SLEEPJ, 2019, 1–12

doi: 10.1093/sleep/zsz078
Advance Access Publication Date: 4 April 2019
Original Article

Original Article

What does a good night's sleep mean? Nonlinear relations between sleep and children's cognitive functioning and mental health

Mona El-Sheikh[1,*], Lauren E. Philbrook[2], Ryan J. Kelly[3], J. Benjamin Hinnant[1] and Joseph A. Buckhalt[4]

[1]Department of Human Development and Family Studies, Auburn University, Auburn, AL, [2]Department of Psychological and Brain Sciences, Colgate University, Hamilton, NY [3]Department of Individual, Family, and Community Education, University of New Mexico, Albuquerque, NM and [4]Department of Special Education, Rehabilitation, and Counseling, Auburn University Auburn, AL

Work Performed: Auburn University

*Corresponding author. Mona El-Sheikh, Human Development and Family Studies, 203 Spidle Hall, Auburn University, Auburn, AL 36849-5214. Email: elshemm@auburn.edu.

Abstract

Study Objectives: We attempted to identify the duration and quality of sleep associated with the optimal child outcomes in key developmental domains including cognitive functioning, academic performance, and mental health. In doing so, we examined nonlinear associations between the sleep and developmental variables. Based on racial/ethnic disparities in children's sleep, we assessed this variable as a moderator of examined relations.

Methods: Two hundred eighty-two children participated (M_{age} = 9.4 years, *SD* = .72; 52% boys; 65% white/European American, 35% black/African American). Sleep was examined with actigraphy for seven consecutive nights and with self-reports. Actigraphy-based sleep duration (minutes) and quality (efficiency), as well as self-reported sleep quality were derived. Children reported on their mental health and were administered cognitive performance tests. Mothers and teachers reported on children's mental health; teachers also reported on academic functioning. Schools provided academic achievement data.

Results: Sleep duration had an accelerating nonlinear negative association with externalizing behaviors. Nonlinear associations were also detected between both actigraphy-derived and subjective reports of sleep quality and multiple developmental domains including academic functioning and mental health and the best functioning corresponded with the highest levels of sleep quality. Emphasizing the importance of individual differences, several examined associations were moderated by race/ethnicity.

Conclusions: Sleep duration and quality emerged as nonlinear predictors of multiple domains of child development. Findings illustrate that the benefits of longer and better-quality sleep did not taper off and that assessments of nonlinear relations may enhance understanding of the nature of associations between sleep and child functioning.

Statement of Significance

Examination and identification of what constitutes optimal sleep for various child outcomes is critical yet scarce. This gap in the literature is especially evident when considering objectively derived sleep duration and measurement of sleep quality. Based on actigraphy-based assessment of sleep duration and efficiency as well as subjective sleep problems, findings show that relations between sleep and children's cognitive functioning, academic achievement and mental health are nonlinear. Overall, the benefits of longer sleep duration and better sleep quality do not taper off and continue at an accelerated pace across the full range of sleep duration and quality. Highlighting the importance of examining race/ethnicity, the pattern of associations between sleep and child functioning differed for white/European American and black/African American children.

Key words: sleep; children; actigraphy; cognitive functioning; academic achievement; mental health

Submitted: 1 October, 2018; **Revised:** 23 January, 2019

Introduction

Sleep represents a critical domain of children's health. Among community samples of school-aged children, studies are increasingly establishing that longer sleep duration and better sleep quality relate positively to multiple domains of child adaptation [1, 2]. Despite these advances, open questions remain and debate surrounds the duration and quality of sleep children require for optimum functioning across various adjustment and health domains. Leading scholars and practitioners have provided general guidelines for optimal duration [3] and quality [4]. Based on recommendations by the National Sleep Foundation (NSF) multidisciplinary expert panel [3], a sleep duration between 9 and 11 hr was suggested for school-aged children. These recommendations were based largely on shared opinion and pertain to sleep duration based on reported time in bed (not actual sleep duration that is derived through objective measures). Furthermore, recommendations in the field do not differentiate between the amount of sleep needed for various domains of child functioning [5].

Regarding sleep quality, an expert panel conducted a literature review and made recommendations for what constitutes good sleep quality [4]. For example, a sleep efficiency greater than 85% was considered good quality sleep for school-aged children. Collectively, existing recommendations are not without controversy and empirical examinations conducted to ascertain optimal sleep duration and quality that children need for best levels of functioning across various domains are scarce [5, 6].

This study is consistent with recommendations in the field for conducting empirically based assessments of what may constitute optimal sleep [7]. Our investigation advances the literature by attempting to identify optimal sleep duration and quality parameters associated with primary domains of children's development including cognitive performance [8], academic functioning [9], and mental health [10, 11]. In doing so, we examined nonlinear associations between sleep and child functioning. Similar to others' conceptualizations of this construct [5], we define optimal sleep as the duration or quality required to achieve the best level of cognitive performance, academic achievement, and mental health.

The vast majority of studies investigating links between children's sleep and their development have explored linear associations. This approach assumes that the rate of change in outcomes is equal across all levels of sleep [12]. However, it is plausible that the benefits of longer and better quality sleep may not be evident until, or may taper off at, certain points. Using adult samples, several investigations have demonstrated nonlinear associations between sleep (with most emphasis placed on sleep duration) and multiple outcomes including mental health [13], cognitive functioning [14], and physical health [15]. However, fewer such nonlinear relations have been examined with children and of the existing studies, most emphasis has been placed on children's self-reported sleep duration. For example, in a sample of adolescents (M_{age} = 15.03 years) from Mexican-American backgrounds, nonlinear associations were observed between self-reported sleep duration and externalizing and internalizing behaviors [16]. School-night sleep duration associated with the lowest levels of problem behaviors and symptoms (externalizing, internalizing) ranged between 8.75 and 9 hr. Furthermore, the most optimal academic achievement (GPA and state standardized tests) was observed for youth who obtained between 7 and 7.5 hr of sleep [16]. Findings from this novel study highlight the importance of examining nonlinear effects and multiple outcome domains.

In another study, nonlinear relations between self-reported sleep duration and academic performance on standardized tests were examined in a large sample of 10- to 19-year-olds [17]. Optimal sleep hours associated with the highest levels of performance on several tests were 8.34–8.43 hr for 12-year-olds, and this amount declined with age. Findings indicate that children and adolescents who reported that their sleep duration was below or above this window did not perform as well academically. In one of the few studies to consider school-age children, U-shaped associations between parent-reported child sleep duration and mental health were observed among 9-year-olds [18]. A sleep duration between approximately 9 and 11 hr per night was associated with the fewest internalizing and externalizing behaviors.

Current study

Our primary objective was to determine the duration and quality of sleep that children need for optimal cognitive performance, academic achievement, and mental health. Nonlinear associations between sleep and child outcomes were examined, and multiple sleep parameters were evaluated. Sleep duration was based on actigraphy-based sleep minutes (sleep minutes between sleep onset and morning wake time). Sleep quality was based on actigraphy (efficiency or percentage of the sleep period spent asleep) and self-reports on an established questionnaire (Sleep/Wake Problems scale of the School Sleep Habits Survey [SSHS]) [19]. This scale measures difficulty with falling asleep and waking up in the morning as well as satisfaction with one's sleep. Furthermore, efficiency is a well-established sleep parameter known to be a good index of quality [4, 20]. Given the novelty of research questions and scant pertinent evidence, examinations of nonlinear associations were empirically driven and no hypotheses were proffered.

A secondary objective was to assess whether the putative nonlinear associations were moderated by race/ethnicity (black/African American [AA], white/European American [EA]). Racial/ethnic disparities exist in children's sleep with AAs having shorter and poorer quality sleep than EAs [21]. Furthermore, the extent to which sleep influences children's development is not uniform and varies across racial/ethnic lines. For example, relations between insufficient and poor-quality sleep and children's adjustment may be more robust for AA than EA children [22]. AA children experience race-based stressors, including discrimination, stereotype threat, and prejudice, that increase vulnerability to poor sleep and contribute to disparities in health and achievement [23–25]. It has also been suggested that individual differences (e.g. race/ethnicity) may be related to variability in sleep needs [5, 7, 20]. Thus, it is plausible that what may be considered optimal sleep may vary based on race/ethnicity. In preliminary analyses, we examined socioeconomic status (SES) and gender as potential moderators of relations between the sleep parameters and outcome variables, but no significant effects emerged. To streamline an already complex paper, these variables were not included as moderators in analyses.

