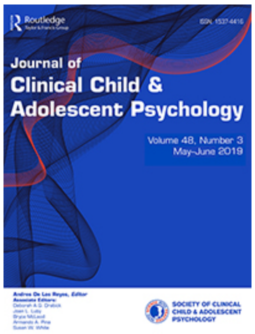

Journal of Clinical Child & Adolescent Psychology

ISSN: 1537-4416 (Print) 1537-4424 (Online) Journal homepage: https://www.tandfonline.com/loi/hcap20

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To cite this article: Andrew J. Fuligni, Sunhye Bai, Jennifer L. Krull & Nancy A. Gonzales (2019) Individual Differences in Optimum Sleep for Daily Mood During Adolescence, Journal of Clinical Child & Adolescent Psychology, 48:3, 469-479, DOI: 10.1080/15374416.2017.1357126

To link to this article: https://doi.org/10.1080/15374416.2017.1357126

Published online: 18 Aug 2017.

Journal of Clinical Child & Adolescent Psychology, 48(3), 469–479, 2019

ISSN: 1537-4416 print/1537-4424 online
DOI: https://doi.org/10.1080/15374416.2017.1357126

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SLEEP AND DEVELOPMENTAL PSYCHOPATHOLOGY

Individual Differences in Optimum Sleep for Daily Mood During Adolescence

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Efforts to establish an empirical basis for recommended sleep durations during adolescence need to take into account individual differences in optimum sleep, defined as the amount of sleep at which peak functioning is observed. A total of 419 adolescents (M_{age} = 15.03 years) with Mexican American backgrounds reported their nightly sleep duration and daily mood for a 2-week period at 1 or 2 waves of data collection, 1 year apart. Adolescents also completed an established measure of symptomatology. Multilevel modeling revealed a nonlinear association between sleep duration and next-day mood, whereby both too little and too much sleep were associated with elevated levels of daily distress. Significant individual differences in optimum sleep were observed such that younger adolescents and those with elevated levels of internalizing and total symptomatology evidenced greater sleep durations on nights before they reported their lowest levels of daily distress. Younger adolescents and those with higher internalizing and total symptomatology may need more sleep to reach their peak functioning the next day, at least in terms of daily mood.

INTRODUCTION

The years of adolescence present particular challenges to healthy sleep habits, with the maturationally driven tendency to go to bed and wake up at later hours hitting against the increasingly early school-start times of middle and high school (Carskadon, 2011). As a result, sleep problems have been implicated in virtually every mental health issue during adolescence, underlining the necessity of sleep guidelines for families and practitioners (Carskadon, 2011; Dahl & Harvey, 2007; Meltzer, 2017b). Nevertheless, recent years have witnessed a questioning of the empirical basis for pediatric sleep recommendations. Debate has occurred about whether significant historical changes in the recommended amount of sleep suggest that sleep guidelines may be based more on opinion than definitive empirical support (Matricciani, Olds, Blunden, Rigney, & Williams, 2012; Owens, 2012). Observers have argued that traditional methods to determine sleep need, such as free-sleep paradigms allowing for unrestricted sleep, are inappropriate because sleep can be an appetitive behavior and a large amount of sleep is not always ideal (Eide & Showalter, 2012; Matricciani, Blunden, Rigney, Williams, & Olds, 2013). In the midst of the debates, calls have been made from all sides for research that more strongly establishes a scientific basis for recommended sleep durations during childhood.

One approach is to systematically compare functioning and adjustment across different durations to estimate "optimum sleep," defined as the amount at which the highest level of functioning is observed (Blunden & Galland, 2014; Feinberg, 2013; Feinberg & Campbell, 2012; Matricciani

