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Adolescent Sleep Duration, Variability, and Peak Levels of Achievement and Mental Health

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To inform public health recommendations for adolescent sleep, the amounts of sleep associated with the highest levels of academic achievement and mental health were examined. The degree to which daily variability in sleep duration represents an underappreciated but functionally significant sleep behavior also was tested. A total of 421 adolescents (M_{age} = 15.03 years) with Mexican-American backgrounds reported nightly sleep times for 2 weeks; approximately 80% repeated the same protocol 1 year later. Multilevel modeling indicated that the amount of sleep associated with the lowest levels of internalizing and externalizing symptoms was more than 1 hr greater than the amount associated with the highest levels of academic performance. Greater daily variability in sleep duration predicted greater symptomatology and mixed academic outcomes.

Despite near-universal professional agreement about the critical importance of sleep for adolescent health and development (Carskadon, 2011; Carskadon, Acebo, & Jenni, 2004; Dahl & Harvey, 2007; Gregory & Sadeh, 2012), the empirical basis for specific public health recommendations for adolescents has been a matter of debate. Historical analyses documenting large changes in recommendations over time have been seen by some as evidence that guidelines are based more on shared opinion than objective evidence, although others have disagreed (Matricciani, Olds, Blunden, Rigney, & Williams, 2012; Owens, 2012). The use of "free-sleep" studies that allow small, select samples of youth to sleep as much as they desire to determine the amount of sleep that adolescents need has been criticized (Eide & Showalter, 2012; Matricciani, Blunden, Rigney, Williams, & Olds, 2013). Observers increasingly have called for a stronger empirical basis for sleep recommendations, particularly studies that focus on functioning by comparing adolescent adjustment across differing amounts of sleep (Blunden & Galland, 2014; Feinberg, 2013; Feinberg & Campbell, 2012; Matricciani et al., 2013).

Given that both low and high sleep durations have been linked with compromised functioning (e.g., lower school performance and higher depression), some have called for studies of "optimal" sleep that examine the nonlinear associations between sleep duration and functioning in order to determine the amount of sleep at which peak functioning is observed (Feinberg, 2013; Matricciani et al., 2013). Along these lines, Eide and Showalter (2012) determined that the highest performance on standardized tests among 16-year-olds was observed among high school students who averaged 7.02–7.36 hr of sleep per night—approximately 1–3 hr less than most commonly promoted recommendations of 8–10 hr (National Sleep Foundation, 2016).

We endeavored to contribute to the critical dialog about sleep guidelines for youth in two distinct ways. First, we wished to examine "optimal" sleep simultaneously for two key aspects of adolescent functioning: academic achievement and mental health. The approximately 7 hours of sleep obtained by the highest achieving students in the study by Eide and Showalter (2012) may come at a cost to mental health, which has been consistently linked

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to sleep (Dahl & Harvey, 2007; Gregory & Sadeh, 2012). Therefore, although we predicted to find a similar curvilinear association between sleep duration and achievement as reported by Eide and Schowalter, we expected the "optimal" level of mental health to be observed among adolescents who slept more than their highest achieving peers. Second, we wished to add the concept of sleep variability—day-to-day intraindividual variation in sleep duration—to the ongoing discussion on sleep recommendations for youth. The almost exclusive focus on sleep duration as the target of clinical guidelines may lead those concerned with adolescent health to neglect a key aspect of sleep behavior that could be just as consequential for functioning (Bei, Wiley, Trinder, & Manber, 2016; Blunden & Galland, 2014). Frequently shifting the circadian rhythm and creating continuous gaps between circadian and sleep–wake cycles have been associated with several physical and psychological difficulties (Fuligni & Hardway, 2006; Levandovski et al., 2011; Wittmann, Dinich, Merrow, & Roenneberg, 2006). As such, we expected greater day-to-day variability in sleep duration to be predictive of poorer functioning above and beyond the average amount of sleep received by youth.

Method

Sample

A total of 421 adolescents (M_{age} = 15.03 years, *SD* = 0.83) were recruited from the 9th and 10th grades of two high schools in the Los Angeles area to participate in a study of Mexican-American families during the 2009–2010 academic year. The final sample represented 63% of the adolescents whose parents were reached by phone and who were deemed eligible to participate by self-reporting a Mexican ethnic background. Using contact information obtained from participants at the first wave of the study, youth were recruited to participate in a second wave of data collection 1 year later. A total of 341 adolescents took part in the second wave of the study (81% of the original sample).

The sample of adolescents was balanced according to gender (50% female) and the majority of the parents reported completing at most some high school education at the first wave of the study (66.7% less than a high school degree, 7.6% high school degree only, 5.5% trade or vocational school, and 18.8% at least some college). Most of the parents were foreign born (82.4%), whereas most of the adolescents were born in the United States (87.2%).