Methods

Participants

Participants were drawn from the Auburn University Sleep (AUS) Study. Data collection occurred in 2009–2010. Two hundred eighty-two children and their families were recruited from local elementary schools. According to mothers, children did not have a diagnosis of a learning disability or clinical sleep disorder.

On average, children were 9.4 years old (*SD* = .72); 52% boys, 65% EA, and 35% AA. The racial/ethnic composition of the sample reflects the community from which the participants were recruited. Family income-to-needs ratio (annual family income divided by the poverty threshold with respect to family size [26]) was used to indicate SES. The majority of participants (63%) lived at or below the poverty line (ratio ≤ 2), 28% were lower middle class (ratio > 2 and < 3), and 9% were middle class (ratio ≥ 3).

Procedure

All study procedures were approved by the institution's review board. Parents gave written consent and children provided assent. Actigraphic data were obtained with an actigraph worn on the nondominant wrist for seven consecutive nights during the school year. Following the collection of actigraphy information, families participated in a laboratory visit, during which mothers completed questionnaires, including those regarding children's mental health. Children reported on their subjective sleep problems and mental health with questionnaires and completed cognitive performance testing. The laboratory visit took place shortly after completing the actigraphy assessment (*M* = 3.43 days; *SD* = 8.74). With permission of the families, children's scores on national standardized tests were obtained from their schools, and their teachers completed questionnaires about classroom academic functioning and behavior problems.

Measures

Sleep

Sleep is a multifaceted construct, and therefore in line with recommendations to incorporate assessments of several sleep parameters [27], we examined sleep duration and both objective and subjective indicators of children's sleep quality.

Actigraphy. Children's sleep minutes and efficiency were estimated with Motionlogger Octagonal Basic actigraphs (Ambulatory Monitoring Inc., Ardsley, NY). The actigraph uses an accelerometer to measure movement, and Sadeh's algorithm [28] was used via a computer software package [29] to calculate intervals when the child was awake or sleeping in 1 min epochs using zero-crossing mode. Two sleep parameters were derived: "sleep minutes," defined as the number of epochs scored as asleep between sleep onset and morning wake time; and "sleep efficiency," defined as the percentage of epochs scored as asleep between actigraphy-determined sleep onset and morning wake time. To corroborate the actigraphy data, a research assistant called parents each night of the 7 days of actigraphy data collection to obtain the child's bed- and wake-times as well as medication use. In accordance with established guidelines [30, 31], actigraphy information was only analyzed for children who had 5 or more nights of complete data (87% of the sample, which is similar to rates in the literature). Nights of data collection during which children were given medication for an acute illness (e.g. Benadryl, cough syrup) were not included in the analyses. Good night-to-night stability over the week was observed for both sleep minutes (α = .85) and sleep efficiency (α = .90).

Child Report. Subjective sleep quality was assessed using children's reports on the 10-item Sleep/Wake Problems scale of the School Sleep Habits Survey (SSHS) [19]. Items ask children to report the frequency of multiple sleep problems such as "Needed more than 1 reminder to get up in the morning"; "Had an extremely hard time falling asleep"; and "Fallen asleep in a morning class." Likert response choices range from 1 ("Never") to 5 ("Everyday"). The SSHS has demonstrated good reliability and validity in previous work [32, 33] and the Sleep/Wake Problems scale had adequate internal consistency in the present study (α = .62).

Child functioning

Toward a more comprehensive and methodologically sound assessment of the research question, we examined child functioning using a multimethod and multireporter approach.

Cognitive Performance. Children's cognitive performance was measured in the laboratory using the well-validated and individually administered Woodcock Johnson Tests of Cognitive Abilities (WJ-III) [34, 35]. Brief Intellectual Ability (BIA) scores were derived from this assessment. BIA is a composite score based on tests of Verbal Comprehension (analogies, synonyms & antonyms, vocabulary), Concept Formation (fluid and categorical reasoning), and Visual Matching (perceptual processing). BIA scores are thought to tap into children's crystallized and fluid intelligence. Consistent with prior literature [36, 37], vertically equated item response theory-scaled scores (also known as W scores), which indicate an individual's deviation from a criterion score, were used in analyses.

Academic Achievement. Children's academic achievement was assessed using the Stanford Achievement Test (SAT-10). The SAT is nationally standardized and includes age-normed scores for reading, math, and language skills. Children took the SAT in their classrooms on the same day at the end of the academic school year. Children's scores on the three domains were highly correlated (*r*'s = .75–.79). Thus, to reduce the number of analyses and Type I error risk, and per common practice, the average of children's scores on the reading, math, and language sections was used in analyses.

Teacher-Reported Academic Functioning. Teachers completed the well-established Student Behavior Survey (SBS) [38], which includes questions regarding children's academic performance (8 items) and habits (13 items). Academic performance items ask teachers to rate children's performance relative to their peers in domains such as reading skills, spelling, and mathematics on a 5-point scale ranging from 1 ("Deficient") to 5 ("Superior"). Academic habits concern the frequency with which children show skills such as completing homework assignments and persisting even when an activity is difficult, on a 4-point scale from 1 ("Never") to 4 ("Usually"). The two scales were moderately correlated (r = .58) and consistent with other studies [39] were standardized and summed to create an Academic Functioning scale. The two scales were standardized prior to summing because they were on different response scales. Prior work has demonstrated the validity and reliability of the SBS [38].

Teacher-Reported Mental Health. Teachers reported on children's externalizing behaviors and internalizing symptoms using the SBS. Externalizing behaviors were comprised of three domains: Behavior Problems (15 items, e.g. "Disobeys class or school rules"); Verbal Aggression (7 items, e.g. "Teases or taunts other students"); and Physical Aggression (5 items, e.g. "Hits or pushes other students"). Teachers reported the frequency of these behaviors on a 4-point scale from 1 ("Never") to 4 ("Usually"). Scores in the three domains were highly correlated (rs = .74–.79) and as is common [39], were summed to create one Externalizing Behaviors scale. Internalizing symptoms were measured via the Emotional Distress scale (15 items; e.g. "Appears sad or unhappy"). Teachers reported the frequency of these behaviors on the same 4-point scale as externalizing behaviors.

Mother-Reported Mental Health. Children's functioning varies across school and home contexts and a multiinformant approach can provide a more thorough assessment of children's mental health [40]. Thus, in addition to teachers' reports, mothers also reported on children's externalizing and internalizing behaviors. The Personality Inventory for Children-2 (PIC-2) was used, which parallels the SBS completed by teachers. The Externalizing composite assesses problems such as aggression, impulsivity, disruptive behavior, delinquency, and noncompliance. The Internalizing composite comprises depression, anxiety, fear, worry, and psychosomatic symptoms. Prior work has demonstrated the test–retest reliability, inter-rater reliability, and discriminant and construct validity of the two scales [41, 42].

Covariates

Mothers reported on child race/ethnicity, sex, family income, and the number of people living in the household (for calculating income-to-needs ratio, which was used to index SES). To reduce potential confounds, and towards conservative assessment of the research questions, child race/ethnicity and SES were covaried in all analyses. Child sex was also considered as a covariate but was not significantly associated with any outcome variable and thus was excluded from analyses.

