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Developmental Trends in Sleep During Adolescents' Transition to Young Adulthood

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Abstract

Objective: Poor sleep poses negative health consequences for youth, yet few longitudinal actigraphy studies have examined basic developmental trends in sleep across adolescents' transition to young adulthood. In this longitudinal actigraphy study, stability of individual differences and trajectories of sleep during and after high school were examined. The degree to which sleep trajectories differed by college attendance status was also studied.

Methods: A total of 343 youth with Asian, Latino, and European American backgrounds completed eight days of wrist actigraphy at two-year intervals in Wave 1 (n = 295, M_{age} = 16.39), Wave 2 (n = 211 including 34 new participants to refresh the sample, M_{age} = 18.31), and Wave 3 (n = 144, M_{age} = 20.29). Sleep duration, efficiency, and latency were estimated for weekdays and weekends. Intra-individual variability in duration across nights was also obtained.

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Declarations of interest:
none

Results: Sleep parameters were correlated modestly between Wave 1 and Wave 2, but not correlated between Wave 1 and Wave 3, indicating modest shorter-term and little longer-term stability of individual differences. Multilevel growth models demonstrated declines in weekday sleep duration and efficiency across high school and post-high school years. Intra-individual variability in duration increased over the years. Latency trajectories changed more for non-college attendees compared with college attendees.

Conclusions: Overall the findings suggest developmental trends of worsening sleep during adolescents' transition to young adulthood. Interventions to improve sleep may need to target specific issues faced by youth at that particular period in their lives.

Keywords

sleep; actigraphy; longitudinal; adolescence; college

1. Introduction

The prevalence of poor sleep during adolescence in industrialized nations [1] raises alarms given its implications for psychosocial, behavioral, and health issues. Poor sleep during adolescence has been linked to poor decision-making, risk-taking, mood disruptions, and lower academic performance [2–5]. Additionally, adolescents' poor sleep has been associated with higher levels of chronic inflammation predictive of adult cardiovascular problems [6,7] and lower white matter integrity in adolescents' brains a year later, indicating consequences of poor sleep on the brain development [4]. Despite burgeoning research suggesting that poor sleep during adolescence poses negative developmental and health consequences, basic developmental trajectories of sleep during adolescents' transition to young adulthood remain poorly understood.

In sharp contrast with evidence that obtaining poor sleep has serious consequences for adolescents, high school students often curtail sleep amounts due in part their rigid school schedules and intense academic and social demands [8]. Many of these demands tend to increase across the high school years and are carried into the post-high school years as adolescents take on academic, social, and financial responsibilities of young adulthood [9]. Thus, sleep may worsen across the high school years, and preexisting poor sleep may become more pervasive after high school. Initial support for this notion comes from cross-sectional studies indicating that older age and grade are associated with shorter sleep within school-aged adolescents [10,11], longitudinal studies with children and adolescents not older than 18 years suggesting worsening sleep trends prior to young adulthood [12–16], and studies showing that college students experience a variety of widespread sleep issues including insufficient and inconsistent sleep amounts and poor sleep quality [17,18].

However, it is unclear whether sleep actually worsens during adolescents' transition to young adulthood. Despite the salience of sleep difficulties in adolescence, only four longitudinal studies have examined sleep trajectories during adolescents' transition to young adulthood [19–22] and yielded mixed results. Two of these studies suggest improved sleep in the course of the transition based on self-reported increased sleep duration ($N = 15{,}701$) [21] and actigraphy-derived increased sleep duration and efficiency ($N = 82$) [20]. Yet the other two studies suggest a more complicated picture, with marked differences between weekday and weekend sleep trends. Specifically, an actigraphy study (*N* = 56) showed that weekend duration continuously declined 15–18+ years, suggesting worsening sleep, while weekday duration declined from ages 15–17, but then increased as adolescents reached young adulthood of ages 18+ [19]. Adding to the mixed findings, another actigraphy study reported stability in both school and non-school day sleep durations as adolescents transitioned from high school to college (*N* = 24).

As such, few extant longitudinal studies on sleep trends from adolescence to young adulthood present mixed results of improving, worsening, and stable sleep, which in part may result from inconsistencies in weekday vs. weekend assessment and self-reported vs. actigraphy-based sleep assessments. Moreover, except for the self-reported study [21], all the actigraphy studies [19,20,22] were based on small sample sizes (*N*s = 24–82). Given these issues and the paucity of research, we do not adequately understand how sleep changes as adolescents move beyond high school years. It is particularly important to provide objective, actigraphy-derived sleep data [12] to avoid limitations of self-reported sleep including participants' biases and ambiguous sleep questions that may be interpreted differently across participants.

Another strength of actigraphy is its ability to capture multiple dimensions of sleep to provide a comprehensive understanding of developmental sleep trends. Based on past research linking sleep with developmental outcomes, longer duration generally indicates better sleep during adolescence [3,6]. Higher efficiency indicates better sleep, as it suggests less disturbance during the course of one's sleep [10]. Lower variability in sleep duration across nights indicates more consistent, better sleep [6,23]. Latency is conceptually a less clear dimension, as short latency may signal tiredness and sleep deprivation [24], whereas long latency may indicate difficulty falling asleep in bed [20,25]. Too short or long latency are likely both problematic, but the ideal amount of latency is unknown. Moreover, emerging evidence indicates clear weekday vs. weekend differences in adolescents' sleep [7,12], suggesting the need to distinguish weekday vs. weekend sleep parameters.

