of sixth to twelfth graders reported getting less than 8 hours of sleep on a typical school night. Importantly, adequate sleep plays a critical role across multiple domains of adolescent functioning (15–19). Therefore, understanding the factors that predict adolescent sleep is an important undertaking.

One proposed contributing factor to the problem of adolescent sleep debt is technology use (6, 7). Among a U.S. sample of adolescents, longer bedtime technology use was associated with shorter sleep duration during the week and poorer sleep quality (1). Similar findings were reported with a Canadian sample of 10–11-year-olds, such that the presence of multiple media devices (e.g., TV, computer) in the bedroom, as well as the frequency of bedtime technology use, were associated with shorter sleep duration (20). Notably, the link between technology use and poor sleep has been supported in diverse samples of adolescents from China (21), Belgium (22), and Japan (23).

A few studies, however, have failed to find significant associations between technology use and poor sleep. For example, among a nationally representative sample of adolescents in China, neither the presence of a computer in the home nor the number of different online activities predicted sleep quality (24). The authors did, however, find that adolescents' use of the internet for "fun" or "catharsis" was linked to poorer sleep, whereas the use of internet for scholastic purposes was linked to better sleep quality (24). In another study of university students in Brazil, Mesquita and Reimão (25) reported that television viewing in the evening was not associated with perceived sleep quality but evening computer use was associated with an increased likelihood of reporting poor sleep quality. These findings highlight the need to assess multiple forms of technology use, particularly given the myriad of online activities currently available. Thus, in the present study, we specifically assessed a range of technology-based activities to determine the relative associations of various forms of technology use and sleep behaviors. Overall, although some exceptions exist, the evidence to date offers strong support for a link between technology use and poor sleep (6). In fact, a recent review indicated that 90% of the 67 studies reviewed (published between 1999 and 2014) found evidence for a significant association between technology use and some index of poor sleep (7).

The majority of past studies have assessed between-person associations, which allow us to determine how variability in technology use *between* individuals relate to average differences in sleep behaviors. An important gap in the literature, however, is determining how day-to-day changes in an individual's technology use are associated with that same individual's sleep from one night to the next (i.e., *within-person* associations). Furthermore, in contrast to a between-person design, a within-person design makes it possible to draw inferences about reverse-causal associations due to the temporal precedence of daily technology-use behaviors (assessed during the day) in relation to subsequent sleep (assessed that night). In one recent study, Cespedes and colleagues (26) investigated within-person associations between television use and sleep duration and found that more time spent watching television was associated with shorter sleep duration. Of note, the repeated assessments were based on annual parental reports of children's sleep and technology use (children were first assessed when they were 6 months up until 7 years old). Additionally, in a daily diary study of adults, using smartphones for work close to bedtime – more than was typical for that individual – was associated with less sleep that night, which, in turn, was associated with increased feelings of depletion the following morning (27). Therefore, it remains unclear whether day-to-day variations in time spent engaged in various technology-based activities are associated with corresponding *day-to-day* changes in objective sleep outcomes among adolescents.

A second limitation of past research has been an overreliance on subjectively-measured sleep behaviors. Furthermore, given the multi-dimensional nature of sleep, it is important to include assessments of multiple sleep behaviors (28). The current study, therefore, employs objective assessments of three sleep behaviors: sleep latency, sleep hours, and sleep efficiency. A third limitation of past studies is the lack of assessment of time spent engaged in face-to-face interactions in addition to time spent engaged in technology-based activities. Given the link between technology-based and face-to-face interpersonal communication, as well as the significant amount of time adolescents spend engaged in face-to-face interactions (29), it is worthwhile to determine the relative associations of both technology-based and face-to-face interactions in relation to adolescent sleep. Notably, past research has indicated that a critical function of technology-based activities such as texting and instant messaging is the maintenance of "offline" or in-person relationships with friends (30). An important developmental task of adolescence is the establishment and maintenance of close social ties and the development of intimacy through friendships and romantic relationships (31). Consequently a major concern within developmental psychology has been the potential for increased time spent engaged with technology to interfere with time spent in face-to-face interactions with friends and thus detract from key developmental tasks of adolescence (32). For these reasons, it is crucial to assess the relative contribution of adolescents' technology-based activities and face-to-face interactions.

