Bedtime Autonomy and Cellphone Use Influence Sleep Duration in Adolescents

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Acknowledgments

Support for this study was provided by a Scholars Grant from the William T. Grant Foundation and the Jeffrey/Wenzel Chair in Behavioral Neuroscience to Dr. Adriana Galván. Preparation of this manuscript was supported in part by the National Science Foundation Graduate Fellowship to Sarah M. Tashjian.

Abbreviations:

Ambulatory Monitoring, Incorporated (AMI)

principal component analysis (PCA)

95% bias-corrected confidence intervals (95% BC CI)

Abstract

Purpose

The aim of this study was to examine modifiable environmental contributors of shortened sleep duration in adolescents.

Method

We assayed sleep duration over two weeks using actigraphy in a sample of 98 adolescents (ages 14-18, 51 female). Reports of adolescents setting their own bedtime and parental monitoring of bedtime were collected and, using principal components analysis, reduced to one factor representing bedtime autonomy. In a subsample of participants (n=63) frequency of nighttime cellphone use and reports of cellphone disruption were assessed and combined into a composite score of cellphone usage.

Results

Increasing age was associated with shorter total sleep duration, $r(98)$=-.28, p=.006. Age-related sleep duration was mediated by bedtime autonomy, ab_{cs}=-.11, 95% BC CI [-.2167, -.0370]. The effects of bedtime autonomy were moderated by nighttime cellphone use such that bedtime autonomy was most problematic for adolescents who used cellphones more frequently, B=-10.44, SE=4.64, 95% BC CI [-21.3749, -2.8139], compared to those who used cellphones less frequently, B=-1.94, SE=3.28, 95% BC CI [-9.8694, 3.6205].

Conclusions

Adolescence is characterized by insufficient sleep due to biological and environmental factors. Although age is frequently cited as an important element in declining sleep duration, our results suggest age may be a proxy for other co-occurring psychosocial changes during adolescence.

These findings identify mechanisms by which parents and adolescents may help increase the amount of sleep adolescents achieve.

Keywords: actigraphy; adolescents; sleep; technology

Implications and Contribution

The unique contribution of the current study is to identify milieu associated with decreased sleep durations during adolescence. The data suggest that age-related declines in sleep duration during this important period of development are related, in part, to modifiable environmental factors in adolescents' bedtime routine.

Adolescents regularly experience insufficient sleep duration, with only 10% of high-school adolescents in the United States achieving National Sleep Foundation (NSF) recommendations of more than 8 hours of sleep per night [1-2]. Insufficient sleep is associated with widespread negative outcomes including mood disturbances, poor grades, behavior problems, substance use, driving crashes, and obesity [3-5]. Decreases in sleep duration as children transition into adolescence is linked to various biological and environmental influences [6]. Whereas biological factors are relatively immutable for adolescents, environmental contributors may be more malleable; recent efforts have sought to uncover opportunities for identifying modifiable environmental factors that contribute to insufficient adolescent sleep. In the current study, we examined whether bedtime autonomy and nighttime cellphone usage related to adolescent nighttime sleep duration. A central piece of our analysis was to examine the influence of these factors over and above age to determine whether age-sleep associations may be explained by psychosocial changes during adolescence.

Age has been repeatedly linked to shorter sleep duration, with shorter sleep durations being more common for older adolescents [1, 7-9]. Most adolescents undergo a circadian shift and slowing of sleep homeostatic pressure accumulation that contribute to shorter sleep durations compared to pre-puberty [4, 10-11]. These biological contributors of shorter sleep duration tend to be more pronounced for older adolescents compared to early or pre-pubertal adolescents [12]. While biological factors are one important piece of this age-sleep association, it is also possible that co-occurring environmental changes account for some of these associations. For example, many adolescents experience dramatic changes in autonomy as they age, reducing parental oversight of sleep habits [13]. During adolescence, socializing becomes increasingly important, with cellphones being the primary mode of communication among adolescents [14]. Adolescents

who use their cellphone before bed report increased tiredness [15], greater sleep disruption [16], and evince disruption of circadian timing and melatonin suppression [17-18] compared to those who do not use their phones at night. This prior work identifies adolescent autonomy and technology use as potential problems for sleep but has not considered these environmental factors as proxies for the established association between age and sleep duration.