Data from this study were used in a previously published article on the daily concordance between parent and adolescent sleep behaviors (Fuligni, Tsai, Krull, & Gonzales, 2015).

Procedures

All procedures were reviewed and approved by the UCLA Institutional Review Board. Classrooms were randomly selected for home mailings and visits by research staff at different times across the school year, followed up by calls to the families to determine their eligibility (i.e., having Mexican background) and interest in the study. Once families were deemed interested and eligible, interviewers visited families' homes where adolescents completed a self-report questionnaire that assessed various aspects of their adjustment. Primary caregivers (83% mothers, 13% fathers, and 4% other relatives) reported demographic information and provided consent for their adolescents, who in turn provided their own assent. At the end of each school year, adolescents' course grades, standardized test scores, and attendance records were obtained from their official school records.

Adolescents were provided with a set of 14 daily checklists to be completed privately and independently each night before going to bed at each wave of the study. Checklists were three pages long, took 5–10 min to complete, and included questions about nightly sleep. Upon completion, participants folded and sealed the diary checklist, stamping the seal with an electronic time stamper. Interviewers called participants during the 2-week period in order to answer questions and encourage compliance. Diary checklists were picked up from the home at the end of the 2-week period, when adolescents and parents were given $30 for their participation. Additionally, participants were told at the beginning of the study that they would receive an additional incentive of two free movie passes if inspection of the data indicated that the participants had completed the diaries correctly and on time (i.e., before noon on the following day). Compliance was high, with adolescents completing an average of 96% of their potential diaries.

Measures

Sleep

School night sleep duration. We focused on school night sleep duration, as that is the time of greatest restriction of adolescent sleep and is found to be similar to previous studies of "optimal" sleep that focused on weeknight sleep (Eide & Showalter, 2012). As described next, we also included a separate measure of the difference between school night and nonschool night sleep to examine the additive predictive value of sleep on nonschool nights (e.g., weekend).

Sleep duration was the number of hours adolescents' gave in response to the following question on the daily checklist: "How much time did you sleep last night?" The question is typically used in sleep diary studies, and responses are moderately correlated with sleep estimates obtained from more objective methods, such as wrist actigraphy (Gillen-O'Neel, Huynh, & Fuligni, 2012; Lockley, Skene, & Arendt, 1999; Wolfson et al., 2003). In order to minimize errors of estimation, adolescents also responded to two additional questions: "What time did you go to bed last night?" and "What time did you wake up this morning?" Reports to the sleep duration question (i.e., "How much time did you sleep last night") averaged 0.11 and 0.21 hr less than the reported interval between bed and wake times for Waves 1 and 2, respectively, suggesting that youth were reporting the time they believed they actually were asleep. Any report of sleep duration that extended beyond the interval between the reported bed and wake times were recoded to be equal to the duration between the bed and wake time, but that was necessary for only small minority of days (e.g., 10% of days at Wave 1). Sleep durations at Waves 1 and 2 were significantly associated at $r = .32$, $p < .001$.

Official school calendars were referenced to create a dummy-coded school night/nonschool night variable (school night = 0, nonschool night = 1), which was then used to predict nightly sleep in a multilevel model in which both intercepts and slopes were allowed to randomly vary across waves and individuals. Output from this model was used to calculate the empirical best linear unbiased predictor of "average" school night sleep (i.e., the individual-specific intercept at each wave).

School/nonschool night sleep difference. Output from the multilevel model referenced above was also used to calculate the empirical best linear unbiased predictor of the difference between a person's "average" school and nonschool night sleep duration (i.e., the individual-specific slope at each wave). More positive scores indicate greater sleep on nonschool nights. This indicator allowed us to examine whether additional (or less) sleep on nonschool nights (e.g., weekends) provided additional predictive ability of adjustment beyond just school night sleep.

Nightly sleep variability. Variability of the Level 1 residuals from the multilevel model referenced above across a maximum 14 days for each adolescent at each wave was calculated to reflect nightly sleep variability, after accounting for a person's school night/nonschool night difference to remove the effect of that significant structural source of sleep variability from the nightly variability estimate. The indicator was a squared metric of the average number of hours of variability for each adolescent.

Academic Achievement

Grade point average. Official school records were obtained from each school at the end of the academic year of each wave of data collection. Grades were coded (F = 0, D = 1, C = 2, B = 3, and A = 4) and averaged for a composite grade point average (GPA). A majority of students enrolled in similar academic levels (e.g., remedial, regular, or AP/honors) of English, social studies, and science courses (65%–74% were in the same level of courses, with the modal enrollment being a regular level). The levels of mathematics classes varied more across students, as is typical during the high school years, with the modal enrollment being regular levels of Algebra I in 9th grade, geometry in 10th grade, and Algebra II in 11th grade. Grades were not weighted or standardized according to course level because students who enrolled in higher level courses typically earned higher grades than those in the lower level classes. GPA showed high stability between Waves 1 and 2 ($r = .77$, $p < .001$).