Additionally, it is unclear whether individual differences in sleep remain during adolescents' high school and post-high school years. Examining the stability of individual differences in sleep addresses whether adolescents with more problematic sleep during high school continue to have difficulties as they move into young adulthood. Evidence of long-term stability would suggest the importance of early identification to prevent later problems during young adulthood. A lack of stability, in contrast, would suggest that efforts to improve sleep would need to focus on the specific issues faced by youth at that particular period in their lives. Preliminary evidence suggests short-term stability of individual differences, with a study showing that sleep duration and efficiency had significant medium-sized correlations between 12th grade and the first year of college [20]. In another study, five-year longer-term stability of individual differences in sleep duration emerged for school days, but not for non-school days.

Furthermore, it remains unknown whether adolescents' sleep after high school changes differently depending on whether they attend college, a key feature that could create divergence in life trajectories. Adolescents who transition from high school to college experience more shared environmental characteristics such as academic demands and peers as the main social group, compared with those who do not attend college and move away from academic settings and engage in more responsibilities of adulthood. Thus, examining whether college attendance status modulates changes in adolescents' sleep helps to understand the significance of environmental contexts in sleep trajectories. No past studies in this research area have contrasted college attendees with those not in college, and past studies have focused on those who went on to college [20,22].

The aim of the present study was to contribute to the limited literature on sleep trajectories during adolescents' transition to young adulthood by using a longitudinal design and actigraphy assessments of multiple sleep dimensions. Growth trajectories of sleep and stability of individual differences were examined during and after high school. The degree to which sleep trajectories differed by college attendance status was also studied. Our sample size was significantly larger compared with the past longitudinal actigraphy studies on sleep trends from adolescence to young adulthood, and participants represented ethnically diverse Asian, Latino, and European American backgrounds.

2. Method

2.1. Participants

Participants came from a three-wave longitudinal project that followed adolescents and their primary caregivers at two-year intervals. A total of 350 adolescents participated in the project, and the current study sample included 343 who completed actigraphy in at least one of the three waves (56% female). Participants came from diverse ethnic (21% Asian, 31% European American, 42% Latino, 6% other ethnicity) backgrounds. Adolescents' primary caregivers reported their and their spouse's highest level of education (1 = some elementary school; 2 = completed elementary school; 3 = some junior-high school; 4 = completed junior-high school; 5 = some high school; 6 = graduated from high school; 7 = trade or vocational school; 8 = some college; 9 = graduated from college; 10 = some medical, law, or graduate school; 11 = graduated from medical, law, or graduate school). Averaging the primary caregivers' and spouses' level of education suggested that participants' parents averaged a little more than trade or vocational school ($M = 7.17$, $SD = 1.87$).

Initially in Wave 1, 316 adolescents were recruited from 10th and 11th grade classrooms at four public high schools in the Los Angeles metropolitan area from October 2011 to June 2012. Research staff visited the classrooms to make announcements about the study and distributed flyers to students. Where permitted, flyers were also mailed to the students' homes around the time that presentations were made. Research staff followed up by calling interested families to provide more details about the study and answer any questions. During the phone conversation, the staff obtained verbal consent and scheduled a visit for families who confirmed their wish to participate in the study. Written consents were obtained during the first visit, which took place in the family's home or a local research center. A total of 295 (93%) of the Wave 1 adolescents completed actigraphy (age range = 14.50–20.50 years, $M_{age} = 16.39$, $SD = 0.74$).

Participants from Wave 1 were assessed during two additional waves at two-year intervals. Of the initial sample, 214 participants returned for Wave 2. Additionally, 34 new participants (26 12^{th} grade and eight one-year post high school) who matched the grade of the initial participants at Wave 2 were recruited to refresh the sample, a method used in longitudinal studies to adjust for attrition bias [26]. Of the 248 youth who participated in Wave 2 (October 2013–August 2014), 211 (85%) youth (age range = 14.50–22.17 years, M_{age} = 18.31, SD = 0.77) completed actigraphy. In Wave 3 (October 2015–August 2016), 180 youth who participated in at least one previous wave returned, and 144 (80%) of them (age range = 16.50–22.09 years, M_{age} = 20.29, SD = 0.74) completed actigraphy.

Previously-published papers from this project have examined the link between sleep and inflammation [6], HPA-axis functioning [27], mood [28], discrimination [29] and family stress [30], using data from only the first wave of the study during high school.

2.2. Measures and Procedures

During the first visit with the families, adolescents and their primary caregivers reported demographic information. In addition, adolescents were given a wrist actigraph to wear for eight consecutive nights at home. Both adolescents and parents completed other measures and tasks not reported in this paper. Research staff returned to the participant's home to collect the materials at the end of the data collection period. Adolescents received $50 in Wave 1, $75 in Wave 2, and $120 in Wave 3. Additionally, two movie theater passes were provided to incentivize full participation in other protocols of the project. All procedures were approved by the University of California, Los Angeles Institutional Review Board.