Becoming independent from caregivers is a hallmark of adolescence that involves both increases in autonomous decision-making and socializing with peers [19]. Although increased autonomous functioning is developmentally normative, it may add to the confluence of causes that diminish sleep time. Additionally, as peers become increasingly important, socializing may compete with sleep [20]. We focused on adolescent control over bedtimes (herein referred to as bedtime autonomy) and nighttime cellphone use as two potentially influential factors related to reductions in adolescent sleep duration. Unlike school start times, a hot topic in adolescent sleep research [5] garnering attention from NSF and United States Congress, these are behaviors that parents and adolescents can more readily modify.

A central framework guiding this research is that bedtime autonomy might be a mechanism explaining age-related changes in sleep duration. As children mature, parents adjust their level of control to allow for more independent decision-making [21], including in the domain of sleep. Relative to younger children (9-11-year-olds), early adolescents (12-13-year-olds) are more likely to report they control their bedtime, which is correlated with less sleep time [8]. Parent-set bedtimes also decrease from ages 13 to 18 years [6]. Adolescents with parent-set bedtimes reported going to bed earlier, obtaining more sleep, and experiencing less fatigue during the day [6-8], consistent with the notion that parental control over adolescent bedtimes

promotes healthy sleep [6, 22]. We investigated the association between bedtime autonomy and sleep among high-school adolescents using actigraphy, an objective measure of sleep duration.

Adolescence is a time of social reorientation and increased importance of peers [23]. Adolescent consumption of technology, particularly smartphones, has dramatically increased over the past decade [16, 24]. In comparison to other age groups, adolescents spend greater amounts of time using technology [25], which is arousing and delays nighttime sleep onset [4-5, 26-27]. Cellphone use before bed increases light exposure that can deregulate the circadian system and also increases psychological stimulation that can delay sleep onset [4, 28]. Adolescents who report more cellphone use before bed attain shorter sleep duration than those who use less media [29]. Thus, it is possible that nighttime cellphone use may add to other biological and psychosocial causes of problematic sleep in adolescence.

Current Study

We tested the hypothesis that bedtime autonomy and cellphone use influence sleep duration over and above age in a sample of American adolescents. Rather than relying on self-reports, we utilized actigraphy, which has been validated for use in adolescent populations [30-33]. Our sample included 98 adolescents (14-18 years, 51 female). We focused on high-school adolescents because adolescence is a period of heightened vulnerability to insufficient sleep [7] and our motivating hypothesis was that as age increased, bedtime autonomy would increase, and this change in autonomy would mediate the association between decreased sleep duration and age. We tested cellphone use as a moderator, predicting that bedtime autonomy would be most problematic for adolescents who reported using cellphones before bed more frequently.

Methods

Participants

The sample included 98 adolescents (51 female; M_{Age}=16.10 years, *SD*=1.16, range=14-18 years). Males and females did not differ in age $t(96)=-1.19$, $p=.24$; females: M_{Age}=16.24, *SD*=1.03; males: M_{Age}=15.96, *SD*=1.29=. Forty-five percent of our sample identified as Hispanic/Latino, 28% Caucasian, 13% African American, 3% Asian, and 11% mixed ethnicity/ "other". A subsample of 63 participants completed cellphone usage measures (36 female; M_{Age}=16.03 years, *SD*=1.11, range=14-18 years; 51% Hispanic/Latino, 27% Caucasian, 14% African American, 3% Asian, 5% mixed ethnicity/ "other") (the remaining 35 of the total sample of 98 adolescents failed to understand the Likert scale instructions for the cellphone usage questions, providing binary "yes/no" responses instead of ratings). Analyses including cellphone use were conducted using the subsample (n=63) whereas analyses of actigraph sleep duration, bedtime autonomy, and age were conducted in the full sample (n=98). Participants who completed cellphone use questions correctly did not differ from those who did not complete the questions correctly as to age $t(96)=.80$, $p=.43$, sex $\chi^2(1, N=98)=1.84$, $p=.18$, sleep duration $t(96)=-1.36$, $p=.18$, weekday sleep duration $t(96)=-1.29$, $p=.20$, weekend sleep duration $t(94)=-.69$, $p=.50$, or bedtime autonomy $t(96)=-.23$, $p=.82$.