Standardized test scores. Students' scores on the California Standards Test in mathematics and English were obtained from official school records. At the time of the study, these tests were administered to all 9th-, 10th-, and 11th-grade students in the state of California to measure student progress toward state standards in mathematics and English language arts. All students at a particular grade level took the same English test, and students took mathematics tests in accord with the specific mathematics course in which they were enrolled (predominantly Algebra I in 9th grade, geometry in 10th grade, and Algebra II in 11th grade). Test scores were moderately stable across Waves 1 and 2 (English: $r = .52$, math: $r = .46$, $ps < .001$).

Attendance. The percent of possible school days that students officially attended school was computed from school records. Attendance percentages at Waves 1 and 2 were significantly associated at $r = .56$, $p < .001$.

Internalizing and Externalizing Symptoms

Adolescents completed the widely used Youth Self-Report form of the Child Behavior Checklist (Achenbach, 1991). Responses (0 = *not true of me*, 1 = *somewhat or sometimes true of me*, 2 = *true or often true of me*) to the 31 items comprising the internalizing subscale (e.g., "I cry a lot," "I worry a lot") and the 32 items comprising the externalizing subscale (e.g., "I break rules at home, school, or elsewhere," "I get in many fights") were summed. The total score, which was a summation of all of the subscales, also was computed. Symptomatology showed moderate stability between Waves 1 and 2 (internalizing: $r = .58$, externalizing: $r = .58$, total: $r = .62$, $ps < .001$).

Results

Attrition Analyses

Adolescents who participated only in Wave 1 had a lower GPA ($M = 1.49$, $SD = 1.11$) and percentage of school attendance ($M = 92.33$, $SD = 8.74$) than peers who took part in both waves ($Ms = 2.24$, 94.29, $SDs = 0.89$, 6.00, respectively), ts (426,409) = −2.85, −2.69, $ps = .005$, .007. Attrition was not related to the sleep indicators, California Standards Test scores, or symptomatology.

Analysis Plan

Given that the question of "optimal" sleep generally centers on contemporaneous associations between sleep and adolescent functioning (Eide & Showalter, 2012; Matricciani et al., 2013), our analyses focused on the cross-sectional associations between sleep estimates for a particular year and academic achievement and mental health during the same year. Our accelerated longitudinal design allowed us to make our estimates across 3 years of high school (9th, 10th, and 11th grades) when sleep restriction increases for adolescents (Carskadon, 2011). Adolescents who began the study in the 9th grade contributed to the 9th- and 10th-grade estimates, and those who began the study in the 10th grade contributed to the 10th- and 11th-grade estimates.

Given the multilevel nature of the data (i.e., waves within individuals), SAS PROC MIXED V9.4 (SAS Institute, Inc., Cary, NC) was used to estimate the associations between the outcomes of interest and the sleep predictors of sleep duration, school night/nonschool night difference, and within-individual variability. The estimation procedure accommodates the missing data inherent in repeated measures designs, allowing for the inclusion of participants with incomplete data. Two-level (i.e., waves nested within individuals) hierarchical models with random intercepts to accommodate correlated errors were conducted for each outcome. Because participants were from only two schools, school was included as a predictor rather than defining a higher level of aggregation in this model. Each of the sleep predictors was centered to avoid issues with multicollinearity and facilitate interpretations.

Descriptive Statistics

Two-level multilevel models with grade and gender were used in order to estimate average levels of sleep, achievement, and symptomatology pooled across both waves of the study. As shown in Table 1, adolescent 9th-grade boys averaged 8.13 hr of sleep per school night, and this declined in the 10th (8.00 hr) and 11th (7.93 hr) grades. The average school night/nonschool night difference in sleep was a little more than 1 hr, and this declined across high school (10th grade: 0.85 hr, 11th grade: 0.60 hr). Taking the square root of the estimate for individual variability in Table 1 indicates that even after accounting for the average school night/nonschool night difference, adolescent 9th-grade boys varied the nightly duration of their sleep an average of 1.40 hr across the 2-week period, and this did not differ across grades. No gender differences were evident in sleep duration and variability.