Moreover, although past research has examined whether age moderates the association between technology use and sleep (5), no studies to date have examined whether age moderates the link between face-to-face interactions and objectively-measured sleep behaviors. This is an important question, given that adolescents increasingly spend more time with their peers as they age, as well as the fact that sleep behaviors undergo marked changes from childhood to adolescence (10, 33). The present study addresses this limitation by examining whether age moderates the association between time spent with both friends and family and three sleep behaviors.

The purpose of the present 3-day study was to examine both within- and between-person associations between adolescents' time use (technology-based activities and face-to-face interactions) and sleep behaviors. Specifically, we assessed time spent engaged in eight different technology-based activities (e.g., texting, working on the computer, video games and social media), as well as time spent engaged in face-to-face interactions with friends and family. Additionally, we examined age as a potential moderator of the associations between time spent engaged in face-to-face interactions and sleep, given developmental changes in time spent with family and friends. Three actigraphy-based sleep behaviors were measured: sleep latency, sleep hours, and sleep efficiency. We employed hierarchical linear modeling (HLM) to examine: 1) *within-person associations* to determine whether day-to-day changes in technology-based and face-to-face time use were associated with corresponding day-to-day changes in three sleep behaviors; and 2) *between–person associations* to determine whether individual differences in technology-based and face-to-face time use were associated with adolescents' typical sleep behaviors. We hypothesized that more time spent engaged with technology would generally be associated with poor sleep ; whereas time spent engaged in face-to-face interactions would generally be associated with good sleep.

Method

Participants and Procedures

Participants were high school students recruited from 3 different high schools in a large city in the Midwest, who were part of a larger study (*N* = 379) on stress and psychological adjustment. A subsample of participants (*n* = 138, 36% of the total sample) was randomly selected and invited to participate in the sleep component of the study. Of those who were invited, *n* = 116 agreed to participate. Due to a limited number of sleep monitoring devices, only 94 adolescents were given sleep monitors. One adolescent did not return the monitor and 11 devices contained no usable data, leaving 82 adolescents with at least one full night of data. Of those, 77 participants had completed some information on their evening surveys (which contained questions on adolescents' time use). The final sample comprised of *n* = 71 participants (43.7% female), who had complete actigraphy data for at least 2 out of the 3 nights, as well as data on the time use variables. Results of independent *t*-tests indicated that participants who were excluded, either because of refusal to participate or inadequate sleep data (*n* = 61) did not differ from participants in the final sample (*n* = 71) on key demographics, including, age, mother employment status, parent education and income (all *p*'s > .05). However, participants in the final sample had a higher prevalence of paternal employment (92%) relative to participants who were excluded (72%).

Of the 116 participants who consented to participate in the sleep component of the study, no significant differences were found between those who were excluded because of inadequate data (*n* = 45) and those who were part of the final sample (*n* = 71) on any of the time use predictors (all *p*'s >.05). Furthermore, comparisons between participants in the final sample and participants in the larger parent study indicated no significant differences on key parental characteristics, including parental education, age and income.

Participants in the final sample ranged from 11 to 18 years old (*M* = 14.50 years, *SD* = 1.84) and were racially/ethnically diverse: Non-Hispanic white (14, 19.7%), Black or African-American (14, 19.7%), Hispanic or Latino (16, 22.5%), Mixed (14, 19.7%) and Other (13, 18.3%). Participants wore an actigraph sleep monitor for 4 nights (Saturday-Tuesday) but we analyzed data from 3 nights (Sunday to Tuesday) in order to account for adjustment to the study's protocol of wearing a novel sleep monitoring device (i.e., the Hawthorne effect). On those 3 nights, participants also completed brief paper-pencil evening surveys before bedtime. Questions assessed participants' technology-based and face-to-face time use. Data collection took place in the fall of 2012 (September 29 to November 3). The study was approved by the Northwestern and DePaul University's Institutional Review Boards. Parents provided consent and participants provided assent prior to participation.

Measures

Demographics—Age, sex, race-ethnicity, parental income and caffeine use were assessed by a self-report questionnaire prior to sleep monitoring.