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et al., 2013). Given the practical and ethical hurdles of titrating sleep durations with experimental sleep restrictions among minors, a first step to studying optimum sleep is to plot observational data of sleep in naturalistic settings against indices of functioning. Along these lines, Eide and Showalter (2012) used reports of sleep duration from the time diaries of a nationally representative sample to estimate that the highest standardized test scores among 16-year-old youth were obtained by those reporting 7.02 to 7.36 hr of sleep per night, less than the commonly recommended 8–10 hr (National Sleep Foundation, 2017). Our previous analyses of the present community sample averaging 15 years of age produced similar sleep durations at which the highest grade point averages and standardized test scores were observed but suggested greater durations (i.e., 8.78–9.00 hr) for optimum levels of mental health (i.e., lowest internalizing and externalizing symptomatology; Fuligni, Arruda, Krull, & Gonzales, 2017). Other analyses of two samples of children observed the lowest levels of behavioral or internalizing problems among 9-year-olds who slept 8–10 hr per night (James & Hale, 2017) and somewhat higher sleep ranges for younger children (Rubens, Evans, Becker, Fite, & Tountas, 2016), although precise point estimates of optimum sleep were not provided.

An unaddressed issue in the debate, particularly from a clinical perspective, is the existence of individual differences in sleep need and optimum sleep (Meltzer, 2017a). Sleep guidelines inevitably generate questions about whether some people need less sleep than others, and experiments do produce individual variations in the extent to which functioning comprises sleep restrictions (Van Dongen, Vitellaro, & Dinges, 2005). Documenting variations in sleep need would be important for public health efforts in order to avoid one-size-fits-all benchmarks that can be difficult and unnecessary for some youth to achieve. In addition, it would be helpful for treatment and intervention plans that increasingly include sleep behaviors as targets of change (e.g., Waloszek et al., 2015) to determine whether youth facing mental health problems have different sleep needs than others.

Examining individual differences in optimum sleep requires frequent, repeated measurements of sleep and functioning across many adolescents in order to observe sufficient variation both within and between individuals. Absent experimental protocols that can feasibly meet these data demands, one approach is to make repeated daily assessments of nightly sleep and daily functioning among large samples of youth. Such techniques provide intensive assessment of naturalistic sleep and how it fits into the everyday demands of teenage life (Arora, Broglia, Pushpakumar, Lodhi, & Taheri, 2013; Kuo et al., 2014). In addition, the study of individual differences in optimal sleep requires a focus on indices of functioning that vary within a person along with sleep and have implications for chronic levels of mental health and adjustment.

Daily mood can be a useful index to examine individual differences in optimum sleep. Anxious and depressive moods vary in meaningful ways across days as a function of daily experiences such as stress and interpersonal conflict (Chung, Flook, & Fuligni, 2009). Numerous studies have demonstrated an association between problematic nightly sleep (i.e., shorter duration or poorer quality) and elevated negative mood during the day (Barber, Munz, Bagsby, & Powell, 2010; Cousins et al., 2011; Fuligni & Hardway, 2006; Galambos, Dalton, & Maggs, 2009; Kouros & El-Sheikh, 2015). The causal impact of sleep on mood during adolescence has been demonstrated through experimental sleep restriction (McMakin et al., 2016) and may operate through comprised emotional regulation (Dahl, 1996). The clinical significance and validity of daily mood have been shown by its associations with more enduring and clinically relevant aspects of mental health, such as depression and internalizing symptomatology (Charles, Piazza, Mogle, Sliwinski, & Almeida, 2013; Silk, Steinberg, & Morris, 2003), with a recent study suggesting that daily mood may indeed function as an important mediator between sleep and internalizing and externalizing symptomatology (Kouros & El-Sheikh, 2015).

In the current study, we used repeated daily measurements to examine variations across adolescents in the importance of nightly sleep duration for mood on the following day. First, we estimated the magnitude of the association between nightly sleep duration and psychological distress (i.e., anxious and depressive mood) the following day for each individual adolescent. We estimated nonlinear associations between duration and distress to determine whether distress is linked to both insufficient and excessive sleep. Second, using individuals' own nonlinear associations, we derived an estimate of optimum sleep for each adolescent by estimating the amount of nightly sleep at which adolescents had the lowest level of distress on the following day.