As shown in Table 2, GPA averaged around the equivalent of a "C" and average test scores fell between the state cutoff of 300 for a "Basic" or limited level of performance and 350 for a "Proficient"

Table 1
Gender and Grade Differences in Sleep Duration and Variability

	School day average		Sch/No sch diff.		Indiv. var.	
	b	*SE*	*b*	*SE*	*b*	*SE*
Intercept	8.13***	0.06	1.10***	0.05	1.95***	0.15
Gender	−0.01	0.06	0.03	0.05	0.20	0.15
10th	−0.13*	0.06	−0.25***	0.05	−0.02	0.16
11th	−0.20**	0.08	−0.50***	0.07	0.08	0.20

Note. Gender is dummy coded 1 = female; 10th and 11th grades are dummy coded with 9th grade as referent group; therefore, the intercept = 9th-grade males; sleep unit for school day average and sch/no sch diff. = hours; sleep unit for Indiv. var. = hours^2. Sch/No sch diff. = School/no school sleep difference; Indiv. var. = individual variability. *$p < .05$. **$p < .01$. ***$p < .001$.

level of performance. Girls evidenced significantly higher GPAs (2.41), lower levels of attendance (92.99%), and higher total (47.49) and internalizing (14.02) Youth Self-Report scores. The only grade differences were the significantly lower mathematics test scores among the 10th- (278.64) and 11th-grade (266.19) students.

Sleep Duration

We first estimated the linear and nonlinear associations of sleep duration with achievement and symptomatology. Linear, quadratic, and cubic terms for sleep duration were used along with gender, grade, school, and parental education as controls. If higher order terms (i.e., quadratic, cubic) were not significant, the models were reestimated without those terms. If cubic trends were found significant, quartic terms were checked, but none were significant. Final models are reported in Table 3. When significant nonlinear associations were observed, partial derivatives of the regression equations were obtained and used to determine the sleep duration values associated with verified relative maxima or minima. Confidence intervals around these sleep duration values were constructed using standard errors produced via delta method approximation of the distribution of the function for the turning points.

In terms of achievement, results indicated nonlinear associations of sleep duration with GPA and English test scores (quadratic and cubic, respectively, Columns 1 and 2). No association was evident for mathematics test scores (Column 3), and a linear, negative association emerged for attendance such that greater sleep was associated with lower attendance (Column 4). Figure 1 displays the nonlinear associations in graphical form, with the achievement measures converted to standard deviation units to allow for comparisons. Additionally, the figure includes the point estimates of amount of sleep at which the highest levels of achievement are observed for the two nonlinear associations (i.e., English test, GPA); these point estimates are also shown in Table 4. Peak performance was evident at a little past 7 hr for English test scores and about 7.5 hr for GPA.

The results for symptomatology are shown in Table 3, Columns 5 through 7. Significant nonlinear associations were observed for total scores (quadratic) and internalizing (cubic), and a marginally significant quadratic trend was evident for externalizing. These results are displayed in Figure 2, with the symptomatology measures converted to standard deviation units. Estimates varied slightly across the indicators, but the amount of sleep associated with lowest levels of symptomatology ranged from 8.75 to 9 hr per school night (also see Table 4).

To better compare the findings for achievement and symptomatology, the results for one measure of each (i.e., GPA and internalizing) are presented together in Figure 3. The figure demonstrates two important differences in the implications of sleep duration for achievement and internalizing symptoms. First, the "optimal" sleep for mental health is more than 1 hr per night than the "optimal" sleep for achievement. Second, the implications of sleep for mental health appear greater, with the sleep duration in Figure 1 accounting for twice the range between the peak and nadir levels of internalizing symptoms (approximately 0.5 *SD*s) as compared to GPA (approximately 0.2 *SD*s). As another way to demonstrate this second point, decreasing sleep from the optimum level for internalizing to the optimum level for GPA results in an approximately 0.2 *SD* rise in internalizing symptoms. In contrast, increasing sleep from the optimum level for GPA to the optimum level for internalizing results in approximately 0.1 *SD* loss in GPA. Additionally,

Table 2
Gender and Grade Differences in Academic Achievement and Symptomatology

	GPA		CST–ENG		CST–MATH		ATTEND		YSR–TOT		YSR–INT		YSR–EXT	
	b	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*
Intercept	2.10***	0.07	331.75***	4.18	302.55***	4.00	94.93***	0.75	42.57***	1.76	10.84***	0.62	12.02***	0.59
Gender	0.31***	0.09	7.22	4.57	−1.78	4.31	−1.94*	0.81	4.92**	2.04	3.18***	0.70	0.35	0.67
10th	−0.09	0.05	−1.79	3.77	−23.91***	3.72	−1.40	0.78	−2.17	1.41	−0.45	0.52	−0.51	0.49
11th	−0.01	0.06	−4.80	4.82	−36.36***	4.86	−1.40	1.07	−3.47	1.84	−0.92	0.67	−0.51	0.64

Note. Gender is dummy coded 1 = female; 10th and 11th grades are dummy coded with 9th grade as referent group; therefore, the intercept = 9th-grade boys. GPA = Grade point average (unweighted); CST–ENG = California Standards Test–English; CST–MATH = California Standards Test–Math; ATTEND = attendance; YSR–TOT = Youth Self-Report–Total score; YSR–INT = Youth Self-Report–Internalizing; YSR–EXT = Youth Self-Report–Externalizing. *$p < .05$. **$p < .01$. ***$p < .001$.