2.2.1. Actigraphy sleep variables—In each wave of data collection, adolescents wore a wrist actigraph (Micro Motionlogger Sleep Watch, Ambulatory Monitoring, Inc.; Ardsley, NY) on their non-dominant hand before going to bed for eight consecutive nights. They were instructed to keep it on until the following morning when they woke up and got out of bed. Adolescents were instructed to press the event marker on the actigraph to indicate when they: 1) turned off the lights to go to sleep at night, 2) got out of bed in the middle of the night, such as to use the bathroom, or 3) got out of bed in the morning. Adolescents wore the actigraph for an average of 6.19 nights across waves.

The software package Action 4 (Ambulatory Monitoring, Inc.; Ardsley, NY) was used to code and score the resulting actigraphy data. The in-bed period began at the time of the first event marker indicating when a participant turned off the lights to go to sleep, and ended at the time of the last event marker indicating when the participant got out of bed in the morning. In accordance with past studies, if event markers were not present for a particular night, adolescents' daily self-reports were used to identify the time at which they went to bed and got up in the morning. Sleep statistics for each night were calculated using one-minute epochs and the Sadeh actigraph scoring algorithm, which has been validated and used in studies with children and adolescents [6,31–33]. Sleep onset time was the first of at least three consecutive minutes of sleep, and sleep offset time was the time of the last five or more consecutive minutes of sleep [6,31]. Table 1 displays the descriptive statistics for each dimension of sleep according to the years during and after high school at which they were measured.

2.2.1.1. Duration (hours): Sleep duration for each night was total hours scored as sleep during adolescents' in-bed period. Adolescents' sleep durations across weekdays (Sunday–Thursday nights) were averaged to assess their mean weekday sleep duration. Friday and Saturday night sleep durations were averaged to assess their mean weekend sleep duration.

2.2.1.2. Efficiency (%): Sleep efficiency was the proportion of the total sleep interval scored as sleep. Thus, it represented the proportion of the time adolescents actually slept between their first sleep onset and final sleep offset time. Separate estimates of weekday and weekend efficiency were obtained.

2.2.1.3. Latency (minutes): Sleep latency was the number of minutes between adolescents' in-bed time and the first sleep onset time, representing the amount of time it took for adolescents to fall asleep once in bed. Separate estimates of weekday and weekend latency were obtained.

2.2.1.4. Variability (minutes): Nightly variability in sleep duration was calculated by taking the mean of the absolute differences between a participant's mean nightly sleep duration and each individual night's sleep duration [6,34].

2.2.2. College attendance—Participants who remained in the study in Wave 2 or 3 and graduated from high school responded to a question asking whether or not they were enrolled in college, which was used to identify whether they attended college after high school (0 = no college, $n = 37$ [18%]; 1 = college, $n = 172$ [82%]).

2.3. Data Analysis Strategy

All analyses were conducted in Stata SE 15.0 (College Station, TX). First, participation analyses were conducted to examine whether adolescents who returned in at least one subsequent wave differed from those who did not return. Second, bivariate correlations between the same measures of sleep across the three waves were computed in order to estimate the stability of individual differences in sleep during adolescents' transition to young adulthood.

Next, multilevel growth curve models were conducted to estimate developmental trajectories of adolescents' sleep during and after high school. Year was centered around 10^{th} grade and entered as the Level 1 predictor while controlling for sex, ethnicity, and parental education entered at Level 2. In order to test for both linear and nonlinear trends, we included linear, quadratic, and cubic terms for year in each model. When higher order terms were non-significant, we proceeded with stepwise removal of higher order terms (first cubic, then quadratic term) and re-estimated the model [35]. After fitting the final model, we obtained partial derivatives of the regression equations to estimate sleep values for each year using the margins command. These estimated values for each year were used to plot graphs as well as to identify turning point years at which sleep trends changed in case of significant nonlinear trends. Prior to fitting the models, outliers for sleep variables (+/− 3 SD) were replaced with highest/lowest values within the range using the winsorizing method [36,37]. Separate models were fit for each of the eight sleep measures.

Our accelerated longitudinal design (i.e., two age cohorts, one year apart) provided data to estimate sleep parameters for each year from the 10th grade to three years after high school. Adolescents who entered the study at the 10th grade contributed to the 10th grade, 12th grade, and two-year post-high school estimates, whereas those who entered the study at the 11th grade contributed to the 11th grade, one-year post-high school, and three-year post-high school estimates. New study entrants at Wave 2 contributed to the estimates appropriate to their year of entrance. The number of observation at each year was as follows: 134 10th grade, 154 11th grade, 124 12th grade, 90 one-year post-high school, 79 two-year post-high school, and 64 three-year post-high school. Additionally, two 9th grade students and four 12th grade students unexpectedly entered the study in Wave 1, and three of the 12th grade students continued participation through four years post high school. The data for these latter participants contributed to the trajectory estimates, but results are presented for the 10th grade through three years post high school. The models permitted the existence of missing data, allowing for the inclusion of adolescents who participated in one, two, or three waves of the study and pooling all data to estimate developmental trajectories.

Finally, cross-level interaction terms between year (Level 1) and college attendance (Level 2) were added to the base model described above, along with their lower-order main effect terms. The interaction terms indicated whether developmental trends in sleep differed as a function of college attendance. In case of significant interaction, tests of simple slopes were conducted where the effect of year on sleep was estimated for college attendees and non-college attendees. Additionally, for comprehensive interpretation of the significant interaction, the college vs. no college difference was estimated at each year.