We then predicted individual differences in (a) the magnitudes of the associations between sleep and distress and (b) the estimates of optimum sleep, as a function of adolescents' more enduring levels of symptomatology, age, and gender. The link between sleep and clinically significant internalizing and externalizing symptomatology has been well-established (Carskadon, 2011; Dahl & Harvey, 2007; Dahl & Lewin, 2001), with treatments and intervention programs incorporating improved sleep hygiene (e.g., increased sleep duration, regular bed and wake times) as a key feature (e.g., Waloszek et al., 2015). Important to note, our analyses of optimal mood did not focus on whether those with increased symptomatology slept less than their peers. Instead, we predicted that youth with higher levels of symptomatology would show a stronger association between nightly sleep and next-day distress—suggesting that sleep is more consequential for their daily mood. In addition, we expected that the youth with chronically higher symptomatology would need more sleep at night to reduce their next-day distress to the lowest level possible for them. That is, their optimum sleep would be higher than others.

Although current sleep guidelines recommend more sleep for younger adolescents (e.g., National Sleep Foundation, 2017), there have been few studies that have demonstrated that younger youth need more sleep to reach optimal functioning. Nevertheless, given Eide and Schowalter's (2012) findings that peak levels of achievement are observed at greater sleep durations for younger children, we predicted that both the association between sleep and distress and the optimum sleep of older youth to be less than those for younger youth. We did not have specific predictions for gender differences, given the inconsistency in previous work on gender differences in sleep behaviors during adolescence (Adam, Snell, & Pendry, 2007; Fuligni & Hardway, 2006).

METHOD

Sample and Procedures

The parents of students attending the ninth and 10th grades at two high schools in Los Angeles were sent letters and called to determine their eligibility to participate in a study of Mexican American families. A total of 428 adolescents (50.5% female) participated in the first wave of the study, representing 63% of those whose parents were reached by phone and who were deemed eligible to participate by self-reporting a Mexican ethnic background. This response rate compares favorably with similarly intensive daily diary checklist studies of Latino families (Updegraff, McHale, Whiteman, Thayer, & Crouter, 2006). The youth were again contacted 1 year later to participate in a second wave of data collection. A total of 337 adolescents took part in the second wave of the study (78.7% of the original sample). The sample was used in a previous article on optimum sleep for achievement and symptomatology that did not examine individual differences in the implications of sleep for daily mood (Fuligni et al., 2017).

All procedures were reviewed and approved by the University of California, Los Angeles Institutional Review Board. Primary caregivers (83% mothers, 13% fathers, 4% other relatives) reported demographic information and provided consent for their adolescents, who in turn provided their own assent. Interviewers visited families' homes, where adolescents completed a self-report questionnaire that assessed various aspects of their adjustment.

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 to 10 min to complete, and included questions about nightly sleep and daily mood. 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 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. In addition, 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. Compliance was high, with adolescents completing an average of 96% of their diaries.

Multiple daily reports of sleep and distress from a least one wave of data collection were necessary for the computation of individual differences in optimum sleep. Therefore, the total analytical sample for the present study included 419 adolescents (M_{age} = 15.03 years) who completed multiple daily reports at Wave 1 (n = 415) and/or Wave 2 (n = 333). Note that the Wave 2 sample included those who completed multiple daily reports at both waves (n = 329) and only at Wave 2 (n = 4). The sample distributions by age for each wave were as follows: Wave 1: 13 years, n = 2; 14 years, n = 106; 15 years, n = 202; 16 years, n = 91; 17 years, n = 7; 18 years, n = 6, missing, n = 1; Wave 2: 14 years, n = 1; 15 years, n = 83; 16 years, n = 148; 17 years, n = 78; 18 years, n = 3; 19 years, n = 3; 20 years, n = 1; missing, n = 16.

According to caregiver reports at the first wave of the study, the majority of caregivers in the analytical sample of 419 completed at most some high school education (66.1% less than a high school degree, 7.8% high school degree only, 5.8% trade or vocational school, 20.4% at least some college). The majority of adolescents were born in the United States (87.4%), whereas most of their parents were foreign-born (76.6 %).