Table 3
Predicting Academic Achievement and Symptomatology From Sleep Duration

Parameter	GPA		CST–ENG		CST–MATH		ATTEND		YSR–TOT		YSR–INT		YSR–EXT	
Fixed effects	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*
Intercept	2.15***	0.12	335.12***	6.31	296.36***	23.55	107.57***	4.42	41.84***	2.75	10.76***	0.97	11.86***	0.91
Av sleep sch-C	−0.05	0.04	−9.34*	4.00	−3.59	2.87	−1.36**	0.53	−3.02**	1.09	−1.84***	0.54	−0.88**	0.37
Av sleep sch-C^2	−0.06*	0.03	−0.26	2.66					1.52 *	0.71	0.80**	0.30	0.50†	0.24
Av sleep sch-C^3			3.36*	1.39							0.35**	0.14		
Gender	0.30***	0.09	5.66	4.87	−2.78	4.64	−2.16**	0.84	3.99†	2.19	2.94***	0.76	0.05	0.72
Grade 10	−0.06	0.05	−4.98	4.13	−25.44***	4.10	−2.52	1.73	−2.50	1.48	−0.55	0.57	−0.65	0.52
Grade 11	0.01	0.08	−9.16	5.62	−37.50***	5.66	−2.14	1.13	−5.79**	2.06	−1.54	0.78	−1.37	0.72
School	−0.15	0.1	5.10	5.06	20.70***	4.83	−1.59†	0.92	3.48	2.10	1.14	0.75	1.31	0.70
Parent ed	0.01	0.02	0.21	0.97	−0.54	0.92	−0.14	0.17	0.08	0.44	−0.04	0.15	−0.01	0.14
Variance components														
Residual int	0.61***	0.06	1,124.78***	178.44	895.94***	170.39	31.24***	5.65	333.08***	35.62	36.72***	4.36	33.39***	3.89
Residual error	0.20***	0.02	1,330.90***	132.50	1,349.22***	139.97	39.27***	4.63	172.26***	16.21	26.25***	2.44	22.16***	2.07

Note. GPA = Grade point average (unweighted); CST–ENG = California Standards Test–English; CST–MATH = California Standards Test–Math; ATTEND = attendance; YSR–TOT = Youth Self-Report–Total score; YSR–INT = Youth Self-Report–Internalizing; YSR–EXT = Youth Self-Report–Externalizing; Av sleep sch-C = school day average sleep (centered; Parent ed = Parental Education; Residual int = Residual Intercept). †$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$.

Table 4 demonstrates how the 95% confidence intervals for GPA and internalizing do not overlap.

Finally, Table 5 shows the percentage of youth in the sample who reported average sleep durations that fell within various time ranges of the estimated optima for achievement and symptomatology. Approximately 24%–27% of the sample reported sleep times that fell within ± 30 min of the estimated optimum for achievement outcomes and 32%–38% had sleep durations that fell within the same range of the optimum for symptomatology.

Follow-up models that included relevant interaction terms indicated that the linear and nonlinear associations of sleep duration with achievement and symptomatology did not significantly vary across gender or grade.

Sleep Variability

The additive predictive ability of sleep variability above and beyond duration was estimated by adding the linear, quadratic, and cubic terms for daily sleep variability to the duration models described above. The difference in duration between school and nonschool nights was also included in the models in order to determine whether daily variability made a difference above and beyond this significant structural source of variability. As stated earlier, if higher order terms (i.e., quadratic, cubic) were not significant, the models were reestimated without those terms. Initial models included the same predictors as those in the duration models shown in Table 3, but nonsignificant predictors were trimmed from the final model that is reported in Table 6.

Sleep variability predicted achievement and symptomatology above and beyond sleep duration for five of the seven indicators (see Table 6). Greater daily variability was linearly associated with higher scores on English tests (Column 2) but lower rates of attendance (Column 4). Daily variability also predicted more symptomatology on all three indicators (Columns 5, 6, and 7). A greater difference between school and nonschool day sleep marginally predicted higher mathematics test scores and significantly predicted better attendance and higher total scores of symptomatology. None of the higher order effects of variability were significant and are not included in the table.