Statistical analysis

Regression models were conducted to examine whether linear or quadratic terms for the sleep variables (minutes, efficiency, and subjective sleep problems) or interactions between the linear and quadratic effects with the potential moderator (race/ethnicity) predicted each of the cognitive and mental health outcome variables. SES was also entered into all models. Consistent with common practice for examining quadratic effects, linear effects were represented by entering the mean-centered sleep variables into the models; quadratic terms were created by squaring the mean-centered sleep variables. When both significant linear and quadratic effects were detected in a model, the linear effect was lower-order and was subsumed under the quadratic effect and therefore the latter was interpreted. All predictor variables were mean-centered to facilitate interpretation of the intercepts and to minimize multicollinearity between the predictors and interaction terms [43]. We were particularly interested in determining the values of the sleep variables at which the outcome variables were the most optimal (e.g. maximum values for academic and cognitive variables; minimum values for adjustment variables). Therefore, we plotted the interaction effects at the highest values within the data set for sleep minutes (585) and sleep efficiency (99%), and at the lowest value for subjective sleep problems (10). The graphs represent predicted values for the outcome variables rather than actual values. For significant interaction effects, confidence intervals were derived and included in the figures to aid in determining significant differences in conditional intercepts between AA and EA children. Significant differences (p < .05) are indicated where confidence intervals do not overlap; however, overlapping confidence intervals do not necessarily mean that there is not a significant difference in outcomes [44]. Therefore, post hoc tests of differences in conditional intercepts were conducted for AA and EA children in cases where there was a small amount of overlap in confidence intervals using change in chi-square difference tests. Specifically, the conditional intercept for AA children was constrained to be equal to that of EA children and the chi-square difference with one degree of freedom was determined to evaluate whether the intercepts were significantly different at low, average, or high values for the sleep parameters. Significant differences are denoted with asterisks (*) in the figures. Analyses were conducted in Mplus [45], which uses full information maximum likelihood (FIML) estimation to handle missing data. Compared with other methods for dealing with missing data, such as list-wise or pair-wise deletion, and imputation, FIML has been found to produce the least biased estimates and lowest Type I error rates [46, 47].

Results

Means, standard deviations, and correlations among study variables are presented in Table 1. High-leverage values for the sleep variables that were more than 4 SD from the sample mean (one for sleep minutes, five for sleep efficiency) were replaced with the next highest value [48]. There were no outliers more than 4 SD from the sample means for the outcome variables. Skewness values for all main study variables were <2.0, indicating that the variables were relatively normally distributed. T-tests were conducted to examine differences across study variables by race/ethnicity (Table 2). Bonferroni correction was applied to adjust for multiple comparisons (p < .05/10 tests = p < .005). Compared with EA children, AA youth reported more subjective sleep problems, had lower cognitive performance (BIA) and academic achievement (SAT) scores, and were reported by their teachers as having lower academic functioning and more externalizing behaviors. On average, children's actigraphy-derived sleep onset was at 9:39 pm (SD = 47 min) and wake time was at 6:16 am (SD = 34 min), indicating that average sleep duration was 8 hr and 37 min (SD = 40 min) per night.

Sleep minutes

The first set of regression models tested whether linear and quadratic terms for sleep minutes, or the interactions between the sleep minutes terms and the potential moderator (race/

Table 1. Bivariate correlations, means, and standard deviations for main study variables and covariates

	1	2	3	4	5	6	7	8	9	10	11	12
1. Race/ethnicity												
2. SES	−.40***											
3. Sleep minutes	−.12*	.14**										
4. Sleep efficiency	−.03	.13*	.79***									
5. Subjective sleep probs.	.30***	−.21***	−.06	.06								
6. BIA scores	−.25***	.25***	.01	.11*	−.11*							
7. SAT scores	−.22***	.24***	.01	.07	−.23***	.77***						
8. Academics (T)	−.25***	.30***	.15*	.18**	−.18**	.51***	.65***					
9. Externalizing (T)	.27***	−.32***	−.13*	−.14*	.14**	−.27***	−.31***	−.61***				
10. Internalizing (T)	.12*	−.20***	−.03	.02	.08	−.21***	−.19**	−.50***	.54***			
11. Externalizing (M)	.05	−.08	−.08	−.10	.12*	−.21***	−.18**	−.36***	.36***	.24***		
12. Internalizing (M)	−.01	−.07	−.16**	−.07	.13**	−.20***	−.15**	−.22***	.09	.28***	.51***	
M	–	1.72	458.31	88.60	18.98	494.57	641.36	0.00	37.05	22.82	49.41	50.26
SD	–	1.04	56.17	7.09	5.23	10.34	41.71	1.78	12.59	7.86	8.67	8.81
Range	–	.34–4.37	228.67–584.86	61.41–99.09	10.00–35.00	457.00–521.00	545.33–771.67	−5.73–2.84	27.00–80.00	15.00–47.00	38.00–81.00	39.00–81.00

SES = socioeconomic status; Probs. = problems; SAT = Stanford Achievement Test; Academics = academic functioning; T = teacher-report; M = mother-report. Race/ethnicity was coded as 0 = white/European American and 1 = black/African American.
$^{*}p < .10$; $^{**}p \le .05$; $^{***}p < .01$.

Table 2. Descriptive information by race

	White/European American	Black/African American		
	M (*SD*)		t-test	P
Sleep minutes	462.95 (58.90)	449.21 (49.45)	1.82	.070
Sleep efficiency	88.74 (7.37)	88.33 (6.53)	.43	.672
Subjective sleep probs.	17.83 (4.80)	21.12 (5.34)	−5.12	.000
BIA Scores	496.43 (9.96)	491.02 (10.17)	4.17	.000
SAT Scores	647.75 (43.08)	628.67 (35.86)	3.19	.000
Academics (T)	.32 (1.61)	−.60 (1.94)	3.62	.000
Externalizing (T)	34.60 (9.85)	41.61 (15.60)	−3.46	.001
Internalizing (T)	22.12 (7.42)	24.13 (8.52)	−1.76	.081
Externalizing (M)	49.11 (8.17)	49.96 (9.52)	−.74	.459
Internalizing (M)	50.32 (8.99)	50.16 (8.52)	.14	.887

Probs. = problems; SAT = Stanford Achievement Test; Academics = academic functioning; T = teacher-report; M = mother-report.

ethnicity) predicted children's cognitive functioning and mental health. There were four significant effects (Table 3). First, there was a linear effect demonstrating an association between more sleep minutes and higher teacher-reported academic functioning. Together, the predictors explained a significant amount of variance in academic functioning, $R^2 = .12$, $p < .05$. A negative linear relation between sleep minutes and teacher-reported externalizing behaviors was also detected and was modified by a significant quadratic effect. Sleep minutes had an accelerating, negative curvilinear association with teacher-reported externalizing behaviors (Figure 1). Conditional intercepts for externalizing behaviors were very similar at average (7.63 hr; externalizing = 36) and shorter (−2.25 *SD*, 5.52 hr; externalizing = 36) sleep duration, but were much lower when sleep duration was longer (+2.25 *SD*, 9.75 hr; externalizing = 26). Externalizing behaviors were .79 *SD* lower at longer compared with shorter sleep duration. A significant amount of variance in externalizing behaviors was explained by the model, $R^2 = .12$, $p < .05$. Finally, there was a significant linear effect showing a negative relation between sleep minutes and mother-reported internalizing symptoms. However, the overall model did not explain a significant proportion of variance in internalizing symptoms, $R^2 = .04$, $p > .05$. There were no significant interactions between linear or quadratic sleep minutes and race/ethnicity.

There were no significant linear, quadratic, or interaction effects for the sleep minutes terms predicting BIA scores, SAT scores, teacher-reported internalizing symptoms, or mother-reported externalizing behaviors (Supplementary Table S1).