Procedures

The Institutional Review Board approved this study. Participants were recruited via flyers and if they agreed to be contacted for future studies during prior participation in other laboratory studies at the university. Participant eligibility was determined by phone screening with a parent to ensure all enrolled participants reported no current sleep, psychological, or neurological disorders and that participants were not taking prescription psychotropic medications. Written parent consent and participant assent was obtained. Once enrolled, participants were trained on use of the actigraph watch. Participants wore the watch for 14 nights, completed daily written

diary of sleep and wake times, daily responses via text sent to their cellphone, and self-report questionnaires at home. At the end of the study, participants were compensated with cash.

Sleep

Sleep indices were tracked using a Micro Motionlogger® Sleep Watch actigraph by Ambulatory Monitoring, Incorporated (AMI). Actigraphy has been validated for adolescent use [30-33]. Each participant was instructed to wear the actigraph on their non-dominant wrist at night for 14 consecutive nights. Adolescents' body movement during nighttime sleep was monitored in 1-minute epochs using zero crossing mode. Adolescents were instructed to push the event marker button when they turned off the lights to go to sleep and again when they got out of bed in the morning. The in-bed period began at the first event marker indicating when participants turned off the lights to go to sleep and ended at the time when the participant got out of bed in the morning. Nightly records were scored using validated AMI algorithms (Action4) [31] for the portion indicated as nighttime sleep (sleep onset to sleep offset). Sleep duration was calculated by averaging across the 14 consecutive nights (inclusive of weekdays and weekends) the number of minutes of sleep attained each night from the time adolescents fell asleep to the time they awoke the next morning (average total actigraphy days collected per participant M=13.35 days, SD=2.41).

Adolescent self-reports of sleep and wake times were also collected via daily text messages sent to their cellphones and via a written daily diary completed at home. If actigraph event markers were not available for a particular night, adolescent daily diary report and objective indices such as actigraphy light monitoring and motion were used to designate sleep and wake times.

Bedtime Autonomy

Adolescents answered two yes/no (0=no, 1=yes) questions assessing bedtime autonomy: "(1) Are you allowed to set your own bedtime? (2) Do your parents check on whether you to go bed on time?"

These two measures of bedtime autonomy were negatively correlated, $r(98)=-.35$, $p < .001$, such that adolescents who were allowed to set their own bedtime reported less parental checking of bedtimes than those who did not set their own bedtime. The logisticPCA package for R [34], a generalization of principal component analysis (PCA) for binary variables, was used to create a single bedtime autonomy component score. As part of the logisticPCA package, the logpca_cv function was used to estimate m, which is used to approximate the natural parameters from saturated model, with cross validation. An m of 5 was deemed optimal. Five iterations were required for convergence. One component emerged, identified as bedtime autonomy, explaining 67.90% of the deviance. Loading was such that higher scores indicated less autonomy, adolescents allowed to set bedtime had a negative loading whereas parents monitoring bedtime had a positive loading. To aid interpretability, scores were multiplied by -1. In analyses, higher scores indicate more bedtime autonomy.

Cellphone Usage

Of the total sample of 98 adolescents, 63 correctly completed both cellphone usage questions from the Sleep Environment Inventory [35]. These questions asked about cellphone use prior to bed and the extent to which this cellphone use disrupted their sleep. Participants rated how frequently they used their cellphone before bed on a 7-point Likert scale (1=*not at all* to 7=*very much*). They also rated the degree to which their cellphone use before bed was disruptive to their sleep on (1=*not at all disruptive* to 7=*very disruptive*). We created a composite score, herein referred to as cellphone usage, by multiplying frequency by disruption to

create a 1- to 49-point scale. We also measured television and computer use, but probed cellphone usage because of its increasing replacement of other forms of technology like television [36].