Discussion

Our results indicate that the "optimal" sleep duration differs for different developmental outcomes,

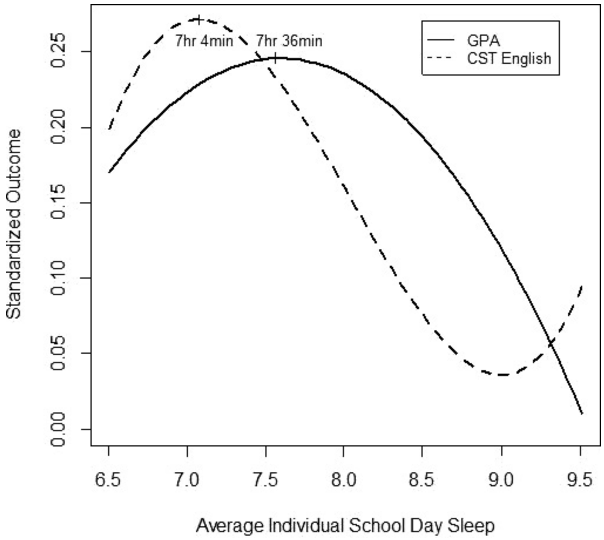

Figure 1. Fitted equation of standardized achievement outcomes GPA and English CST scores as a function of adolescent sleep duration. GPA = grade point average; CST = California Standards Test.

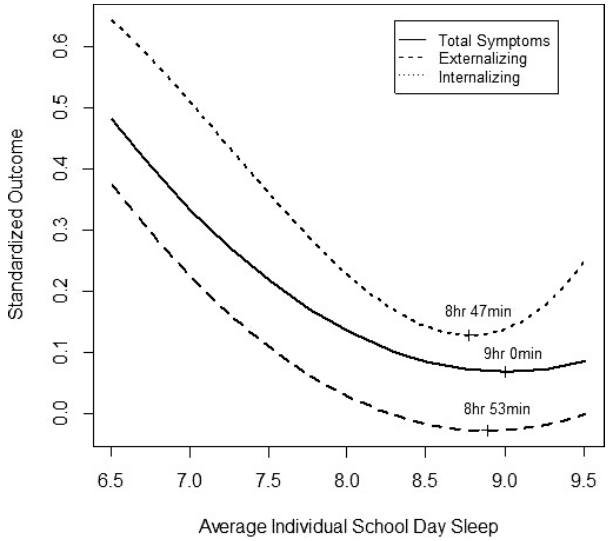

Figure 2. Fitted equation of standardized symptomatology outcomes as a function of adolescent sleep duration.

Table 4

Estimated Sleep Durations for the Highest Levels of Achievement and the Lowest Levels of Symptomatology

	Sleep duration	*SE*	95% CI
Achievement			
GPA	7 hr, 36 min	21 min	6, 55–8, 16
CST–ENG	7 hr, 4 min	16 min	6, 26–7, 35
CST–MATH	N/A		
Attendance	N/A		
Symptomatology			
YSR–TOT	9 hr, 0 min	36 min	7, 51–10, 9
YSR–INT	8 hr, 47 min	11 min	8, 25–9, 8
YSR–EXT	8 hr, 47 min	35 min	7, 46–10, 1

Note. Computations were conducted in the metric of hours and results converted to hours and minutes for ease of interpretation. The 95% confidence intervals (CIs) are presented in the format of "hours, minutes." GPA = Grade point average (unweighted); CST–ENG = California Standards Test–English; CST–MATH = California Standards Test–Math; ATTEND = attendance; YSR–TOT = Youth Self-Report–Total score; YSR–INT = Youth Self-Report–Internalizing; YSR–EXT = Youth Self-Report Externalizing. N/A refers to the absence of a nonlinear association with sleep duration.

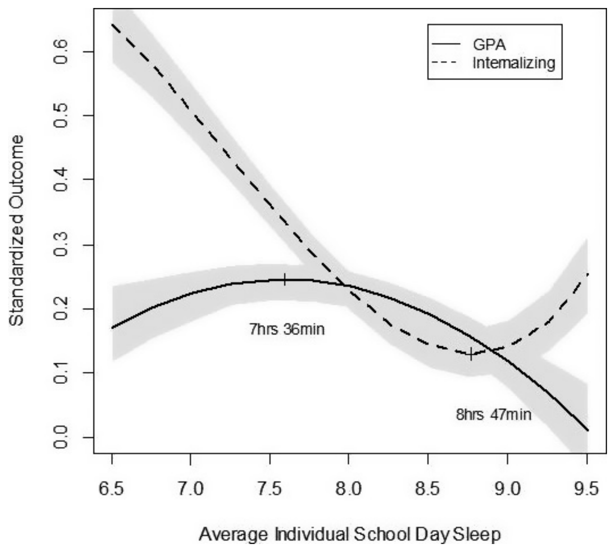

Figure 3. Comparison of standardized grade point average (GPA) and internalizing scores as a function of adolescent sleep duration with a bound of 1 *SE* from the fitted equation.