Measures

Nightly sleep duration

Adolescents reported the number of hours 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 (Lockley, Skene, & Arendt, 1999; Matthews, Hall, & Dahl, 2014). 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?" Responses 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 was recoded to be equal to the duration between the bed and wake time (17% of days). To minimize the outsized impact that outliers might have on the estimation of optimum sleep for each individual, sleep duration values greater than 2 *SD* above or less than 2 *SD* below each adolescent's own mean were excluded from analysis. Only 4.6% of days (i.e., about 1 day per participant) were excluded due to extreme values.

Daily psychological distress

Daily psychological distress was assessed with seven items from the Anxiety and Depression subscales of the Profile of Moods States (Lorr and McNair, 1971), which has previously been used successfully in studies of daily adolescent adjustment (Chung et al., 2009; Fuligni & Hardway, 2006). Each evening, adolescents used a 5-point scale from 1 (*not at all*) to 5 (*extremely*) to rate the extent to which they experienced anxious feelings (items included on edge, nervous, uneasy and unable to concentrate) and depressive feelings (items included discouraged, hopeless and sad) during the day. The seven items were averaged to form an overall index of daily psychological distress ($\alpha = .77$).

Symptomatology

At each wave, 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 composing the Internalizing subscale (e.g., "I cry a lot," "I worry a lot") and the 32 items composing 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 Youth Self-Report subscales, also was computed.

Analytical Plan

Given the multilevel structure of the data (i.e., days within waves within individuals), SAS PROC MIXED and HPMIXED were used to estimate the day-level association between sleep duration and next-day distress, and the higher level variance (e.g., individual differences) in that association. This approach accounts for missing data inherent in intensive repeated designs, and estimates were based on all available data relevant to a particular analysis.

Given that the question of "optimal" sleep generally centers on contemporaneous associations between sleep and adolescent functioning (Eide & Showalter, 2012; Matricciani et al., 2013), age, gender, and symptomatology were treated as predictors of the association between sleep duration and daily mood that was measured at the same wave. Our accelerated longitudinal design included data collected at the ninth and 10th grades for the ninth-grade cohort, and data collected at the 10th and 11th grades for the 10th-grade cohort. We pooled the data across the two cohorts and two waves to estimate the effects of age, with the ninth-grade cohort contributing to estimates for younger ages (i.e., 13 years), the 10th-grade cohort contributing to estimates for older ages (i.e., 19 and 20 years), and both cohorts contributing to estimates for ages at which data collection overlapped (i.e., 14–18 years).

Analyses described next addressed (a) differences in average sleep, distress, and symptomatology according to age and gender; (b) differences in the magnitude of the association between sleep duration and next-day distress according to age, gender, and symptomatology; (c) differences in sleep optima according to age, gender, and symptomatology; and (d) differences in sleep optima according to clinical cutoffs of symptomatology to examine the clinical significance of the previously examined associations between sleep optima and symptomatology. The specific analytical models used to address each question are described next.

RESULTS

Attrition Analyses

Of the 415 adolescents who participated and completed daily checklists at Wave 1, 329 (79.3%) did the same at Wave 2. An additional four adolescents who participated but did not completed daily checklists at Wave 1 completed daily checklists at Wave 2. There were no significant differences between adolescents who participated at both waves and those participated in Wave 1 only with respect to sleep duration, distress, and symptomatology.

Descriptive Statistics

Because of the nested nature of the data, we estimated average sleep duration and distress in two three-level models (i.e., days within waves within individuals) that included adolescent age in years (grand mean centered), gender (–1 = male, 1 = female), and non–school day (0 = school day, 1 = non–school day) as predictors. The models included random intercepts at the wave and person levels. Average levels of internalizing, externalizing, and total symptoms were estimated in three two-level models (i.e., waves within individuals) that included adolescent age and gender as predictors and a random intercept at the person level.

As shown in Table 1, adolescents averaged about 8 hr of sleep on school nights. Sleep duration and symptomatology declined with increasing age. Female adolescents reported higher levels of daily distress, internalizing, and total symptomatology scores. Adolescents slept more on non–school nights and reported lower distress on non–school days.