3. Results

3.1. Participation Analyses

Of the adolescents who provided actigraphy data, 61% returned to complete actigraphy in at least one subsequent wave. Adolescents who returned vs. did not return were comparable across sex (t[332] = −1.18, p = .238), parental education level (t[334] = −1.16, p = .249), ethnicity (χ^2 = 6.88, p = .076), college attendance (t[204] = 1.09, p = .275), and sleep variables (ps > .05).

3.2. Stability of Individual Differences

The correlations across waves for each sleep measure are shown in Table 2. Results suggested significant, but modest shorter-term stability in virtually all sleep parameters between the first two waves of the study. There were fewer significant correlations between the second and third waves of the study, and there was only one significant correlation between the first and third waves of the study, suggesting declining stability of individual differences at later ages and little stability of individual differences across a five-year time span.

3.3. Developmental Trajectories

3.3.1. Weekdays.—As shown in Table 3 (Columns 1 and 2) and Figure 1a and 1b, multilevel growth curve modeling indicated significant, linear declines in weekday sleep duration and efficiency in the years during and after high school. With each passing year, adolescents slept .07 hours less (Year $b = -.07$, $SE = .03$, $p = .004$) and declined 0.38% in their sleep efficiency (Year $b = -.38$, $SE = .09$, $p < .001$) compared to the year before. The significant linear term and non-significant non-linear terms (the latter dropped from the final model) demonstrated that the declines were continuous during and after high school. These linear declines translated into 0.35 hours less weekday sleep and 1.9% less efficiency from the 10th grade (7.43 hrs., 95.51%) to three years post high school (7.08 hrs., 93.61%).

In contrast, sleep latency showed a curvilinear pattern of change over time (Year^2 $b = .46$, $SE = .15$, $p = .003$) (Table 3, Column 3; Figure 1c). Weekday latency declined during high school, reaching a nadir of 8.81 minutes at the 12th grade, then increased in the years after high school.

Females averaged more hours of sleep and greater sleep efficiency on weekdays as compared to males (Table 3, Columns 1 and 2). Asian American youth had shorter sleep duration and Latino youth evidenced longer sleep latency as compared to European American youth (Table 3, Columns 1 and 3). There were no differences in weekday sleep according to parental education (Table 3, Columns 1–3).

3.3.2. Weekends.—In contrast to weekday sleep, few developmental changes in weekday sleep were observed. Weekend sleep duration declined in a linear fashion during and after high school at a similar rate as the weekday decline in duration reported earlier in 3.3.1. (Year $b = -.09$, $SE = .03$, $p = .013$) (Table 3, Column 4; Figure 2). The decline translated into 0.45 hours less sleep from 10th grade (7.54 hrs.) to three-years post high school (7.09 hrs.). Weekend sleep efficiency and latency, however, did not change significantly during and after high school (Table 3, Columns 5 and 6).

As observed during weekdays, females evidenced significantly longer sleep duration and greater sleep efficiency than males on weekends (Table 3, Columns 4 and 5). Those who had parents with higher education averaged shorter sleep duration and latency on weekends (Table 3, Columns 4 an 6). Latino youth had longer weekend sleep latency as compared to European American youth (Table 3, Column 6).

3.3.3. Variability.—Variability in sleep duration across nights increased in a linear fashion during and after high school (Table 3, Columns 7; Figure 3). Each year, adolescents averaged an increase of 1.79 minutes in their nightly variability (Year $b = 1.79$, $SE = .80$, $p = .026$). This trend meant that from the 10th grade to three-years post high school, youth experienced an 8.95-minute increase in nightly sleep variability (52.65 mins. to 61.60 mins.). Variability did not differ according to sex, parental education, or ethnicity.

3.4. Variation by College Attendance

In the second set of models where the Year X College Attendance interaction terms were added along with their lower-order main effect terms, a significant interaction was found for one of the seven dimensions of sleep: weekday latency ($b = -1.55$, $SE = .71$, $p = .028$). As shown in Figure 4, estimation of the slopes by college attendance revealed that the non-linear change in weekday latency reported in 3.3.1. was significant only for non-college attendees ($b = 1.62$, $SE = .62$, $p = .010$), but not for college attendees ($b = .05$, $SE = .33$, $p = .874$). Tests of the group difference in latency at each year further revealed that weekday latency was greater in non-college attendees compared with college attendees starting at the 12th grade ($p = .004$) and continuing in each year after high school (ps = .001).

4. Discussion

During adolescents' high school and post-high school transitional years, modest shorter-term and little longer-term stability of individual differences in sleep were observed. Developmental differences were more evident, especially for weekdays, as five of the seven sleep dimensions changed (weekday duration, efficiency and latency; weekend duration; nightly variability). These developmental changes suggested linearly worsening (shorter, less efficient, and more variable) sleep, with an exception of weekday latency showing a nonlinear, U-shaped trajectory with the lowest latency at the 12th grade. College attendance moderated this weekday latency trajectory, such that the rebound after high school was evident only for youth who did not enroll in college.