Sleep efficiency

The second set of regression models were identical to the first, except that linear and quadratic effects for sleep efficiency replaced sleep minutes. There were several significant main and interaction effects (Table 4). Sleep efficiency had positive linear and quadratic effects on cognitive performance (BIA) scores. The positive linear relation between sleep efficiency and BIA performance was modified by the positive quadratic effect and the quadratic sleep efficiency x race/ethnicity interaction (Figure 2a). For AA children, sleep efficiency showed an accelerating, positive curvilinear relation with cognitive functioning, $p < .01$. For EA children, the association between sleep efficiency and

Table 3. Estimates for regression models showing linear and nonlinear effects for child sleep minutes on cognitive and adjustment variables

	Teacher-reported academic functioning	Teacher-reported externalizing	Mother-reported internalizing
	Estimate (*SE*)		
Intercept	.23(.12)	36.32** (.81)	49.93** (.58)
Race/ethnicity	−.23 (.15)	1.03 (.96)	−.13 (.69)
SES	.35** (.13)	−2.72** (.88)	−.41 (.63)
Sleep minutes	.33* (.17)	−2.30* (1.09)	−1.46* (.74)
Sleep minutes^2	.14 (.17)	−2.43* (1.16)	−.29 (.79)
Sleep minutes × race/ethnicity	−.02 (.17)	−1.23 (1.14)	.47 (.76)
Sleep minutes^2 × Race/ethnicity	.20 (.20)	−1.50 (1.31)	−.41 (.89)
R^2	.12* (.05)	.12* (.05)	.04 (.03)

Unstandardized parameter estimates and standard errors are reported. Race/ethnicity was coded as 0 = white/European American and 1 = black/African American.
*$p \leq .05$; **$p < .01$.

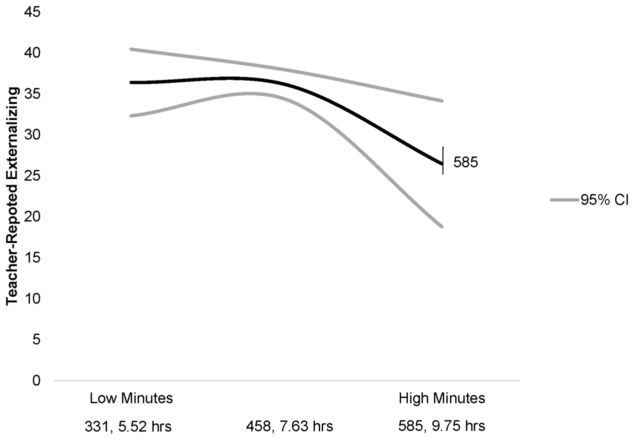

Figure 1. Quadratic effect for minutes^2 predicting teacher-reported externalizing behaviors. CI = confidence interval. The x-axis range is ± 2.25 *SD* (maximum range of the data) for sleep minutes.

cognitive functioning was not significant. The difference in BIA scores at low and high levels of sleep efficiency was equivalent to 1.25 *SD* for AA and .40 *SD* for EA children.

As shown in Figure 2a, the greatest disparities between AA and EA children in cognitive performance were seen at low (−1.5 *SD*, 78%; BIA scores = 490 for AAs, 495 for EAs) and average (89%; BIA scores = 492 for AAs, 497 for EAs) levels of sleep efficiency. At high levels of sleep efficiency, in contrast, conditional intercepts for AA children were greater than those of EA children (+1.5 *SD*, 99%; BIA scores = 503 for AAs, 499 for EAs). Therefore, EA children were estimated to score .50 *SD* higher than AA children at both low and average levels of sleep efficiency, but AA children were predicted to score .34 *SD* higher than EAs at high levels of sleep efficiency. Post hoc tests indicated that the conditional intercepts for AA's were significantly lower than those for EA's at low and average levels of sleep efficiency, but the difference between them was not significant at high-sleep efficiency. The overall model predicted a significant amount of variance in BIA scores, $R^2 = .15$, $p < .01$.

There was also a significant linear relation between children's sleep efficiency and SAT scores, which was modified by a quadratic interaction for sleep efficiency x race/ethnicity, $p = .055$. For AA children, there was a positive, accelerating curvilinear association with SAT scores (Figure 2b), $p < .05$. The association between sleep efficiency and SAT scores was not significant for EA children. The difference in SAT scores at low and high levels of sleep efficiency corresponded to .90 *SD* for AA children and .26 *SD* for EAs. Figure 2b suggests that racial/ethnic disparities in SAT scores existed at low (−1.5 *SD*, 78%; SAT scores = 630 for AAs, 642 for EAs) and average (89%; SAT scores = 634 for AAs, 651 for EAs) levels of sleep efficiency. At high levels of sleep efficiency, however, SAT score conditional intercepts for AA children were higher than those of EA children (+1.5 *SD*, 99%; SAT scores = 663 for AAs, 653 for EAs). EA children were predicted to score .30 *SD* higher than EA children on the SAT at low levels of sleep efficiency and .40 *SD* higher at average sleep efficiency, but at high-sleep efficiency, AAs were estimated to score .25 *SD* higher than EAs. Follow-up tests indicated that the conditional intercepts for EAs and AAs were not significantly different at low- or high-sleep efficiency, but the intercepts were significantly higher for EA's at average sleep efficiency. The overall model explained a significant amount of variance in SAT scores, $R^2 = .11$, $p < .01$.

Additionally, teacher-reported academic functioning was predicted by the linear effect of sleep efficiency and the quadratic sleep efficiency x race/ethnicity interaction. For AA children, sleep efficiency showed a positive curvilinear accelerating association with teacher-reported academic functioning (Figure 3a), $p < .05$. For EA children, the association between sleep efficiency and teacher-reported academic functioning was not significant. The difference in academic functioning scores at low and high levels of sleep efficiency was equivalent to 1.15 *SD* for AA and .56 *SD* for EA children.

As displayed in Figure 3a, this meant that the greatest disparities between children from the various racial/ethnic groups were seen at average (89%; Academic Functioning = −.25 for AAs, .46 for EAs) levels of sleep efficiency. At low-sleep efficiency, AA and EA children were rated similarly for academic functioning (−1.5 *SD*, 78%, Academic Functioning = −.67 for AAs, −.14 for EAs). High levels of sleep efficiency, in contrast, seemed to play a protective role against lower levels of academic functioning for AAs (+1.5 *SD*, 99%; Academic Functioning = 1.38 for AAs, .86 for EAs). In other words, EA children were estimated to outperform AA children on academic functioning by .30 *SD* and .40 *SD* at low and average levels of sleep efficiency, respectively. However, at high levels of sleep efficiency, AAs were estimated to outperform EAs by .30 *SD*. Follow-up tests indicated that the conditional intercepts for EAs and AAs were only significantly different at average levels of sleep efficiency, and not at high or low. The model explained a significant proportion of variance in academic functioning, $R^2 = .16$, $p < .01$.

Table 4. Estimates for regression models showing linear and nonlinear effects for child sleep efficiency on cognitive and adjustment variables

	BIA scores	SAT scores	Teacher-reported academic functioning	Teacher-reported externalizing
	Estimate (*SE*)			
Intercept	495.36*** (.62)	646.21*** (2.84)	.23** (.12)	36.38*** (.92)
Race/ethnicity	−5.34*** (1.60)	−18.21** (7.58)	−.76** (.31)	4.00** (2.07)
SES	1.36** (.65)	5.42* (2.85)	.30** (.12)	−2.30*** (.79)
Sleep efficiency	.42*** (.12)	1.20** (.57)	.07*** (.02)	−.44*** (.16)
Sleep efficiency^2	.02*** (.01)	.04 (.03)	.00* (.00)	−.02** (.01)
Sleep efficiency × race/ethnicity	.41 (.26)	.87 (1.21)	.05 (.05)	−.63* (.33)
Sleep efficiency^2 × race/ethnicity	.04** (.02)	.14** (.07)	.01** (.00)	−.04 (.02)
R^2	.15*** (.05)	.11*** (.05)	.16*** (.05)	.15*** (.05)

Unstandardized parameter estimates and standard errors are reported. BIA = Brief Intellectual Ability; SAT = Stanford Achievement Test. Race/ethnicity was coded as 0 = white/European American and 1 = black/African American; sex was coded as 0 = female and 1 = male.
*$p < .06$; **$p \leq .05$; ***$p < .01$.