TABLE 1
Average Sleep, Distress, Internalizing Symptoms, Externalizing Symptoms, and Total Symptoms

	Sleep Duration		*Distress*		*Internalizing Symptoms*		*Externalizing Symptoms*		*Total Symptoms*	
Fixed Effects	*Coeff.*	*SE*	*Coeff.*	*SE*	*Coeff.*	*SE*	*Coeff.*	*SE*	*Coeff.*	*SE*
Intercept	7.97***	0.04	1.56***	0.02	12.01***	0.36	11.61***	0.33	42.86***	1.03
Age	−0.12***	0.03	0.00	0.02	−0.67*	0.28	−0.75**	0.26	−2.84***	0.77
Gender	0.00	0.04	0.07**	0.02	1.61***	0.36	0.18	0.33	2.42*	1.03
Non–School Day	0.79***	0.03	−0.09***	0.01	—	—	—	—	—	—
Random Effects	*Var*	*SE*	*Var*	*SE*	*Var*	*SE*	*Var*	*SE*	*Var*	*SE*
Person Level										
Intercept	0.46***	0.06	0.13***	0.02	37.82***	4.09	32.40***	3.38	329.45***	32.66
Wave Level										
Intercept	0.33***	0.04	0.16***	0.01	—	—	—	—	—	—
Residual	1.62***	0.03	0.19***	0.003	26.85***	2.21	22.58***	1.82	190.55***	15.56

Note: Sleep duration is coded in hours and uncentered. Age is coded in years and grand-mean centered. Adolescent gender is effect coded –1 = male, 1 = female. School day is coded 0 = school day, 1 = non–school day. Given the coding, the intercept for sleep time refers to mean hours of sleep for adolescents of average age on school days. Likewise, the intercept for internalizing, externalizing, and total symptoms refers to mean sum scores for adolescents of average age. Coeff. = coefficient, Var = variance.

*$p < .05$. **$p < .01$. ***$p < .001$.

Individual Differences in the Association Between Sleep Duration and Next-Day Distress

A three-level (i.e., days within waves within individuals) model was estimated to predict daily distress as a function of sleep duration during the previous night. We examined nonlinear associations by including sleep and sleep^2 as predictors. Sleep was coded as a continuous variable representing the duration of sleep in hours; we used uncentered values of sleep in all analyses. We included non–school day (0 = school day, 1 = non–school day), as well as the two-way interactions between non–school day and the two sleep terms (Non–School Day × Sleep, Non–School Day × Sleep^2) as fixed effects at the day level. The model included random intercepts at the wave and person levels. To examine individual differences in the relevance of sleep for daily mood, we also included random effects for sleep and sleep^2 at the person level. A first-order autoregressive covariance structure was specified for residuals to correct for time dependencies across days within waves.

As shown in Model 1 of Table 2, both the linear and quadratic terms for sleep duration showed significant positive associations with distress at the daily level, suggesting a nonlinear association between sleep and next-day distress. These associations were moderated by non–school day such that they were evident only on school days. Moreover, there was significant individual variability in the association between school-day sleep and distress, as indicated by significant likelihood ratio tests of the variance components for sleep, $\chi^2(3) = 21.7$, $p < .001$, and sleep^2, $\chi^2(3) = 17.3$, $p < .001$.

We expanded on this three-level model to test age, gender, and symptomatology as person-level predictors of individual variability in the associations between sleep and distress. First, age, and gender were added as predictors in the three-level model (Table 2, Model 2). Next, the three measures of youth symptomatology were tested as predictors, along with age and gender, in three separate models (Table 2, Models 3–5). In each of the three models, we also examined age, gender, and symptomatology as predictors of the linear and quadratic sleep slopes by including the cross-level interactions of the predictors with sleep and sleep^2.

Models 2–5 in Table 2 indicate that despite the significant individual variability in the linear and quadratic associations between school night sleep and next-day distress, adolescents' age, gender, and symptomatology did not predict individual differences in the strength of these associations.