Sleep—Participants wore an Actiwatch Score (Phillips Respironics, Inc.) on their non-dominant wrist for 3 nights (Sunday to Tuesday), following one night of acclimatization

(i.e., Saturday) to the device, as has been recommended by other authors (34). The Actiwatch is a wrist-band accelerometer that records motor activity. The Actiware-Sleep software (version 3.4, MiniMitter/Philips Respironics) and its associated validated algorithm were used to score the data (35). This algorithm calculates a number of sleep parameters using 1-minute epochs based on significant movement after at least 10 minutes of inactivity. The following three sleep parameters were calculated: i) *sleep latency:* the number of minutes between the start of the period of rest and the first epoch of sleep, as determined by the sleep onset algorithm (in conjunction with participants' brief morning surveys, which assessed sleep duration and quality from the previous night); ii) *sleep hours:* actual amount of time spent asleep, minus time spent awake throughout the night; and iii) *sleep efficiency:* % of time spent sleeping (actual sleep time divided by total time in bed, multiplied by 100).

Technology and Face-to-Face Time Use—Evening surveys assessed daily amount of time spent engaged in 8 technology-based activities and face-to-face interactions with friends and family. This approach is similar to several other studies that have assessed technology use with this age group (1, 16), but specific items were carefully adapted to fit the technology landscape in 2012. *Texting* was a composite of two items: "*Thinking about your day today, how many times did you: a) send a text message and b) receive a text message?*" Response options were: 1 = none, 2 = 1–20; 3 = 20–40; 4 = 40–60; 5 = 60–80; 6 = 80–100; and 7 = 100+. Participants were asked to indicate the amount of time spent doing each of the following each day for 3 days: "*instant messaging (e.g., Facebook chat, AIM)"; "using Facebook/other social media"; "using Twitter"; "talking on the phone"; "watching TV, video, or DVD"; "playing video games (e.g., Xbox or computer)"; and "working on a computer (desktop or laptop)*". For face-to-face time use, adolescents indicated the amount of time spent: "*interacting with friends in person*" and "*interacting with family in person*." Response options were 1 = 0 minutes; 2 = 1–15 minutes; 3 = 16–29 minutes; 4 = 30–59 minutes; 5 = 1–2 hours; 6 = 2–4 hours; and 7 = 4+ hours. Participants also rated their interactions as positive and negative: i) "*Thinking about the in-person interactions you mentioned above, how many would you say were: a) negative and b) positive?*" and ii) *Thinking about the phone, internet, texting, social media, and videogame interactions you mentioned above, how many would you say were: a. positive and b) negative?*" Responses were: 1 = none, 2 = some, 3 = most, and 4 = all. A positive-negative ratio was calculated for each of the two items by dividing positive scores by negative scores; thus higher scores indicate a higher relative balance of perceived positive to negative time use.

Plan of Analysis

Missing Data—We analyzed data from participants with complete sleep data; thus, there was no missing data for the three sleep outcomes. There was some missing data on the time use predictors. At the day-level, average missing data across the key time use predictors was 6.2% (range: 3.6% to 13.8%). We used the expectation maximization (EM) algorithm to impute missing values in S.P.S.S (Statistical Package for the Social Sciences, Version 24). The EM approach has been shown to be a valid method of missing values imputation over the list-wise deletion or mean substitution methods (36).

Primary Analyses—We analyzed a 2-level hierarchical linear model (HLM) using HLM software (version 6.0) in order to assess both within-person (level 1) and between-person (level 2) associations between technology and face-to-face time use and each of the three sleep outcomes. Because scores in this study varied from day to day and also between individuals, HLM partitions the variance into Level 1 (the "day level," repeated daily scores on the time use predictors and sleep outcomes) and Level 2 (the "person level," or the average of participants' scores on the time use predictors and sleep outcomes, across 3 days). Day-level predictors were group-mean centered at level 1 (i.e., daily deviations from an individual's average) and person-level predictors were grand-mean centered at level 2 (i.e., individual deviations from the sample average). Two interaction terms were computed using the product of standardized scores and entered at Level 2: 1) time spent with friends by age and 2) time spent with family by age. Significant two-way interactions were investigated using simple slopes techniques for hierarchical linear modeling (37). Simple slopes were estimated for associations between time use and sleep at 1 *SD* above and below the mean age (38). All models controlled for age, gender, race, ethnicity, parental income, caffeine use, and positive-negative ratios (equations for Level 1 and Level 2 models are provided in an online supplement).