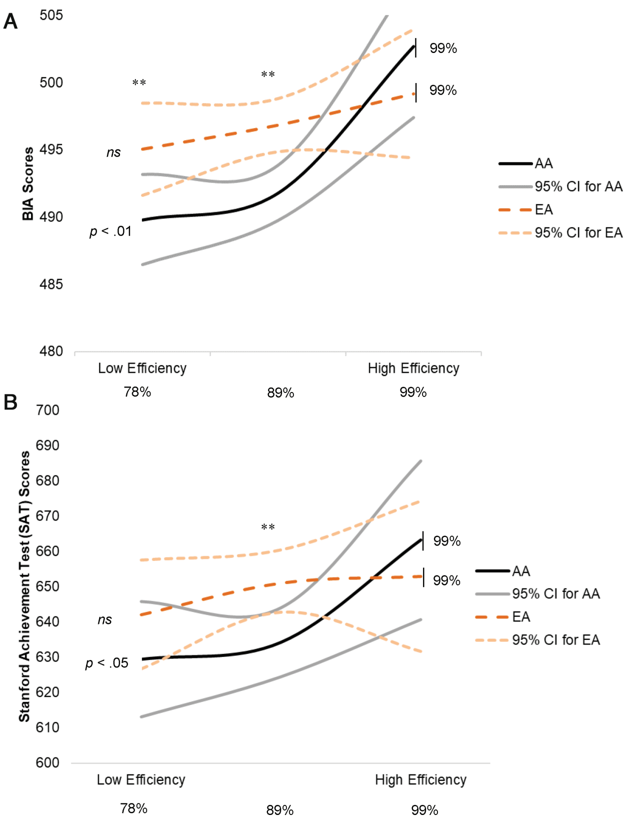

Figure 2. Quadratic interaction effects for sleep efficiency^2 x race/ethnicity predicting (a) BIA and (b) Stanford Achievement Test (SAT) scores. EA = white/European American; AA = black/African American; CI = confidence interval. The x-axis range is ± 1.5 *SD* (maximum range of the data) for sleep efficiency. *$p < .05$; **$p < .01$.

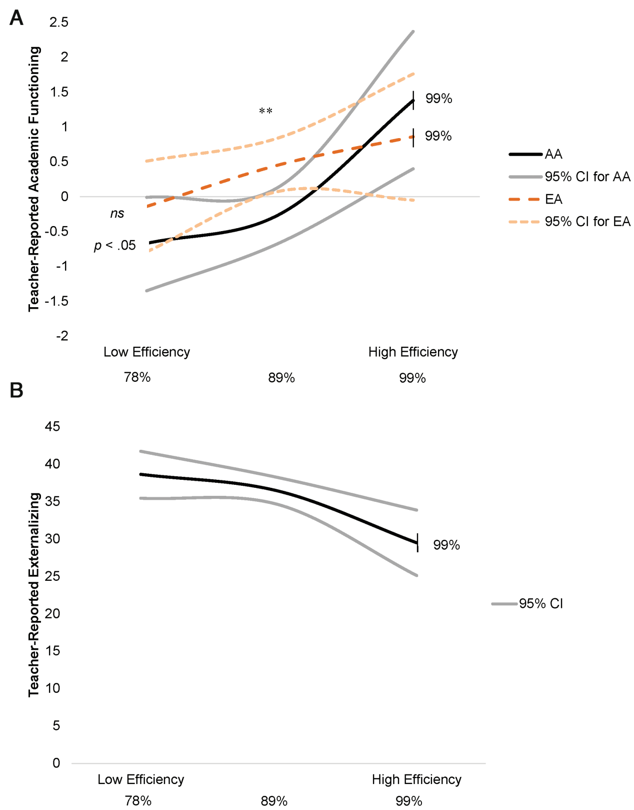

Figure 3. (a) Quadratic interaction effect for sleep efficiency^2 x race/ethnicity predicting teacher-reported academic functioning and (b) quadratic effect for efficiency^2 predicting teacher-reported externalizing. EA = white/European American; AA = black/African American; CI = confidence interval. The x-axis range is ± 1.5 *SD* (maximum range of the data) for sleep efficiency. *$p < .05$

Furthermore, sleep efficiency had linear and quadratic effects on teacher-reported externalizing behaviors (Figure 3b). The negative linear relation was modified by the negative quadratic effect such that sleep efficiency had an accelerating, negative curvilinear association with externalizing behaviors. No interaction effects emerged for this association. The conditional intercepts for teacher-reported externalizing behaviors were slightly lower at average (89%; externalizing = 36) in comparison to lower (−1.5 *SD*, 78%; externalizing = 39) levels of sleep efficiency. However, externalizing behaviors were much lower (externalizing = 29) at higher levels of sleep efficiency (+1.5 *SD*, 99%). The difference in teacher-reported externalizing behaviors at low and high levels of sleep efficiency corresponded to .73 *SD*. The model explained a significant amount of variance in externalizing behaviors, $R^2 = .15$, $p < .01$.

There were no significant linear, quadratic, or interaction effects for the sleep efficiency terms predicting teacher-reported

Table 5. Estimates for regression models showing linear and nonlinear effects for subjective sleep problems on cognitive and adjustment variables

	SAT scores	Teacher-reported internalizing	Mother-reported internalizing
	Estimate (*SE*)		
Intercept	645.70*** (3.49)	23.33*** (.67)	50.32*** (.55)
Race/ethnicity	−3.44(7.71)	.58 (1.46)	1.09 (1.50)
SES	6.53** (2.81)	−1.19** (.55)	−.55 (.58)
Sleep problems	−1.08 (.61)	.15 (.12)	.21 (.13)
Sleep problems [2]	−.15** (.08)	−.03* (.02)	.04** (.02)
Sleep problems X Race/ethnicity	1.53 (1.36)	−.05 (.27)	−.17 (.29)
Sleep problems [2] X Race/ethnicity	−.19 (.17)	.01 (.03)	−.07** (.03)
R^2	.13*** (.05)	.07* (.04)	.08** (.03)

Unstandardized parameter estimates and standard errors are reported. Sleep problems = sleep/wake problems; SAT = Stanford Achievement Test. Race/ethnicity was coded as 0 = white/European American and 1 = black/African American.
*$p < .06$; **$p \le .05$; ***$p < .01$.

internalizing or mother-reported externalizing or internalizing symptoms (Supplementary Table S2).

Subjective sleep problems

The final set of regression models examined relations between children's subjective sleep problems and their cognitive functioning and mental health (Table 5). The quadratic relation between subjective sleep problems and SAT scores was significant. The association between subjective sleep problems and SAT scores was initially flat and became increasingly negative as sleep problems increased (Figure 4a). Thus, the conditional intercepts for SAT scores were nearly identical at low (−1.75 *SD*, 10; SAT score = 644) and average (19; SAT score = 646) levels of sleep problems. However, SAT scores were much lower (SAT score = 624) at higher levels of sleep problems (+1.75 *SD*, 28). The difference in SAT scores between children with low and high levels of sleep problems was .48 *SD*. A significant proportion of variance in SAT scores was explained, $R^2 = .13$, $p < .01$.

The quadratic effect for teacher-reported internalizing symptoms approached conventional levels of statistical significance ($p = .058$) such that there was a negative, accelerating curvilinear association between subjective sleep problems and internalizing symptoms (Figure 4b); we chose to interpret the trend given the scarcity of such information in the field. The conditional intercepts for internalizing symptoms were similar at average (19; internalizing = 23.33) and higher (+1.75 *SD*, 28; internalizing = 22.45) levels of sleep problems. Internalizing symptoms were lower (19.74) at lower levels of sleep problems (−1.75 *SD*, 10). The difference in internalizing symptoms scores at low and high levels of sleep problems corresponded to .34 *SD*. A marginally significant amount of variance in teacher-reported internalizing symptoms was explained by the model, $R^2 = .07$, $p = .058$.

There were several effects for mother-reported internalizing symptoms (Figure 5). Sleep problems had a significant quadratic effect and a significant quadratic x race/ethnicity interaction effect. As shown in the figure, the association between sleep problems and internalizing symptoms showed a clear accelerating curvilinear effect for EA children only, $p < .01$. EAs had fewer internalizing symptoms at low (−1.75 *SD*, 10; internalizing = 52) and average (19; internalizing = 49) levels of sleep problems compared with high levels of such problems (+1.75 *SD*, 28; internalizing = 55).