as suggested by recent observers (Blunden & Galland, 2014; Matricciani et al., 2013). Peak levels of mental health were evident among those averaging 8.75–9 hr per school night, an amount consistent with commonly promoted existing sleep guidelines (National Sleep Foundation, 2016). The highest level of academic performance was evident at sleep durations (7–7.5 hr) about 1 to 3 hr shorter than the guidelines, the same durations observed by Eide and Showalter (2012). Clearly, there are trade offs in the optimal sleep for different aspects of adolescent health and adjustment (Blunden & Galland, 2014; Matricciani et al., 2013). At the same time, it is important to note that our results suggest that reducing sleep for the sake of academic performance may result in a greater decline in mental health than the decline in academic performance resulting from increasing sleep for the sake of mental health. The tighter association of sleep with symptomatology may have been due to both measures being obtained from the same reporter at roughly the same period of time, but the findings suggest mental health may be more sensitive to variations in sleep duration than academic achievement.

Daily variability in sleep duration proved to be consequential for adjustment above and beyond average sleep duration, consistent with some previous research (Bei et al., 2016; Fuligni & Hardway, 2006). Greater variation in sleep time across days predicted greater internalizing and externalizing symptoms, whereas the implications for achievement were fewer and more mixed. The fact that more variable adolescents received both higher English test scores and greater symptoms suggests that these may be high achieving students with somewhat elevated levels of distress, with negative implications for their daily school attendance. The absence of nonlinear associations indicated that more variability had greater implications for adjustment, with no change in the magnitude or direction of the association according to the amount of variability. Findings for the difference between school night and nonschool night sleep, which may be considered an indication of "catch up" sleep on nonschool nights (e.g., weekends), showed similarly mixed associations with a larger difference being associated with greater overall symptomatology but better attendance and marginally higher math test scores.

Table 5
Percentage of Cases With Estimated Sleep Durations Within +/− Minutes of Durations Associated With Highest Achievement and Lowest Symptomatology

	10 min.	15 min.	20 min.	25 min.	30 min.
Achievement					
GPA	3%	13%	17%	22%	27%
CST–ENG	3%	10%	15%	19%	24%
CST–MATH	N/A				
Attendance	N/A				
Symptomatology					
YSR–TOT	4%	15%	20%	26%	32%
YSR–INT	4%	20%	26%	32%	38%
YSR–EXT	4%	18%	23%	30%	35%

Note. GPA = Grade point average (unweighted); CST–ENG = California Standards Test–English; CST–MATH = California Standards Test–Math; ATTEND = attendance; YSR–TOT = Youth Self-Report–Total score; YSR–INT = Youth Self-Report–Internalizing; YSR–EXT = Youth Self-Report–Externalizing. N/A refers to the absence of a nonlinear association with sleep duration.

It is unclear whether our findings may be limited to only youth from Mexican-American backgrounds. Some studies have suggested that Mexican-American adolescents may sleep about one third of an hour more each night than their European-American peers (Fuligni & Hardway, 2006), but a national study did not observe more or less sleep among Hispanic youth (Adam, Snell, & Pendry, 2007). Additionally, our findings regarding achievement closely mirrored those obtained by Eide and Showalter (2012) in a national sample of ethnically diverse youth. Nevertheless, potential group differences in both sleep behaviors and indices of adolescent adjustment such as achievement and symptomatology necessitate the replication of these analyses with adolescents from multiple ethnic and socioeconomic backgrounds. For example, studies reporting that African American youth obtain significantly less sleep than their peers raise the possibility that results may differ for those adolescents (Adam et al., 2007; Matthews, Hall, & Dahl, 2014).

We did not assess the role of pubertal status, which is known to be linked with both sleep patterns and mental health (Dahl & Lewin, 2001). Although we documented official school days, we did not know whether other scheduled events (e.g., medical appointments, extracurricular activities) may have contributed to the variability in sleep times across the days. It also would be important to determine whether our findings generalize to clinical samples of adolescents, who sometimes show different patterns and correlates of sleep indices (Johnson et al., 2007).

We unfortunately did not have actigraphy measures of sleep and do not know whether our sample's diary reports over- or underestimated sleep duration compared to actigraphy. Previous studies have suggested moderate correlations between the two methods during adolescence (e.g., $r = .58$; Matthews et al., 2014), suggesting similarities in the rank ordering of youth for the type of predictive analyses done in this article. Some studies have suggested that diary reports produce higher sleep duration estimates (Arora, Broglia, Pushpakumar, Lodhi, & Taheri, 2013; Matthews et al., 2014; Short, Gradisar, Lack, Wright, & Carskadon, 2012). The difference may be due to higher wake-after-sleep onset (WASO) estimates from actigraphy, which can be difficult for adolescents to report themselves. Yet, the difference also may be due to an overestimation of WASO by actigraphy, even when compared to polysomnography, due to greater movement during sleep among adolescents

Table 6
Predicting Academic Achievement and Symptomatology From Sleep Duration and Variability