Results

Descriptive statistics and bivariate correlations for key study variables are presented in Table 1 and Table 2, respectively. On average, adolescents took approximately 23 minutes to fall asleep; slept for 6 hours and 30 minutes and had sleep efficiency scores of 81%. Adolescents reported spending the most time with friends (Median = 4.00, "30–59 minutes") and family (Median = 5.00, "1–2 hours") during the day. Adolescents reported a median of 1–20 text messages per day and reported spending similar amount of time watching TV and working on their computers (Median = 3, "16–29 minutes"). Less time was reportedly spent talking on the phone and using Facebook (Median = 2, "1–15 minutes"). Clustered bar graphs depicting the number of adolescents and their self-reported time use across all technology-based and face-to-face activities are presented in an online supplement.

Sleep Latency

Coefficients for both within– and between– person associations for all time use predictors and sleep outcomes are presented in Table 3. At the day-level, participants had shorter sleep latencies following days when they spent more time than usual interacting with their friends in person ($B = -0.077$, $p = .025$), but had longer sleep latencies following days when they interacted with family more than usual ($B = 0.094$, $p = .035$).

At the person level, individuals who generally spent more time interacting face-to-face with friends fell asleep more quickly ($B = -0.134$, $p = .031$). Neither the family by age nor the friend by age interaction was significant.

Sleep Hours

At the day level, adolescents slept less following days when they reported spending more time than usual texting ($B = -0.236$, $p = .011$) and working on their computers ($B = -0.269$,

p = .009). In contrast, they had longer sleep hours following days when they spent more time than usual talking on the phone (B = 0.325, p = .024).

At the person level, individuals who generally spent more time working on the computer had shorter sleep hours (B = −0.323, p = .006). Neither the family by age nor the friend by age interaction was significant.

Sleep Efficiency

At the day level, longer time than usual spent using the computer was associated with lower sleep efficiency (B = −1.319, p = .010).

At the person-level, there was a significant friend by age interaction, B = −2.753, SE = 1.141, p = .019. Follow-up analyses indicated that among younger adolescents (1 SD below the mean age, at 12.66 years old), there was a significant positive association between time spent interacting with friends and sleep efficiency, B = 4.518, SE = 1.208, p < .001, whereas the association between time spent with friends and sleep efficiency was not significant among older adolescents (1 SD above mean age, at 16.34 years old), B = −0.988, SE = 1.657, p = .551. Figure 1A depicts sleep efficiency scores in relation to low (1 SD below the mean), average (M = 4.28, SD = 1.53) and high (1 SD above the mean) time spent with friends for both younger and older adolescents, while holding all other variables in the model at their sample means.

Furthermore, the family by age interaction also was significant, B = 1.837, SE = 0.707, p = .012. Figure 1B shows scores on sleep efficiency for low (1 SD below the mean), average (M = 4.83, SD = 1.42), and high (1 SD above the mean) family time for both younger (1 SD below mean age, at 12.66 years old) and older (1 SD above mean age, at 16.34 years old) adolescents. As depicted in Figure 1B, more time spent with family was associated with higher sleep efficiency (i.e., better sleep) among older adolescents, B = 2.373, SE = 1.150, p = .039, whereas the association between time spent with family and sleep efficiency was not significant among younger adolescents, B = −1.301, SE = 1.314, p = .322.

Discussion

The purpose of the present study was to examine associations between adolescents' technology-based and face-to-face time use and three sleep outcomes: sleep latency, sleep hours and sleep efficiency. We also examined age as a moderator of the association between time spent with friends and family and each sleep outcome. Interestingly, adolescents had shorter sleep latencies (i.e., fell asleep more easily) on days when they spent more time than usual interacting with friends but had longer sleep latencies on days when they reported spending more time than usual with family. Furthermore, adolescents slept less on days when they spent more time than usual texting and working on the computer but slept longer on days when they had spent more time than usual talking on the phone. More time spent working on the computer than usual also was associated with lower sleep efficiency. At the person-level, adolescents who typically spend more time in-person with friends had shorter sleep latencies and those who typically spend more time working on the computer had shorter sleep hours. The associations between time spent with both friends and family and

sleep efficiency were moderated by age. Generally, time spent interacting with family was associated with better sleep for older adolescents; whereas time spent interacting with friends was associated with better sleep for younger adolescents.