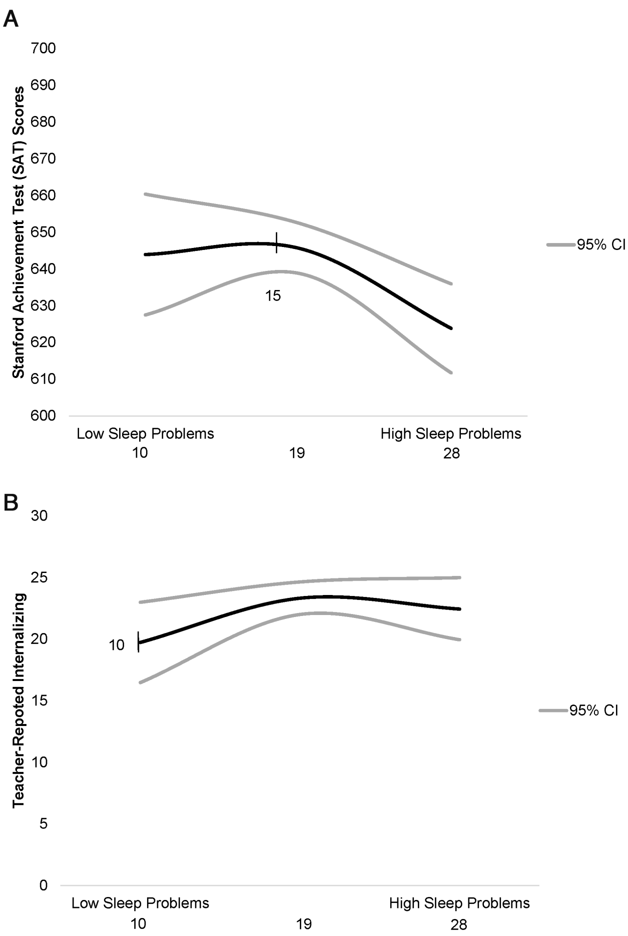

Figure 4. Quadratic effect for subjective sleep problems² predicting (a) average Stanford Achievement Test (SAT) scores and (b) teacher-reported internalizing (trend level association). CI = confidence interval. The x-axis range is ± 1.75 SD (maximum range of the data) for sleep problems.

In contrast to findings with EA children, there were no significant associations between AA children's reported sleep quality and mother-reported internalizing symptoms. For AA children, conditional intercepts for internalizing symptoms were very similar across low (−1.75 *SD*; 10; internalizing = 49), average (19; internalizing = 50), and high (+1.75 *SD*, 27; internalizing = 51) levels of sleep problems. The difference between conditional intercepts for internalizing symptoms at low and high levels of sleep problems was .26 *SD* for EAs and .16 for AAs. The intercepts for EAs were .36 and .47 *SD* higher than the intercepts for AAs at low and high levels of sleep problems, respectively. However, at average levels of sleep problems, the intercepts for the two groups were nearly identical (difference of .11 *SD*). Follow-up tests indicated that the conditional intercepts for EAs and AAs were significantly different at high levels of sleep efficiency, but not low or average. The overall model explained a significant amount of variance in internalizing symptoms, $R^2 = .08$, $p < .05$.

There were no significant linear, quadratic, or interaction effects for the sleep problems terms predicting BIA scores, teacher-reported academic functioning and externalizing behavior, or mother-reported externalizing symptoms (Supplementary Table S3).

Summary of findings

In Table 6, we summarize the models run, for which models there were significant effects, and the nature of these effects (linear, nonlinear, and nonlinear interaction). Overall, the table shows that there were seven linear effects, six nonlinear effects, and four nonlinear interactions with race. Sleep efficiency was more frequently associated with the outcome variables, relative to sleep minutes and sleep problems. With regard to outcomes, the largest number of significant effects was for the teacher-reported externalizing behaviors variable.

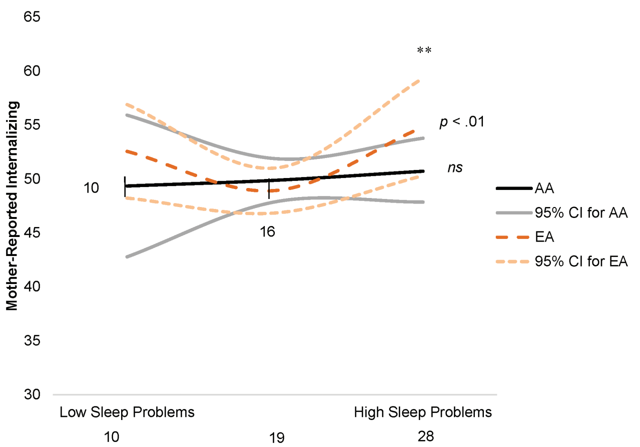

Figure 5. Quadratic interaction effect for subjective sleep problems^2 x race/ethnicity predicting mother-reported internalizing symptoms. EA = white/European American; AA = black/African American; CI = confidence interval. The x-axis range is ± 1.75 *SD* (maximum range of the data) for sleep problems. Internalizing values are represented in T-scores. ***p* < .01.

Discussion

What constitutes optimal sleep for various child functioning domains has become an important research question. Addressing this issue, we investigated nonlinear associations between sleep duration and quality and several primary domains of development among school-aged children (10-year-olds). A nonlinear negative association emerged between sleep duration and externalizing behaviors, and several nonlinear associations were detected between sleep quality and cognitive performance, academic achievement, and mental health. The findings provide new insight into what may constitute optimal sleep during this developmental period. Furthermore, supportive of the importance of assessments of race/ethnicity, moderation analyses indicated that varying levels of sleep quality may be needed to achieve optimal daytime functioning for EA and AA children.

Although empirical studies are scarce, there is increasing recognition of the importance of examining nonlinear relations between sleep and child functioning [5, 7, 20]. Of the few existing studies, the examination of nonlinear associations between subjective reports of children's sleep duration and their daytime functioning has provided novel understanding of optimal sleep duration for various outcomes [7, 17, 18]. Expanding on existing evidence, our findings supportive of nonlinear effects are based on multiple self-report and actigraphy-derived sleep parameters and address several critical child functioning variables.

Actigraphy-derived sleep duration shared an accelerating nonlinear association with teacher-reported externalizing behaviors. Conditional intercepts for externalizing behaviors were slightly higher at average (7 hr and 38 min) in comparison to lower levels of sleep duration (−2.25 *SD*: 5 hr and 31 min). However, externalizing behaviors decreased at a rapid pace between average and longer sleep duration (+2.25 *SD* from the mean; 9 hr and 45 min) and the lowest level of externalizing behaviors was observed at 9 hr and 45 min. This finding illustrates the continued positive influence of sleep duration on mental health. Recommendations in the field suggest that 9 to 11 hr be allotted to time spent in bed [3] and researchers recently discovered that the lowest level of externalizing behavior occurred in this window [18]. Our findings are generally consistent with these

Table 6. Summary of significant linear and nonlinear effects

	BIA scores	SAT scores	Teacher-reported academic functioning	Teacher-reported externalizing	Teacher-reported internalizing	Mother-reported externalizing	Mother-reported internalizing
Sleep minutes			7. Linear	10. Linear 11. Nonlinear			15. Linear
Sleep efficiency	1. Linear 2. Nonlinear 3. Nonlinear x race	4. Linear 5. Nonlinear x race	8. Linear 9. Nonlinear x race	12. Linear 13. Nonlinear			
Sleep problems		6. Nonlinear			14. Nonlinear (trend)		16. Nonlinear 17. Nonlinear x race

Sleep problems = sleep/wake problems; BIA = Brief Intellectual Ability; SAT = Stanford Achievement Test.

recommendations, yet differ in that the optimal levels of sleep in our sample are based on actual sleep time.