These findings contribute to the limited research on sleep during adolescents' transition to young adulthood in five key ways. First, the multiple trajectories of worsening sleep help to clarify past mixed results on whether and how sleep quantity and quality change during this developmental period. Few studies have tracked adolescents' sleep during the transition to young adulthood and yielded mixed results of better [19–21], poorer [19], and stable [22] sleep patterns from high school to post-high school years, questioning the age-related declines in sleep quantity and quality drawn from the larger body of studies with children and adolescents prior to the age of 18 [10–16]. Using actigraphy to trace sleep patterns across six years from 10th grade to three years post high school, we found that youth experienced shorter, less efficient, and more inconsistent sleep over the years.

Moreover, adolescents slept less than the recommended 8–10 hours [38] throughout their high school years, even during the 10th grade when their sleep durations were at their highest (7.43 weekday; 7.54 weekend hours). Adolescents' sleep durations during high school years were comparable to 7.40 hours that were recently reported as normative sleep durations for 15–18 years [12], and continuous declines after high school placed adolescents in this study at only 6.88 weekday and 6.79 weekend hours of sleep by three years post high school. The pervasive and worsening sleep issues throughout the high school and post-high school years raise concerns in light of the widespread reports on poor sleep in adolescents [1], and the known link between poor sleep and a range of developmental risks including diminished mental health [39], physical health [6,40], and academic functioning [2,3]. The worsening sleep during adolescents' transition to young adulthood may have both biological and social basis, such as pubertal maturation that continues well into young adulthood to influence sleep and circadian regulation [13,41] and less regulated schedules that may contribute to poor sleep practice during the transitional years.

The concerns are bolstered given that developmental differences were more evident than individual differences in sleep. Although earlier poor sleepers were more likely to be later poor sleepers in the high school years, poor sleep patterns in the earlier years of high school had nearly no association with youth's post-high school sleep patterns. Thus, initial poor sleepers did not appear to drive the developmental trends of worsening sleep, whereas there seemed to be normative developmental trends of worsening sleep, particularly for weekday sleep. Given that this is one of the few studies to examine the stability of individual differences, these findings need to be replicated by additional studies. Past two longitudinal actigraphy studies suggested more stability of individual differences, but one study was limited to 24 participants [22] while the other study was limited to a one-year time span [20]. Our results from a larger sample and longer timespan suggest that the prevention of sleep problems during young adulthood would need to be delivered at this time and focus specifically on the challenges faced by youth during this unique transitional period.

Second, our study differentiates between weekday and weekend sleep trajectories and suggests that the transition to young adulthood may alter sleep patterns more on relatively rigid days (weekdays) as compared to flexible days (weekends). Over the years, adolescents' weekday demands may significantly increase as they fit more obligations into their rigid weekday schedules [9], whereas their flexible weekend schedules may remain relatively stable [10]. As such, adjusting to the heightened demands of the young adulthood years may jeopardize adolescents' weekday sleep to a greater degree than their weekend sleep.

Nevertheless, both weekday and weekend duration trajectories declined, indicating that obtaining increasingly insufficient amounts of sleep may be a pervasive issue across rigid and flexible days during the years. This set of findings contradicts a past meta-analysis study suggesting that sleep durations decline only for school days but not for non-school days, drawn from 18 cross-sectional studies with children and adolescents using objectively measured sleep [10]. Our findings align with a longitudinal study that reported preliminary patterns of declining weekend sleep durations in late adolescence to young adulthood (15–19 years), although the reports were limited to basic descriptive average sleep duration by age group based on 56 participants [19].

Third, multiple dimensions of sleep trends were examined, extending past focus on duration. Understanding the trajectories of different dimensions of sleep helps to suggest more targeted interventions during adolescents' transition to young adulthood. Notably, intra-individual nightly variability in sleep duration increased from slightly less than an hour at the 10th grade to somewhat over an hour three years post high school. The linear increase suggests that sleep durations become increasingly inconsistent across the high school and post-high school years. Given prior research that found the links between greater sleep variability and indicators of psychosocial [34], physical health [6], and neurodevelopmental [4] issues in adolescents, our study highlights the need to promote consistent sleep practices as well as a healthy amount of sleep.

Latency was another meaningful dimension to study given its conceptual ambiguity. Short latency may signal tiredness and sleep deprivation [24], whereas long latency may indicate difficulty falling asleep in bed [20,25]. Although a recent report suggested that latency less than 30 minutes might be considered appropriate [42], not only excessively long but also short latency should be both unhealthy. In our study, weekday latency stood out as the only sleep dimension that changed nonlinearly over the years. In the U-shaped curve, latency declined from the 10th to 12th grade, then increased in post-high school years. It is possible that greater academic demands of later high school years tire adolescents, leading to increased sleepiness and shorter latency over the high school years [43,44]. At the 12th grade, it took only 8.81 minutes for adolescents to fall asleep, which might indicate excessive short latency resulting from daytime sleepiness. Furthermore, the rebound increase in latency after high school raises the possibility that adolescents may experience less daytime sleepiness once released from rigid high school schedules and academic demands.

Alternatively, the nadir of 8.81 minutes may not be excessively short latency for adolescents [42]. Rather, longer weekday latency in years prior to as well as after the 12th grade may signal relative difficulty falling asleep. To clarify whether the shortest latency of 8.81 minutes at the 12th grade is problematic or normative, future research should examine the ideal amount of latency during adolescence, for instance by finding a value that predicts best developmental outcomes [35].