Results of the present study highlight the key role of face-to-face interactions with friends for facilitating sleep onset among adolescents. Face-to-face interactions with friends may provide opportunities to experience positive affect (39), which subsequently promote good sleep. Time spent in-person with friends also had positive associations with sleep efficiency – particularly for younger adolescents. Specifically, among younger adolescents (i.e., 12–13 year olds), spending approximately 2–4 hours interacting with friends was associated with 6% higher sleep efficiency compared to spending approximately 16–29 minutes interacting with friends. Past research has shown that higher feelings of loneliness are linked with increased sleep disturbance among early (12–14 years) but not among late (18–21 years) adolescents (40). The transition from childhood to adolescence is associated with increased value in peer relationships. Younger adolescents' sleep outcomes, therefore, may be more susceptible to the negative implications of their peer relationships, compared to older adolescents.

Moreover, at the day-level, more time spent working on the computer was associated with both shorter and less efficient sleep. Increased time spent working on the computer may be due to higher academic demands (e.g., exam or paper due the next day), which have been linked to shorter sleep (16). Results at the day-level also indicated that adolescents slept less following days characterized by more time texting but slept longer following days characterized by more time talking on the phone. Although adolescents report both texting and calling friends after bedtime, the prevalence of texting at bedtime is slightly higher than that of calling (22). Therefore, the negative association between texting and short sleep may be due to a direct displacement effect. Additionally, given the nature of text-messages, adolescents are more likely to be awoken by text notifications relative to phone calls. In one recent study, over 20% of U.S. adolescents reported that their sleep was disrupted because of incoming text messages (5). A third variable affecting both increased propensity to text and sleep problems (e.g., a stressful event) also may be at play. In contrast to text conversations, talking to a friend on the phone may provide more immediate, contingent feedback and added emotional nuance, which may positively influence adolescents' emotional state and promote longer sleep. Furthermore, texting requires more exposure to light-emitting screens than talking on the phone - a factor which has been shown to reduce melatonin and perceived sleepiness (41), resulting in shorter sleep.

In terms of family time and sleep, our findings indicate that adolescents had longer sleep latencies (i.e., took longer to fall asleep) on days when they reported spending more time with family than was typical. This finding, which was somewhat unexpected, may be explained by the specific types of activities that adolescents do with their families. For example, increased family time may be due to increased family conflict, as adolescents and their family members work through disagreements (42). It is also possible that increased family time – regardless of valence – may be highly arousing and thus interfere with adolescents' sleep onset (43). Furthermore, results showed that age moderated the association between family time and sleep efficiency at the person-level: spending 2–4 hours

with family was associated with 4% higher sleep efficiency relative to spending approximately 16–29 minutes with family among 16–17 year olds. Past research has indicated that positive family characteristics are associated with better sleep among adolescents (11). The association between family time and sleep efficiency was particular significant for older adolescents. Older adolescents may face increased academic and social challenges that require familial support in navigating these challenges. Thus, increased family time may serve as one possible source of social support for older adolescents, which, in turn, may improve sleep quality.

Findings of the present study must be interpreted within the context of the study's limitations. First, although sleep behaviors were assessed using actigraphy, the assessment of time spent engaged in technology-based activities and face-to-face interactions with friends and family were based on self-reports, which may be biased. This is an important limitation particularly in light of recent findings that have indicated low agreement between individuals' self-report and phone-bill assessments of texting frequency (44). Future studies, therefore, should incorporate objective measures of adolescents' technology use (e.g., use of special monitoring applications on adolescents' smartphones).

Second, we assessed time use but did not measure the specific time of day of the activities. Additionally, we lack insight into the content of adolescents' technology-based activities, including the degree of violence or competition in video games, different genres of TV shows/movies, and passive browsing versus highly interactive video-based activity on Facebook and other social media. It will be important for future studies to determine the extent to which such contextual variables related to adolescents' time use moderate associations between timing of technology-based activities and sleep outcomes. Additional possible moderators may include the scholastic purpose of technology use (homework versus recreational), presence of others (solitary versus co-use), weekday versus weekend, and location of technology use (bedroom versus living room).

Third, because our research questions specifically focussed on the *unique* contributions of time spent across various forms of technology and time spent in face-to-face interactions with friends and family, we did not measure the extent to which multi-tasking – a common phenomenon among adolescents – was associated with our sleep outcomes (45). In other words, although we have presented the assessment of adolescents' technology time use as distinct from adolescents' face-to-face interactions with friends and family, the two categories are not mutually exclusive (for example, adolescents could be watching TV while interacting with their family). Future studies, therefore, should examine how multi-tasking across both domains of technology and face-to-face time use predicts objective sleep outcomes among adolescents.