Mediation and Moderation

To analyze the relation between age, sleep duration, and bedtime autonomy, mediation (Model 4) was examined using Hayes' PROCESS macro for SPSS [37]. A completely standardized index of mediation (ab_{cs}) was calculated for comparability to direct effects [38]. To test the moderating effect of cellphone use, moderated mediation (Model 14) was examined. Each analysis utilized a bootstrapping approach with 5000 samples, and significance was determined at 95% bias-corrected confidence intervals (95% BC CI). All variables were continuous and centered prior to analysis, and the estimated effects are reported as unstandardized regression coefficients. In all analyses, age (years) was the predictor, bedtime autonomy (PCA score) was the mediator, and sleep duration (minutes) was the outcome variable. Cellphone use (composite score) was tested as a moderator using interaction effects with bedtime autonomy.

Results

Descriptive statistics are reported in Table 1 and bivariate correlations are reported in Table 2.

Sleep Duration

Adolescents attained 424.85 minutes (7.08 hours; *SD*=56.11 minutes) of sleep per night ranging from 279.78 (4.66 hours) to 563.60 minutes (9.39 hours), averaging across all nights of the study including both weekdays and weekends. Age was significantly correlated with sleep duration such that higher age was associated with shorter sleep duration, $r(98)=-.28$, $p=.006$

(Table 2, Fig. 1). Independent samples *t*-tests revealed significant sex differences for sleep duration, $t(96)=-2.48$, $p=.015$, $d=.50$, such that females ($M=438.00$ minutes, $SD=56.56$) attained longer sleep durations than males ($M=410.58$ minutes, $SD=52.56$).

On weekdays, participants went to bed at 11:44 p.m. on average (range 8:15 p.m. to 3:42 a.m.) and woke up at 7:21 a.m. on average (5:24 a.m. to 10:02 a.m.). On weekends, adolescents went to bed at 12:12 a.m. on average (range 9:09 p.m. to 3:38 a.m.) and woke up at 8:27 a.m. on average (5:32 a.m. to 11:38 a.m.).

On average, participants slept 31.36 minutes longer (*SD* 61.78) on weekends than on weekdays. We did not obtain any weekend information from two participants. Age was correlated with weekday sleep duration, $r(98)=-.27$, $p=.008$, and weekend sleep duration, $r(96)=-.21$, $p=.038$. Females attained longer sleep durations than males for both weekdays and weekends: $t(96)=-2.11$, $p=.038$, $d=.43$, $t(94)=-2.58$, $p=.011$, $d=.53$, respectively.

We probed sleep duration across the entire study (regardless of type of day) in order to test effects as they related to general sleep patterns. We also separately tested whether results held for variations in weekday and weekend sleep duration given longer average sleep durations on weekend days. Seventy-one percent ($n=70$) of participants were enrolled in the study during the school year. Timing of study participation (school versus break) did not relate to any variable of interest.

Bedtime Autonomy

Sixty-seven percent ($n=66$) of participants reported being allowed to set their own bedtime and 33% ($n=32$) of participants reported parents monitoring whether they went to bed on time. Bedtime autonomy component scores were negatively correlated with average sleep duration such that more bedtime autonomy was associated with shorter overall sleep duration,

$r(98)=-.36$, $p < .001$ (Table 2). Bedtime autonomy was correlated with shorter sleep duration for both weekdays, $r(98)=-.33$, $p=.001$, and weekends, $r(96)=-.30$, $p=.003$. Bedtime autonomy was also correlated with age such that higher age was associated with more autonomy, $r(98)=.37$, $p < .001$.

Cellphone Usage

A subset of participants ($n=63$) reported the frequency with which they used their cellphone before bed and the extent to which they thought this cellphone usage was disruptive to their sleep. These measures of cellphone usage were not significantly correlated with each other, $r(63)=.22$, $p=.09$. Frequency, disruption, and the composite score were not correlated with age, sleep duration (average, weekday, or weekend), or bedtime autonomy component scores.