Fourth, our findings offer insight into whether and how the sleep trajectories differ by college attendance, a key feature that may create divergence in life trajectories. Past longitudinal actigraphy studies during post-high school transitions were limited to college samples [20,22]. In our study, college attendance moderated the curvilinear weekday latency trend, bolstering the possibility that academic demands may be particularly responsible for adolescents' short latency. Starting at the 12th grade, college attendees began to demonstrate shorter latency compared with non-college attendees, a pattern that continued across post-high school years. Preparation for college in the 12th grade followed by continued academic demands in college may contribute to college-attending youth's sleepiness and thus, short latency.

Fifth, we explored ethnic differences in sleep trajectories and found some ethnic differences in a few sleep parameters, contributing to the rising interest in sleep medicine to grasp the role of ethnicity in sleep disparities [45]. Asian American youth's shorter weekday sleep duration compared with European American youth indicates that the issue of insufficient sleep amounts may be highlighted among youth with Asian backgrounds. Similarly, Latino youth's longer latency compared with European American youth suggests that for another ethnic minority group, sleep disparity may be apparent in a different dimension of sleep. It would be important for future research to understand mechanisms that explain specific ethnic differences across multiple dimensions of sleep.

Our study had limitations to be addressed in future research. First, given that our weekday vs. weekend differentiation was a distal proxy for rigid vs. flexible days, future research should examine variables that more closely capture the degree of rigidity and flexibility, such as the actual timing, schedules, and via assessing the type and amount of daily demands. Second, a subset ($n = 209$) of the sample ($N = 343$) provided data for the college vs. no college attendee distinction and the majority (82%) of them were college-attendees, limiting our college attendance findings to a smaller portion of the sample. Given considerable variations in lifestyles of non-college attending youth, it will be meaningful for future studies to focus on this group and identify factors such as work demands and schedules that may shape their sleep patterns. Third, we did not assess puberty, which has sex differences in timing and plays an important role in sleep and circadian regulation [8]. Variations according to pubertal maturation stages and sex should be examined in future research. Fourth, other aspects of sleep such as midpoint sleep, catch-up sleep, and sleep cycle should be investigated in future research.

Examining developmental trends in sleep during adolescence and the transition to young adulthood remains a largely untapped research area. More research using longitudinal designs and actigraphy will advance the understanding of adolescents' sleep trends during this developmental period of biological and social change. Our findings contribute to the field by demonstrating normative developmental changes in multiple dimensions of sleep across high school and post-high school years. Ours is one of the first to shed light on college attendance as a personal feature that may shape limited sleep trajectories. The findings are strengthened by the use of our longitudinal design across six years of adolescence, actigraphy-derived multiple sleep dimensions, and an ethnically diverse and larger sample compared with past research. The developmental trends of worsening sleep during the transition to young adulthood prompt parents, educators, clinicians, and policy makers to consider ways to promote healthy sleep for adolescents, focusing on the specific issues faced by youth at that particular period in their lives.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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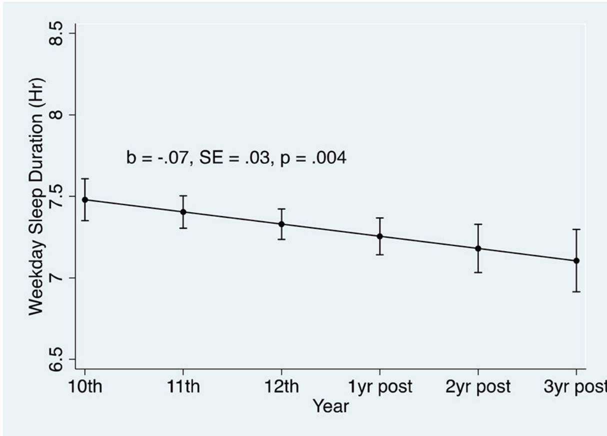
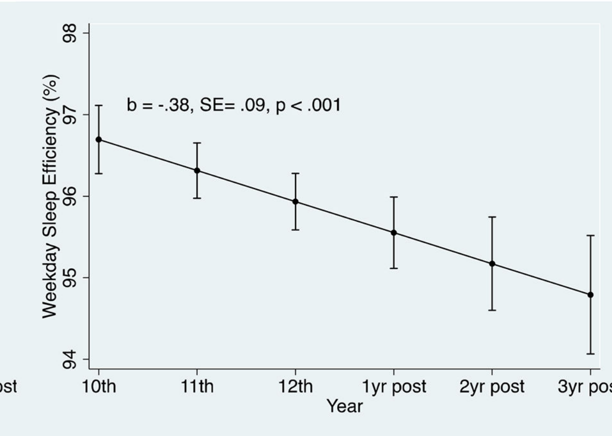
Highlights

- Weekday sleep duration and efficiency declined during and after high school
- Intra-individual variability in duration increased over the years
- College vs. no college adolescents differed in latency trajectories
- Developmental differences were more evident than individual differences in sleep



(a)



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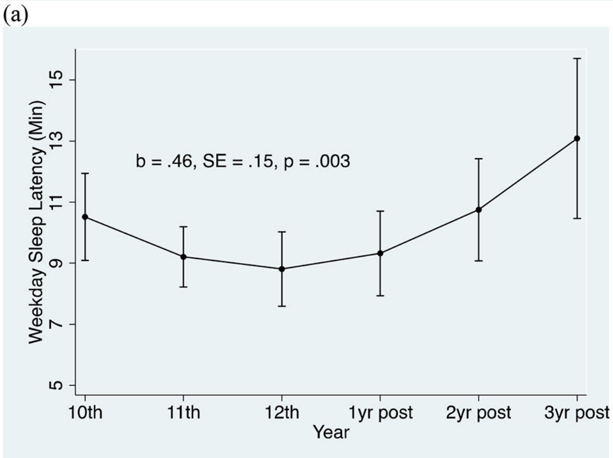

(c)

Figure 1.