Fourth, although we allowed participants one night to acclimatize to the sleep monitoring device following recommendations of previous studies (34), we only assessed the time use and sleep variables across 3 days/nights. Future studies should incorporate a longer assessment period in order to allow participants even more time to acclimatize to the use a sleep-monitoring device and more effectively account for the Hawthorne effect. A longer

assessment period also would allow for a test of week versus weekend effects of time use on sleep outcomes.

Fifth, despite the strength of a day-to-day design, data were correlational and do not address causal effects regarding the association between adolescents' technology and face-to-face time use and their sleep behaviors (46). Future longitudinal studies should examine these associations within the context of experimental designs and specifically assess possible bidirectional effects between these time use variables and sleep behaviors (46).

Sixth, although we analyzed the time use predictors as continuous, these variables were based on ordinal categories of time. Although this does not violate any assumptions about the nature of the predictors in a regression model from a statistical perspective, this approach presents some challenges in making practical recommendations about adolescents' time use in relation to sleep. Future studies, therefore, should require participants to state the specific timing of their various technology-based and face-to-face time use activities (e.g., 10:00PM – 11:00PM: watched TV) in order to yield a true continuous measure of these time use variables, based on a daily diary approach. This approach will facilitate the interpretation of the data and allow researchers to make specific recommendations regarding the actual quantity of technology use associated with poor sleep outcomes. Furthermore, it is necessary for future studies to incorporate more sophisticated, non-linear analytic models of technology use as some research suggests a non-linear association between technology use and psychological wellbeing among adolescents (47).

Despite these limitations, the present study makes an important contribution to available research. We examined eight different technology-based items in order to capture a diverse range of technology-based activities. We also assessed two important face-to-face activities (face-to-face time with friends and family), which have been overlooked in past research. Notably, we assessed both within-person and between-person associations and included three objectively-measured sleep outcomes. Our results lend some support to the negative association between technology-based activities and poor sleep among adolescents (with the exception of talking on the phone, which was linked with longer sleep hours). Importantly, our findings also highlight the role of time spent in-person with friends for promoting good sleep among adolescents (especially for younger adolescents). Furthermore, the finding that increased family time was associated with better sleep particularly for older adolescents should reassure parents and other family members of the value of family time in the lives of adolescents. Teachers, parents and adolescents alike should heed the need to regulate technology use. For example, parents could designate certain places (e.g., bedrooms) and times (e.g., meal times) as "technology-free zones" in order to provide increased regulation of adolescents' technology use. Parents also may consider modeling these behaviors by regulating their own technology use. Additionally, adolescents themselves could encourage their peers to limit bedtime technology use. As technology use continues to be highly interwoven with everyday activities, it is important to support efforts that help provide a balanced approach to technology use, particularly in light of growing evidence for the negative impact of increased technology use on adolescent sleep – a critical factor for overall health and wellbeing.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The present study was funded by a grant from the National Institute of Health (Grant number: R21 AA021073) awarded to the fourth and last authors.

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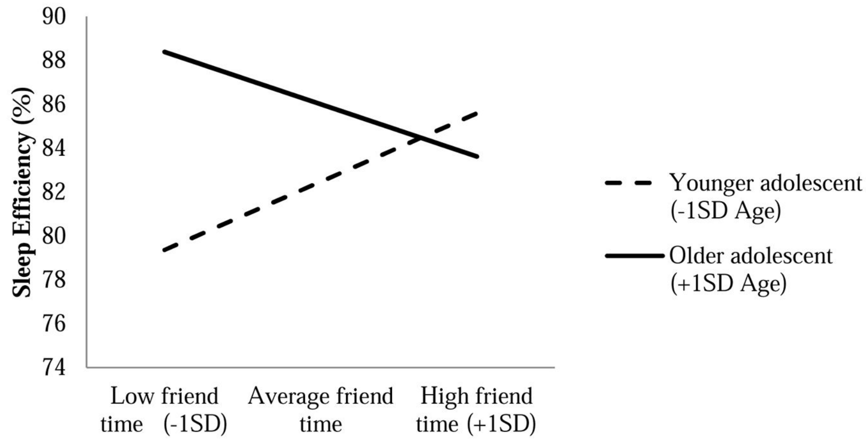