Our findings regarding sleep duration and mental health are not entirely consistent with another study that addressed this question with 15-year-olds from Mexican American backgrounds [16]. The authors reported that optimal self-reported sleep duration associated with the lowest levels of externalizing problems was almost 9 hr, which is lower than 9.75 hr of actual sleep that we found with our sample. In the only other study that we are aware of that examined nonlinear relations between 9-year-olds' sleep duration and externalizing behaviors, a U-shaped curve was observed with children who slept the shortest or longest durations having the highest levels of externalizing difficulties. Furthermore, the optimal parent-reported sleep duration associated with the lowest levels of child- and primary caregiver-reported externalizing problems was 9–10 hr. Of note is that the shape of the nonlinear trajectories reported so far in this small literature varies (e.g. U-shaped or accelerating) and we expect that clarity will not be achieved without substantial growth in studies that assess nonlinear associations. Many factors including age, sample characteristics, and various methodologies employed to examine sleep and adjustment may underlie the discrepancies.

In terms of sleep quality parameters, actigraphy-derived sleep efficiency shared an accelerating nonlinear negative association with teacher-reported externalizing behaviors. Conditional intercepts for externalizing behaviors were slightly higher at lower (−1.5 *SD* from the mean, 78%) in comparison to average levels of sleep efficiency (89%). However, highlighting the continued importance of sleep quality across the spectrum, externalizing behaviors decreased at an accelerated pace between average and high levels of sleep efficiency (+1.5 *SD*, 99%) and the lowest level of externalizing behaviors was observed at a sleep efficiency of 99%. Thus, the benefits of sleep efficiency did not taper off. The larger number of significant effects for sleep efficiency relative to sleep minutes is consistent with some literature [22, 49, 50] and may suggest that poor sleep efficiency disrupts neurodevelopment and deep sleep [51] and causes mental fatigue to a larger extent than reduced sleep duration. Evidently, this is a tentative proposition that should be probed further in future studies towards explication of children's development in the context of sleep problems. Recently endorsed NSF guidelines suggest that a sleep efficiency ≥85% indicates "good sleep quality" [4]; however, our findings indicated that peak levels of mental health and cognitive performance were evident at the highest end of sleep efficiency (99%). As this area of study grows with children from various backgrounds, additional findings will further inform whether optimal development across various domains indeed aligns with current sleep quality recommendations.

In addition to actigraphy-derived sleep quality, nonlinear associations were detected for subjective measures of sleep problems. Academic achievement as assessed by the SAT-10 was high and similar for children who reported both low and average levels of sleep problems. However, children who had the worst academic achievement were those with the highest levels of sleep problems in the sample. Similarly, children with the lowest levels of sleep problems had the fewest internalizing symptoms, based on teacher reports. However, those with average and high levels of such sleep problems tended to have similar and relatively high levels of internalizing symptoms. The benefits of subjective sleep quality were most evident at the highest end of the continuum with fewer distinctions between sleep at the lower and average levels. We are not aware of any studies that examined nonlinear associations between sleep quality and child adjustment and thus comparisons are not possible. Overall, the nature of relations between sleep and children's development should not be assumed as linear and assessments of quadratic effects are encouraged to further explicate the pattern of associations.

Race/ethnicity emerged as an important moderator of nonlinear associations between sleep quality and multiple developmental variables. For example, the nature of relations between sleep efficiency and children's cognitive performance as measured by the BIA differed across racial/ethnic lines. Overall, 3 of the 4 moderation effects show that lower and average levels of sleep efficiency are associated with worse outcomes (cognitive performance, academic achievement, and teacher-reported academic functioning) for AAs in comparison to EAs. However, accelerating curves associated with increasing sleep efficiency from average (89%) to high (99%) were observed only for AAs.

Although the literature is far from conclusive and is relatively recent with children, other findings from our lab show that AAs are more negatively affected by poor sleep than EAs [22] and at the same time, as the present findings show, may benefit more from better sleep. As illustrated in the interaction effects, the fewer significant associations between the sleep and outcome variables that emerged for EAs compared with AAs support this premise, although these results require further replication before any firm conclusions can be made. Vulnerability to poor sleep for AA children may stem from exposure to race-based social stressors, which have been found to contribute to racial/ethnic health and achievement disparities [23, 25]. Although our findings are consistent with others documenting racial/ethnic differences in children's sleep [21, 52, 53], a majority of the nonlinear findings were not moderated by race/ethnicity and thus optimal sleep was the same across all children. Factors that may influence differences in the sleep of children based on their race/ethnicity are not well-understood. Subcultural factors including sleep routines and schedules (e.g. napping), race-related stress, and the sleep environment (e.g. dwelling) need to be examined to explicate why such differences may emerge.

Although much evidence supported significant relations between sleep and children's developmental outcomes, some of the tested models produced null effects. For example, neither sleep minutes nor sleep efficiency shared associations with teacher-reported internalizing symptoms or mother-reported externalizing behavior. Viewing children in the classroom, teachers may be more aware of externalizing behavior relative to mothers and also may be better equipped to compare the child's behavior with that of other children. Mothers, on the other hand, may be more attuned to their individual child's internalizing behavior. However, these null effects are still difficult to interpret, especially given that such associations have been reported as significant many times in the literature [39, 50, 54]. Multiple factors including statistical power and the amount of variance (i.e. range) in primary study variables may also underlie in part the null effects. Furthermore, some trends and significant relations between children's subjective sleep quality and various developmental outcomes observed at the bivariate correlation level were nonsignificant in main analyses. Although critical for clarifying relations between children's sleep and development, the inclusion of influential covariates may have affected the results. Of course, interpretation of null findings is difficult and ought to be done within the confines of sample characteristics and study methods.

The interpretation of the findings needs to occur in the context of several study features and limitations. The sample is composed of 10-year-old children and it is probable that the amount of sleep needed for optimal functioning varies across development [17]. Whether the nonlinear association between sleep quality and the various mental health and cognitive outcomes varies with age is unknown. Subjective sleep problems were based on a measure with sound psychometric properties that tap into difficulty initiating and maintaining sleep, difficulty waking up, and satisfaction with one's sleep. Although the items on this scale are similar to many that examine subjective sleep quality, one cannot generalize to all such measures. Additionally, it is possible that other characteristics of this community sample, including the locale, race/ethnicity, low SES composition, the generally subclinical levels of adjustment problems, and the normative levels of cognitive and academic functioning may have bearing on the findings. As this area of inquiry expands, comparing findings across samples with various demographics is warranted. Likewise, identifying what constitutes optimal sleep is needed for other sleep parameters (e.g. regularity of sleep schedule and duration) and child outcome domains. Lastly, the models explained relatively low to moderate amounts of variance in the outcome variables. It is plausible that a higher amount of variance would be accounted for in samples with clinically significant sleep and adjustment problems. Acknowledging these limitations, the findings provide new insight into what may constitute optimal sleep in childhood and demonstrate the importance of considering individual differences.

Supplementary Material

Supplementary material is available at *SLEEP* online.

Funding

This research was supported by National Institutes of Health grant R01-HL093246 awarded to Mona El-Sheikh. The content is solely the responsibility of the authors and does not necessarily reflect the official views of the National Institutes of Health

Acknowledgments

We wish to thank our research laboratory staff for data collection and preparation, as well as the children, parents, teachers, and schools who participated.
Conflict of interest statement. None declared.