Individual Differences in Amount of Sleep Associated with the Lowest Level of Next-Day Distress

The number of hours of sleep at which each adolescent reported their lowest level of next-day distress was derived in three steps. First, for each wave, a two-level (i.e., days within individuals) model was conducted to predict distress as a function of sleep and sleep^2. Non–school day and the effects of non–school day on the linear and quadratic sleep slopes were included as fixed effects at the day level. Models also included a random intercept and random effects for sleep and sleep^2. A first-order autoregressive structure was specified for residuals to correct for time dependencies across days.

Second, we extracted empirical Bayes estimates of the intercept, sleep, and sleep^2 terms for each adolescent from

TABLE 2
Multilevel Curvilinear Associations Between Nightly Sleep Duration and Next-Day Distress, Moderated by Age, Gender, and Symptomatology

	Model 1		*Model 2*		*Model 3*		*Model 4*		*Model 5*	
	No Person Level Moderators		*Age & Gender Only*		*Age, Gender & Internalizing*		*Age, Gender & Externalizing*		*Age, Gender & Total*	
Fixed Effects	*Coeff.*	*SE*	*Coeff.*	*SE*	*Coeff.*	*SE*	*Coeff.*	*SE*	*Coeff.*	*SE*
Intercept	2.15***	0.16	2.14***	0.17	2.12***	0.17	2.13***	0.17	2.11***	0.17
Sleep	−0.13***	0.04	−0.13**	0.04	−0.13**	0.04	−0.13**	0.04	−0.13**	0.04
Sleep^2	0.01**	0.002	0.01**	0.002	0.01**	0.002	0.01**	0.002	0.01**	0.002
Non-School Day	−0.67***	0.19	−0.68**	0.19	−0.67***	0.19	−0.67***	0.19	−0.67***	0.19
Non-School × Sleep	0.14**	0.04	0.14**	0.05	0.13**	0.05	0.14**	0.05	0.14**	0.05
Non-School × Sleep^2	−0.01**	0.003	−0.01**	0.003	−0.01**	0.003	−0.01**	0.003	−0.01**	0.003
Age	—	—	−0.04	0.10	−0.02	0.10	−0.01	0.10	−0.01	0.10
Age × Sleep	—	—	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02
Age × Sleep^2	—	—	−0.0005	0.001	−0.0004	0.001	−0.0004	0.001	−0.0004	0.001
Gender	—	—	0.11	0.13	0.06	0.13	0.10	0.13	0.08	0.13
Gender × Sleep	—	—	−0.01	0.03	−0.01	0.03	−0.004	0.03	−0.01	0.03
Gender × Sleep^2	—	—	0.0001	0.002	0.0002	0.002	0.0001	0.002	0.0002	0.002
Symptoms	—	—	—	—	0.02	0.01	0.02	0.02	0.01	0.01
Symptoms × Sleep	—	—	—	—	0.002	0.003	−0.000002	0.004	0.001	0.001
Symptoms × Sleep^2	—	—	—	—	−0.0002	0.0002	−0.00002	0.0002	−0.0001	0.0001
Random Effects	*Var*	*SE*	*Var*	*SE*	*Var*	*SE*	*Var*	*SE*	*Var*	*SE*
Person Level										
Intercept	1.14**	0.38	1.21**	0.40	1.16**	0.39	1.18**	0.40	1.17**	0.40
Sleep	0.05***	0.02	0.06**	0.02	0.06**	0.02	0.06**	0.02	0.06**	0.02
Sleep^2	0.0001**	0.0001	0.0002**	0.0001	0.0002**	0.0001	0.0002**	0.0001	0.0002**	0.0001
Wave Level										
Intercept	0.15***	0.01	0.15***	0.01	0.15***	0.01	0.14***	0.01	0.14***	0.01
Day Level										
AR (1)	0.24***	0.01	0.24***	0.01	0.24***	0.01	0.24***	0.01	0.24***	0.01
Residual	0.19***	0.003	0.19***	0.003	0.19***	0.003	0.19***	0.004	0.19***	0.003

Note: Sleep is coded in hours and uncentered; Age is coded in years and grand mean centered. Adolescent gender is effect coded –1 = male, 1 = female; School day is coded 0 = school day, 1 = non–school day. Internalizing, externalizing, and total symptoms were grand mean centered. Coeff. = coefficient; Var = variance; AR = residual errors following a first-order autoregressive structure.