Figure 1A

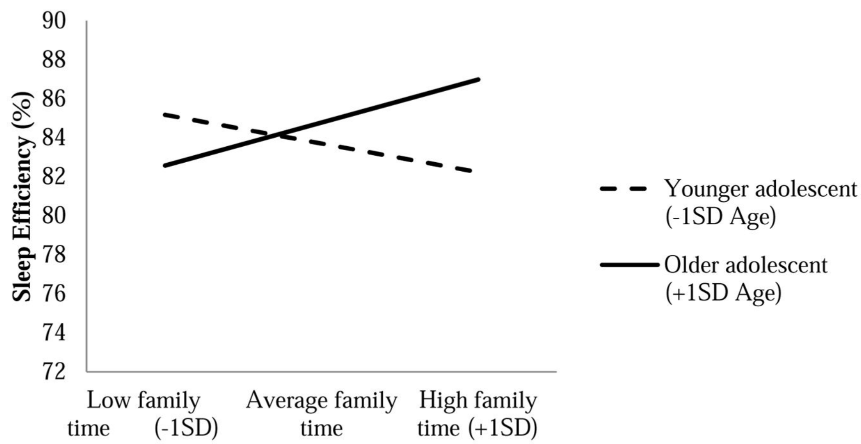

Figure 1B

Figure 1.

Figure 1A. Relationship between friend time and sleep efficiency for younger and older adolescents

Figure 1B. Relationship between family time and sleep efficiency for younger and older adolescents

Table 1

Descriptive Statistics for Key Study Variables

Variables	Median (Interquartile Range)	Scale Range
Income	3.00 (2.93)	1.00–6.00
Text - sent[a]	2.00 (2.00)	1.00–7.00
Text - received[a]	2.00 (2.00)	1.00–7.00
Instant messaging[b]	1.00 (1.25)	1.00–7.00
Facebook[b]	2.00 (3.00)	1.00–7.00
Twitter[b]	1.00 (0.00)	1.00–7.00
Talking on the phone[b]	2.00 (1.00)	1.00–7.00
Watching TV[b]	3.00 (2.00)	1.00–7.00
Video Games[b]	1.00 (2.00)	1.00–7.00
Computer (working)[b]	3.00 (2.25)	1.00–7.00
Friends[b]	4.00 (2.00)	1.00–7.00
Family[b]	5.00 (2.00)	1.00–7.00
Sleep latency (minutes)[c]	22.47 (20.10)	0.00–88.20
Sleep hours[c]	6.50 (0.83)	5.00–9.13
Sleep efficiency (%)[c]	81.39 (5.86)	67.18–91.75

Note.

[a]Scale range: *1 = None; 2 = 1–20; 3 = 20–40; 4 = 40–60; 5 = 60–80; 6 = 80–100; 7 = 100*$^{+}$.

[b]Scale range: *1 = 0 mins; 2 = 1–15 mins; 3 = 16–29 mins; 4 = 30–59 mins; 5 = 1–2 hours; 6 = 2–4 hours; 7 = 4+ hours.*

[c]Values for sleep variables are mean scores with standard deviations in parenthesis.

Table 2

Bivariate Correlations among Key Time Use Predictors and Sleep Outcomes

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Text													
2.IM	.34**												
3. Facebook	0.05	.470**											
4. Twitter	.25*	0.17	−0.02										
5. Talk (phone)	0.09	−0.01	0.18	.32**									
6. TV	0.15	.33**	0.16	0.11	0.00								
7. Video games	− 0.10	−0.11	−.25*	− 0.01	− 0.10	0.16							
8. Computer	0.12	0.00	.351**	0.03	.32**	− 0.09	0.04						
9. Friends	0.06	0.18	0.16	− 0.07	0.09	− 0.13	−.28*	−0.03					
10. Family	0.03	0.10	0.19	−.30*	0.12	0.01	− 0.21	0.07	.56**				
11. Sleep Hours	−0.06	−0.14	−.33**	0.04	0.06	−0.13	0.08	−.33**	−0.04	−0.02			
12. Sleep Latency	0.02	−0.07	−0.10	0.08	−0.01	0.18	0.23	0.09	−.35**	−.24*	−0.11		
13 Sleep Efficiency	0.02	−0.08	−0.07	− 0.01	0.01	−.27*	− 0.14	−0.10	.28*	0.22	.28*	−.83**	

Note: N = 71. IM = instant messaging; TV = time spent watching television.