References

1. Lo JC, *et al*. Cognitive performance, sleepiness, and mood in partially sleep deprived adolescents: the need for sleep study. *Sleep*. 2016;**39**(3):687–698.
2. Shochat T, *et al*. Functional consequences of inadequate sleep in adolescents: a systematic review. *Sleep Med Rev*. 2014;**18**(1):75–87.
3. Hirshkowitz M, *et al*. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health*. 2015;**1**(1):40–43.
4. Ohayon M, *et al*. National Sleep Foundation's sleep quality recommendations: first report. *Sleep Health*. 2017;**3**(1):6–19.
5. Matricciani L, *et al*. Children's sleep needs: is there sufficient evidence to recommend optimal sleep for children? *Sleep*. 2013;**36**(4):527–534.
6. Feinberg I. Recommended sleep durations for children and adolescents: the dearth of empirical evidence. *Sleep*. 2013;**36**(4):461–462.
7. Fuligni AJ, *et al*. Individual differences in optimum sleep for daily mood during adolescence. *J Clin Child Adolesc Psychol*. 2017;1–11.
8. Könen T, *et al*. Cognitive benefits of last night's sleep: daily variations in children's sleep behavior are related to working memory fluctuations. *J Child Psychol Psychiatry*. 2015;**56**(2):171–182.
9. Dewald JF, *et al*. The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: a meta-analytic review. *Sleep Med Rev*. 2010;**14**(3):179–189.
10. Kelly RJ, *et al*. Reciprocal relations between children's sleep and their adjustment over time. *Dev Psychol*. 2014;**50**(4):1137–1147.
11. McMakin DL, *et al*. Sleep and anxiety in late childhood and early adolescence. *Curr Opin Psychiatry*. 2015;**28**(6):483–489.
12. Cohen J, *et al*. *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*. 3rd ed. Mahwah, NJ: Lawrence Erlbaum Associates Publishers; 2003.
13. Zhai L, *et al*. Sleep duration and depression among adults: a meta-analysis of prospective studies. *Depress Anxiety*. 2015;**32**(9):664–670.
14. Kronholm E, *et al*. Self-reported sleep duration and cognitive functioning in the general population. *J Sleep Res*. 2009;**18**(4):436–446.
15. Buxton OM, *et al*. Short and long sleep are positively associated with obesity, diabetes, hypertension, and cardiovascular disease among adults in the United States. *Soc Sci Med*. 2010;**71**(5):1027–1036.
16. Fuligni AJ, *et al*. Adolescent sleep duration, variability, and peak levels of achievement and mental health. *Child Dev*. 2018;**89**(2):e18–e28.
17. Eide ER, *et al*. Sleep and student achievement. *East Econ J*. 2012;**38**(4):512–524.
18. James S, *et al*. Sleep duration and child well-being: a nonlinear association. *J Clin Child Adolesc Psychol*. 2017;**46**(2):258–268.
19. Wolfson AR, *et al*. Sleep schedules and daytime functioning in adolescents. *Child Dev*. 1998;**69**(4):875–887.
20. Blunden S, *et al*. The complexities of defining optimal sleep: empirical and theoretical considerations with a special emphasis on children. *Sleep Med Rev*. 2014;**18**(5):371–378.
21. Guglielmo D, *et al*. Racial/ethnic sleep disparities in US school-aged children and adolescents: a review of the literature. *Sleep Health*. 2018;**4**(1):68–80.
22. Philbrook LE, *et al*. Sleep and cognitive functioning in childhood: ethnicity, socioeconomic status, and sex as moderators. *Dev Psychol*. 2017;**53**(7):1276–1285.
23. Gee GC, *et al*. A life course perspective on how racism may be related to health inequities. *Am J Public Health*. 2012;**102**(5):967–974.
24. Heissel JA, *et al*. Stress, sleep, and performance on standardized tests: understudied pathways to the achievement gap. *AERA Open*. 2017;**3**(3):1–17.
25. Levy DJ, *et al*. Psychological and biological responses to race-based social stress as pathways to disparities in educational outcomes. *Am Psychol*. 2016;**71**(6):455–473.

26. Commerce USDo. How the Census Bureau measures poverty. 2009. https://www.census.gov/topics/income-poverty/poverty/guidance/poverty-measures.html. Accessed December 1, 2009.
27. Sadeh A. Iii. Sleep assessment methods. *Monogr Soc Res Child Dev.* 2015;**80**(1):33–48.
28. Sadeh A, *et al*. Activity-based sleep-wake identification: an empirical test of methodological issues. *Sleep.* 1994;**17**(3):201–207.
29. ActionW. *ActionW user's guide (Version 2.4)*. Ardsley, NY: Ambulatory Monitoring, Inc.; 2002.
30. Acebo C, *et al*. Estimating sleep patterns with activity monitoring in children and adolescents: how many nights are necessary for reliable measures? *Sleep.* 1999;**22**(1):95–103.
31. Meltzer LJ, *et al*. Use of actigraphy for assessment in pediatric sleep research. *Sleep Med Rev.* 2012;**16**(5):463–475.
32. Carskadon MA, *et al*. Reliability of six scales in a sleep questionnaire for adolescents. *Sleep Research.* 1991;**20**:421.
33. Wolfson AR, *et al*. Evidence for the validity of a sleep habits survey for adolescents. *Sleep.* 2003;**26**(2):213–216.
34. McGrew KS, *et al*. *Woodcock–Johnson III technical manual*. Itasca, IL: Riverside Publishing Company; 2001.
35. Woodcock RW, *et al*. *Woodcock–Johnson tests of achievement*. Itasca, IL: Riverside Publishing; 2001.
36. McArdle JJ, *et al*. Comparative longitudinal structural analyses of the growth and decline of multiple intellectual abilities over the life span. *Dev Psychol.* 2002;**38**(1):115–142.
37. Tucker-Drob EM. Differentiation of cognitive abilities across the life span. *Dev Psychol.* 2009;**45**(4):1097–1118.
38. Lachar D, *et al*. *Student behavior survey (SBS) manual*. Los Angeles, CA: Western Psychological Services; 2000.
39. El-Sheikh M, *et al*. Sleep disruptions and emotional insecurity are pathways of risk for children. *J Child Psychol Psychiatry.* 2007;**48**(1):88–96.
40. De Los Reyes A, *et al*. The validity of the multi-informant approach to assessing child and adolescent mental health. *Psychol Bull.* 2015;**141**(4):858–900.
41. Lachar D, *et al*. *Personality inventory for children: second edition (PIC-2)*. Los Angeles, CA: Western Psychological Services; 2001.
42. Wirt RD, *et al*. *Personality inventory for children-revised*. Los Angeles, CA: Western Psychological Services; 1990.
43. Allison PD. *Multiple regression: a primer*. Newbury Park, CA: Pine Forge Press; 1999.
44. Ramsey FL, *et al*. *The Statistical Sleuth: a course in methods of data analysis*. Belmont, CA: Duxbury Press; 2002.
45. Muthén LK, *et al*. *Mplus Version 7 user's guide*. Los Angeles, CA: Muthén & Muthén; 2012.
46. Raykov T. Analysis of longitudinal studies with missing data using covariance structure modeling with full-information maximum likelihood. *Struct Equ Modeling.* 2005;**12**(3):493–505.
47. Enders CK, *et al*. The relative performance of full information maximum likelihood estimation for missing data in structural equation models. *Struct Equ Modeling.* 2001;**8**(3):430–457.
48. Barnett V, *et al*. *Outliers in statistical data*. Vol. **3**. New York: Wiley; 1994.
49. Gruber R, *et al*. Sleep efficiency (but not sleep duration) of healthy school-age children is associated with grades in math and languages. *Sleep Med.* 2014;**15**(12):1517–1525.
50. Sadeh A, *et al*. Sleep, neurobehavioral functioning, and behavior problems in school-age children. *Child Dev.* 2002;**73**(2):405–417.
51. Philip P, *et al*. Sleep fragmentation in normals: a model for sleepiness associated with upper airway resistance syndrome. *Sleep.* 1994;**17**(3):242–247.
52. Matthews KA, *et al*. Sleep in healthy black and white adolescents. *Pediatrics.* 2014;**133**(5):e1189–e1196.
53. Bates CR, *et al*. Sleep is in for summer: patterns of sleep and physical activity in urban minority girls. *J Pediatr Psychol.* 2016;**41**(6):692–700.
54. Bélanger MÈ, *et al*. Sleeping toward behavioral regulation: relations between sleep and externalizing symptoms in toddlers and preschoolers. *J Clin Child Adolesc Psychol.* 2018;**47**(3):366–373.