Mediation and Moderation Analyses

To test whether bedtime autonomy mediated the association between age and sleep duration, we conducted mediation analyses with age as the predictor, bedtime autonomy as the mediator, and sleep duration (combined weekday and weekend sleep) as the outcome. Results revealed a significant mediation such that age was related to sleep duration through bedtime autonomy, $ab_{cs}=-.11$, 95% BC CI [-.2167, -.0370] (Fig. 2). These findings were replicated when using weekday and weekend sleep duration as separate dependent variables: weekday sleep duration, $ab_{cs}=-.10$, 95% BC CI [-.2050, -.0266]; weekend sleep duration, $ab_{cs}=-.10$, 95% BC CI [-.2077, -.0236]. Mediation results remained the same covarying for sex.

To test whether cellphone use influenced the mediated relationship, we tested moderated mediation in the subset of participants ($n=63$) who correctly answered the cellphone usage and disruption questions. Results revealed moderated mediation was significant $B=-.31$, $SE=.20$, 95%BC CI [-.8273, -.0256] (Fig. 3). The interaction between cellphone usage and bedtime

autonomy was significant, *B* =-.18, *t*(58)=-2.02, *p*=.047, 95%BC CI [-.3661, -.0019], such that the conditional effect of age on sleep duration was significant for those who had average or high (+1SD) levels of cellphone usage but not those who had low levels (-1SD). The effect of age on sleep duration through bedtime autonomy was stronger for those who had higher reports of cellphone use and disruption, *B*=-10.44, *SE*=4.64, 95%BC CI [-21.3749, -2.8139], than those who had average, *B*=-6.19, *SE*=2.97, 95%BC CI [-13.9435, -1.7340], or low cellphone usage scores, *B*=-1.94, *SE*=3.28, 95%BC CI [-9.8694, 3.6205]. For each of weekday and weekend sleep duration, indices of moderated mediation were significant, but the interaction effect for weekend sleep was marginal *p*=.16: weekday index of moderated mediation, *B*=-.33, *SE* =.23, 95%BC CI [-.9631, -.0171]; weekend index of moderated mediation, *B*=-.27, *SE* =.20, 95% BC CI [-.8620, -.0002]. Moderated mediation results remained the same covarying for sex.

Discussion

The current findings elucidate contextual factors of bedtime autonomy and cellphone usage that explain links between age and adolescent sleep duration. Bedtime autonomy, assessed as adolescent-set bedtime and parent oversight of bedtime, mediated the relation between age and sleep duration suggesting chronological age may be a proxy for other important environmental factors contributing to insufficient sleep during adolescence. This association was stronger for those who had higher reports of cellphone use and disruption at night; bedtime autonomy was least problematic for nighttime sleep duration among adolescents who infrequently used their cellphone before bed. Although bedtime autonomy and increasing access to technology have been previously examined in relation to sleep, this study provides new evidence that these behaviors may be explaining the link between increasing age and declining sleep duration among adolescents.

In this study, age was negatively associated with sleep duration such that higher age was associated with fewer hours of sleep. Similarly, age was positively correlated with bedtime autonomy, with greater bedtime autonomy being given with increasing age. Our data indicate the association between age and sleep duration was explained by this co-occurring increase in bedtime autonomy, which held for each of weekday and weekend sleep duration. Although insufficient sleep is complicated and factors such as socioeconomic status, health, and the sleep environment may contribute to differences in sleep attained, our findings provide a potentially addressable target to improve adolescent sleep duration. Insufficient sleep has been linked to numerous hazardous health outcomes [3-5], making it critically important to identify ways to intervene and improve sleep duration for adolescents. Much of the ongoing public discourse addresses school start times and weekday sleep, but our findings point to ways in which parents can also help adolescents achieve more sleep.