Parameter	GPA		CST–ENG		CST–MATH		ATTEND		YSR–TOT		YSR–INT		YSR–EXT	
Fixed effects	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*	*b*	*SE*
Intercept	7	0.07	337.09***	2.68	260.86***	11.13	94.44***	0.61	40.90***	1.58	10.42***	0.55	11.87***	0.35
Av sleep sch-C	−0.05	0.04	−2.63	2.86			−1.27*	0.50	−2.79**	1.06	−1.74**	0.53	−0.96**	0.36
Av sleep sch-C^2	−0.06*	0.03	−4.51*	2.22					1.36*	0.71	0.78**	0.31		
Av sleep sch-C^3											0.35**	0.15		
Sch/No sch av diff-C					7.28†	3.90	1.41*	0.54	2.13*	1.13				
Ind var sleep-C			2.38*	1.13			−0.62**	0.23	1.75***	0.44	0.53***	0.16	0.39**	0.15
Gender (1 = female)	0.33***	0.09					−2.06*	0.81	4.02†	2.15	2.87***	0.75		
School					21.08***	6.61	−1.92*	0.91						
Variance components														
Residual int	0.62***	0.05	1,176.70***	173.42	1,077.84***	231.5	28.06***	5.35	330.88***	34.3	36.06***	4.18	33.25***	3.65
Residual error	0.20***	0.01	1,280.50***	123.95	1,270.03***	178.92	40.46***	4.59	170.71***	15.7	26.19***	2.37	21.18***	1.92

Note. GPA = Grade point average (unweighted); CST–ENG = California Standards Test–English; CST–MATH = California Standards Test–Math; ATTEND = attendance; YSR–TOT = Youth Self-Report–Total Score; YSR–INT = Youth Self-Report–Internalizing; YSR–EXT = Youth Self-Report–Externalizing; Av sleep sch-C = school day average sleep (centered); Sch/No sch av diff-C = school versus no school average difference (centered); Ind var sleep-C = individual sleep variability (centered). All covariates from Table 3 included in initial models, and trimmed if nonsignificant to yield final models. †$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$.

(Johnson et al., 2007; Short et al., 2012). Therefore, the degree to which a lower sleep duration estimate obtained from actigraphy is definitively more accurate than a sleep diary estimate is unclear. This is particularly true for Mexican-American adolescents, for whom there has been little, if any, research comparing the two methods. Continued research on the question of optimal sleep needs to encompass multiple methods of assessment in order to best triangulate on the ranges of sleep durations to inform public health recommendations.

Our somewhat restricted age range likely prevented us from detecting potential age differences in optimal sleep, as was found by Eide and Showalter (2012), with their larger, national sample. Nevertheless, our results for the optimal sleep duration for achievement at this age (around 15 years) among our sample of Mexican-American youth match those obtained in that national sample. We also were able to assess a richer array of outcome measures with strong measurement qualities and our inclusion of GPA adds to previous findings by showing the implications of sleep for students' performance in their actual coursework as well as on standardized tests. Our use of daily reporting of sleep for a 14-day period resulted in more representative measurement of naturalistic sleep duration and allowed us to estimate daily variability in duration, the latter of which is generally unavailable in currently available large-scale surveys. Finally, it should be noted that the cross-sectional associations estimated in our study cannot determine the direction of causality between sleep and adjustment. Yet our analyses do provide valuable information given the lack of studies that experimentally vary the amount of adolescent sleep across a range of durations.

Studies that respond to the call for examining nonlinear associations between sleep and functioning can strengthen the empirical basis for public health recommendations for sleep duration during adolescence (Blunden & Galland, 2014; Feinberg & Campbell, 2012; Matricciani et al., 2013). Such efforts can avoid problematic suggestions that more sleep is always preferable and attainable, providing potentially more realistic sleep targets that are based upon the actual daily lives of youth and their families. At the same time, no single study such as ours should be interpreted as being the definitive source for obtaining an exact amount of optimal sleep for adolescents. Continued research across multiple aspects of adjustment, ages, and populations is necessary before strong conclusions can be made. We suspect that the collective evidence will be consistent with the emergent trend of recommending ranges of sleep durations rather than exact targets (National Sleep Foundation, 2016). Such empirically based ranges could allow adolescents and their families to set goals that fit their daily lives and maximize their functioning across multiple facets of health and adjustment.

In conclusion, efforts to develop sleep guidelines that take into account "optimal" sleep need to consider the possibility that there are trade offs of different amounts of sleep duration for different developmental outcomes. In particular, reductions of sleep for the sake of incremental gains in academic performance could have negative implications for mental health. Additionally, promoting healthy sleep behaviors for the sake of improved mental health should include efforts to minimize the variation in adolescents' sleep duration across their daily life.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Table S1. Means and Standard Deviations for Study Variables by Wave, Grade, and Gender