* $p < .05$;

** $p < .01$

Table 3

Results of 2-Level Hierarchical Linear Models of Within- and Between- Person Predictors of Technology and Face-to-Face Time Use Predicting Three Objectively-Measured Sleep Outcomes

	Sleep Latency	Sleep Hours	Sleep Efficiency
Fixed Effect	**Coefficient (SE)**	**Coefficient (SE)**	**Coefficient (SE)**
Person-Level			
Intercept1, Π_0			
Intercept2, β_{00}	18.00 (0.067) ***	6.412 (0.202)***	84.236 (1.541)***
Texting, β_{06}	0.029 (0.043)	−0.035 (0.102)	0.529 (0.749)
Instant messaging, β_{07}	−0.026 (0.063)	−0.018 (0.163)	−0.984 (1.115)
Facebook, β_{08}	0.024 (0.085)	−0.034 (0.135)	−0.168 (1.231)
Twitter, β_{09}	0.015 (0.047)	0.061 (0.117)	0.320 (.905)
Talking on phone, β_{10}	0.008 (0.044)	0.176 (0.100)	−0.303 (1.048)
Watching TV, β_{11}	0.038 (0.043)	−0.150 (0.116)	−1.03 (0.659)
Video games, β_{12}	0.073 (0.042)	−0.017 (0.110)	−0.695 (0.801)
Computer (working), β_{13}	0.050 (0.056)	−0.323 (0.113)**	−0.641 (0.879)
Friends, β_{14}	−0.134 (0.061)*	−0.106 (0.147)	1.765 (0.895)
Family, β_{15}	0.008 (0.066)	0.146 (0.163)	0.536 (1.012)
Positive-negative (electronic), β_{16}	−0.006 (0.035)	−0.109 (0.083)	−0.358 (0.648)
Positive-negative (in-person), β_{17}	−0.032 (0.044)	0.151 (0.134)	0.792 (0.940)
Friend X Age, β_{18}	0.100 (0.065)	0.183 (0.170)	−2.753 (1.141)*
Family X Age, β_{19}	−0.094 (0.051)	−0.187 (0.178)	1.837 (0.707)*
Day-level			
Texting, Π_2			
Intercept, β_{20}	−0.027 (0.034)	−0.236 (0.091)*	0.823 (0.528)
Instant messaging, Π_3			
Intercept, β_{30}	0.045 (0.038)	−0.117 (0.099)	−0.426 (0.541)
Facebook, Π_4			
Intercept, β_{40}	−0.000 (0.030)	−0.030 (0.094)	−0.307 (0.501)
Twitter, Π_5			
Intercept, β_{50}	0.035 (0.058)	0.200 (0.151)	−0.303 (0..799)
Talking on phone, Π_6			
Intercept, β_{60}	−0.008 (0.036)	0.325 (0.142)*	0.363 (0.553)
Video games, Π_7			
Intercept, β_{70}	−0.046 (0.057)	−0.096 (0.126)	0.419 (0.714)
Computer (working), Π_8			
Intercept, β_{80}	0.035 (0.031)	−0.269 (0.101)**	−1.319 (0.504)*
Watching TV, Π_9			
Intercept, β_{90}	−0.050 (0.042)	0.014 (0.104)	0.326 (0.556)

	Sleep Latency	Sleep Hours	Sleep Efficiency
Fixed Effect	**Coefficient (SE)**	**Coefficient (SE)**	**Coefficient (SE)**
Friends, Π_{10}			
Intercept, β_{100}	−0.077 (0.034)*	0.060 (0.094)	1.012 (0.593)
Family, Π_{11}			
Intercept, β_{110}	0.094 (0.044)*	−0.013 (0.110)	−1.111 (0. 640)
Positive-negative (electronic), Π_{12}			
Intercept, β_{120}	−0.021 (0.013)	−0.102 (0.43)*	−0.183 (0.244)
Positive-negative (in-person), Π_{13}			
Intercept, β_{130}	−0.063 (0.034)	0.119 (0.063)$^{+}$	0.579 (0.380)