Frequency of nighttime cellphone use and related sleep disruption moderated the indirect association between age and sleep duration through bedtime autonomy. Conditional effects revealed that this moderation was strongest for adolescents who reported above average cellphone usage scores, suggesting bedtime autonomy was most problematic for sleep duration among those individuals. Future research should consider how different types of adolescent autonomy (e.g., bedtime control versus cellphone use) might have disparate effects depending on the combination of factors at play. Additionally, age was not correlated with cellphone usage illuminating the benefits of parental bedtime oversight for both older adolescents and those who frequently use cellphones before bed, regardless of age.

Although younger adolescents achieved longer sleep duration than older adolescents in our sample, sleep duration was below national recommendations. NSF recommends that high-

school adolescents sleep 8-10 hours per night [2]. In this study, 14-year-olds, the youngest age group, averaged only 7.61 hours of sleep per night whereas 18-year-olds, the oldest age group, averaged just 6.85 hours. Even including weekends, our data suggest teens are suffering from a lack of sleep.

By using actigraphy, the gold standard in sleep research, we captured naturalistic sleep patterns across a two-week period. The range of sleep duration varied across participants with the greatest average sleep duration attained by any single participant being 9.39 hours and the lowest average duration a mere 4.66 hours. Prior work from our lab and others has identified sleep variability as an important factor in optimal daytime functioning [39-40]. Our data support the notion that adolescents vary considerably in the sleep durations they attain. Future work should consider the contribution of bedtime autonomy through nightly assessment to determine how parents giving adolescents increasing control over their bedtime routine might lead to worsened sleep patterns.

The current findings should be considered in the context of potential limitations. We assessed average sleep across a two-week period, which allowed us to assay normative sleep patterns. However, we did not concurrently assess bedtime autonomy and, thus, cannot determine whether frequency or efficacy of bedtime rules differed depending on scheduled versus unscheduled wake times. Similarly, we do not have information as to whether cellphone usage differs during weekdays compared to weekends nor do we know the types of activities adolescents were engaging in with their cellphones. Although our findings add to the growing body of literature examining environmental factors contributing to poor adolescent sleep, future work would benefit from more objective measures of bedtime autonomy and cellphone use beyond self-report. We focused on cellphones because of their increasing replacement of other

forms of technology [36], cellphones are uniquely positioned to increase sleep disruptions [5, 17, 26], and nighttime cellphone use is more prevalent among older adolescents [1, 15]. However, future work may benefit from concurrent examinations of other technology. We were also unable to determine causal pathways given the nature of our study. Although our analyses utilized bootstrapping techniques to assist with our modest sample size, future work in larger samples would be informative.

Our findings demonstrate bedtime autonomy is an important factor for insufficient sleep duration during adolescence, regardless of weekday or weekend. Bedtime autonomy was particularly detrimental among adolescents who frequently used and were disturbed by cellphone use before bed. These findings highlight the importance of considering environmental underpinnings of age-related sleep findings, suggesting that age may be a proxy for other psychosocial changes during this time. Our data suggest increased bedtime monitoring and restriction of nighttime cellphone use may help improve sleep durations for adolescents.

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Figure Legends

Figure 1. Older adolescents obtained shorter sleep duration over the 14-day period as measured by actigraphy, $r(98)=-.28$, $p=.006$. $N=98$.

Figure 2. Bedtime autonomy mediated the association between age and sleep duration. Analyses utilized a bootstrapping approach with 5000 samples, and significance was determined at 95% bias-corrected confidence intervals. All variables were continuous and centered prior to analysis, and the estimated effects are reported as unstandardized regression coefficients.

Figure 3. Cellphone usage significantly moderated the effect of age on sleep duration through bedtime autonomy such that the effect of age on sleep duration through bedtime autonomy was stronger for those who had higher reports of cellphone usage than those who had average or low cellphone usage composite scores. Analyses utilized a bootstrapping approach with 5000 samples, and significance was determined at 95% bias-corrected confidence intervals. All variables were continuous and centered prior to analysis, and the estimated effects are reported as unstandardized regression coefficients.