Changes in weekday sleep (a) duration, (b) efficiency, and (c) latency during and after high school.

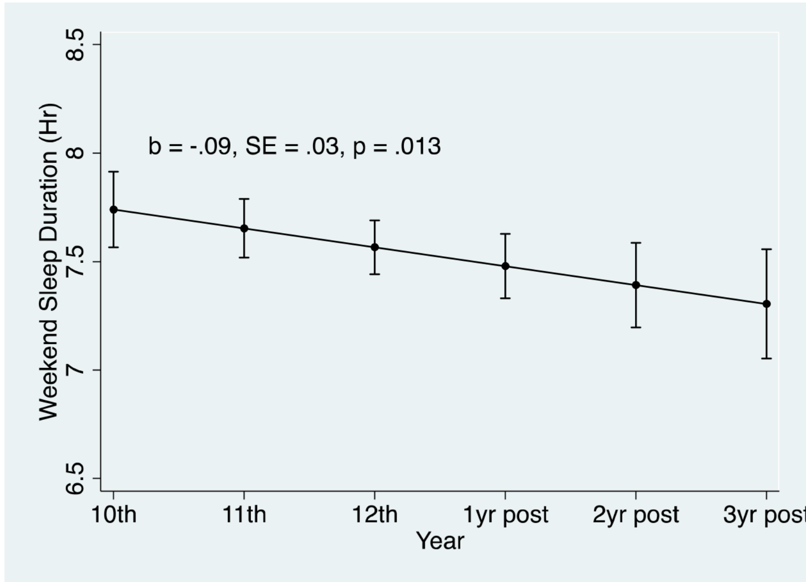

Figure 2.
Change in weekend sleep duration during and after high school.

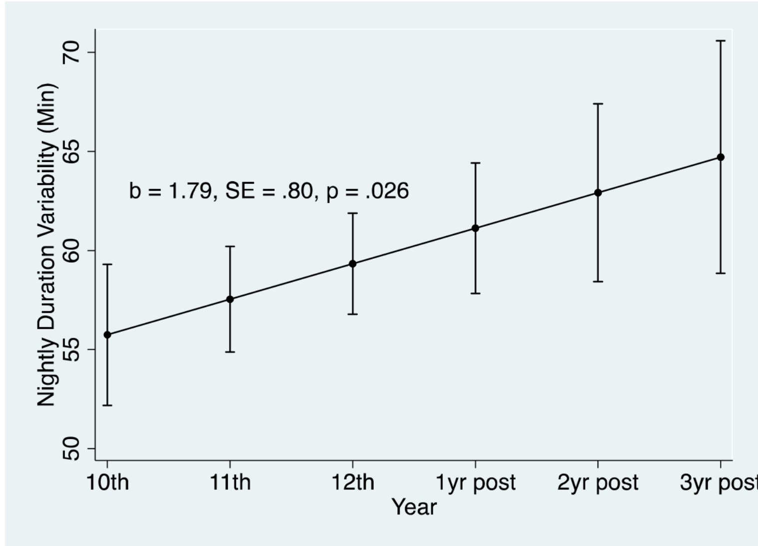

Figure 3.
Change in variability in sleep duration across nights.

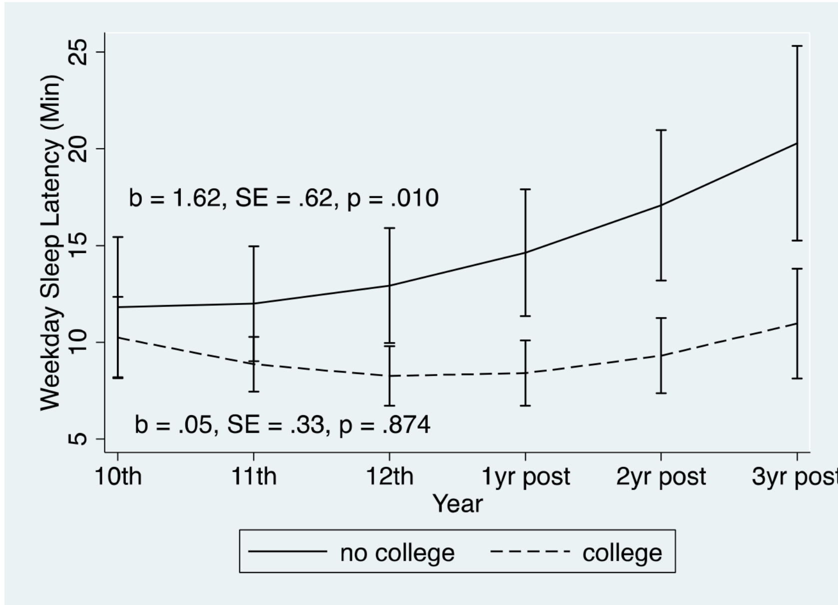

Figure 4.
Change in weekday sleep latency during and after high school according to whether youth attended college after high school.

Table 1

Sleep Descriptive Statistics across Years as High School Grade or Post-High School Length

	10th grade		11th grade		12th grade		1-year post		2-year post		3-year post	
	(*n* = 127–134)		(*n* = 148–154)		(*n*=111–124)		(*n* = 77–90)		(*n* = 68–79)		(*n* = 59–64)	
Sleep dimension	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Weekday duration (hr)	7.56	(0.96)	7.22	(107)	7.27	(115)	7.52	(100)	7.20	(128)	7.16	(121)
Weekend duration (hr)	7.73	(138)	7.61	(138)	7.44	(149)	7.83	(133)	7.34	(166)	7.30	(154)
Weekday efficiency (%)	96.21	(3.97)	96.74	(2.78)	95.82	(4.20)	95.74	(3.98)	94.74	(4.86)	95.54	(3.52)
Weekend efficiency (%)	95.07	(5.87)	96.78	(3.55)	94.72	(5.70)	96.59	(3.97)	94.92	(5.83)	95.04	(5.18)
Weekday latency (min)	11.48	(11.41)	7.92	(7.16)	8.92	(10.03)	9.33	(10.05)	12.80	(15.32)	11.44	(12.14)
Weekend latency (min)	14.92	(18.15)	10.33	(13.23)	12.02	(15.19)	12.03	(16.44)	8.67	(9.91)	10.94	(15.74)
Nightly variability (min)	56.45	(27.47)	58.00	(29.72)	57.01	(28.84)	64.79	(29.93)	61.47	(37.59)	64.69	(37.00)

Note. n = number of observations for each year. The accelerated longitudinal design and two-year data collection intervals resulted in not all participants providing data for each year. Number of observations within each year varies because not every participant provided weekend actigraphy. Given the small observation size, 9th grade ($n = 2$) and 4-year post high school ($n = 3$) observations are not shown here.

Table 2

Correlations between Waves by Sleep Dimension

	Weekday Sleep			Weekend Sleep			Nightly Variability	
	Wave 1	Wave 2		Wave 1	Wave 2		Wave 1	Wave 2
Duration			Duration					
Wave 2	.24**		Wave 2	.32***		Wave 2	.20**	
Wave 3	.17	.32***	Wave 3	.00	.22*	Wave 3	−.05	.11
Efficiency			Efficiency					
Wave 2	34***		Wave 2	.40***				
Wave 3	.15	39***	Wave 3	−.03	.16			
Latency			Latency					
Wave 2	.26***		Wave 2	31***				
Wave 3	.26**	.34***	Wave 3	−.03	.14			

Note.

* $p < .05$,

** $p < .01$,

*** $p < .001$.

Significant correlations in all sleep parameters between the first two waves of the study. Fewer significant correlations between the second and third waves of the study. Only one significant correlation between the first and third waves of the study.

Table 3

Developmental Trajectories by Sleep Dimension

Parameter	Weekday Sleep Duration (hrs.)	Weekday Sleep Efficiency (%)	Weekday Sleep Latency (mins.)	Weekend Sleep Duration (hrs.)	Weekend Sleep Efficiency (%)	Weekend Sleep Latency (mins.)	Nightly Variability (mins.)
	b (SE)	*b (SE)*	*b (SE)*	*b (SE)*	*b (SE)*	*b (SE)*	*b (SE)*
Intercept	7.43 (0.11)***	95.51 (0.40)***	9.71 (1.18)***	7.54 (0.15)***	94.69 (0.66)***	12.14 (1.63)***	52.65 (3.11)***
Year	−0.07 (0.03)	−0.38 (0.09)***	−1.77 (0.75)*	−0.09 (0.03)*	−0.09 (0.18)	−0.68 (0.36)	1.79 (0.80)*
$Year^2$			0.46 (0.15)**				
Sex	0.38 (0.10)***	2.07 (0.34)***	−1.33 (0.95)	0.42 (0.13)**	2.03 (0.42)***	−2.14 (1.37)	4.01 (2.59)
Parent Ed.	−0.02 (0.03)	0.06 (0.10)	−0.45 (0.27)	−0.08 (0.04)*	0.12 (0.12)	−0.87 (0.39)*	−0.97 (0.74)
Asian	−0.41 (0.14)**	0.62 (0.50)	1.89 (1.38)	−0.32 (0.19)	0.29 (0.61)	2.53 (1.97)	5.63 (3.76)
Latino	−0.23 (0.12)	−0.32 (0.43)	2.33 (1.18)*	−0.05 (0.16)	−0.23 (0.50)	3.78 (1.66)*	−0.31 (3.17)
Other	0.07 (0.21)	−0.20 (0.74)	4.07 (2.08)	0.53 (0.28)	−0.43 (0.88)	4.65 (2.95)	−1.67 (5.52)

Note.

* $p < .05$,

** $p < .01$,

*** $p < .001$.

Sex was coded as 0 = male and 1 = female, Parent Education was mean-centered, Ethnicity was dummy-coded with European American as the baseline, and Year was coded with 10th grade = 0 as the referent.