**$p < .01$. ***$p < .001$.

TABLE 3
Youth Self-Reported Distress, and Internalizing, Externalizing, and Total Symptoms by Wave and Direction of the Curvilinear Association Between Daily Sleep and Distress

	Wave 1					*Wave 2*				
	Positive[a]		*Negative*[b]			*Positive*[c]		*Negative*[d]		
	M	*SD*	*M*	*SD*	*t*	*M*	*SD*	*M*	*SD*	*t*
Average Daily Distress	1.45	0.46	2.57	0.83	11.94***	1.36	0.41	2.17	0.74	11.64***
Internalizing Symptoms	11.71	8.08	19.67	19.08	4.65***	10.56	7.30	15.12	8.48	3.78***
Externalizing Symptoms	11.35	7.19	18.00	8.52	4.16***	10.84	7.23	12.72	7.41	1.76
Total Symptoms	42.32	22.26	66.60	23.51	5.47***	38.69	21.37	49.28	22.17	3.30**

Note: "Positive" indicates concave upward curves for which the sleep^2 coefficient was greater than 0. "Negative" indicates curves for which sleep^2 coefficient was less than 0.

[a]$n = 385$.

[b]$n = 30$.

[c]$n = 274$.

[d]$n = 59$.

**$p < .01$. ***$p < .001$.

each model. Empirical Bayes estimates represented the unique associations between sleep and distress on school days for each child at each wave. A total of 385 (93%) of the 415 adolescents in Wave 1 and 274 (82%) out of the 333 adolescents at Wave 2 evidenced concave upward curves, as defined by positive coefficient values (> 0) for the sleep^2 term, suggesting a unique amount of sleep (i.e., an optimum) at which they experienced the lowest level of next-day stress. Those without a concave upward curve (i.e., sleep^2 coefficient < 0) did not have such an optimum. As shown in Table 3, adolescents without concave upward curves evidenced higher levels of distress across diary days, and internalizing, externalizing, and total symptomatology than those with concave upward curves. Age did not differ between youths who showed concave upward curves and those who did not at Wave 1, $t(33.86) = 0.56$, $p = .590$, or Wave 2, $t(117.17) = -0.18$, $p = .855$. However, female adolescents were less likely to show concave upward curves than male adolescents at Wave 1, $\chi^2(1) = 4.87$, $p = .027$, and Wave 2, $\chi^2(1) = 8.63$, $p = .003$.

Third, optimum sleep for mood, defined as the duration of sleep at which the lowest level of distress was observed, was estimated for each adolescent at each wave who evidenced concave upward curvilinear associations between sleep duration and distress. Sleep duration needed for the lowest level of distress was estimated with the equation $x = -b/2a$, which was applied to locate the minimum point of a quadratic function: x is the sleep needed for the lowest level of distress, $-b$ represents the coefficient for the linear sleep term, whereas a represents the coefficient for sleep^2. Extreme estimates of optimum hours of sleep, which sometimes extended beyond the range of possible sleep duration values (0–24 hr), were winsorized to 2 *SD* above or below each child's own mean sleep duration. Optima averaged 9.03 hr ($SD = 0.86$) and ranged from 3.5 to 13, collapsed across both waves. At Wave 1, the optimum averaged 9.22 ($SD = 0.92$), whereas at Wave 2 it averaged 8.76 ($SD = 0.70$), $t(258) = 6.97$, $p < .001$. Figure 1 displays a histogram of the distribution of estimated optimum hours of sleep for each wave.

For descriptive purposes, we computed the effect size (Cohen's *d*) of the difference between predicted distress at optimum hours of sleep and the average and maximum levels of predicted distress across diary days for person at each wave. The average Cohen's *d* of the difference relative to average distress was –0.12 ($SD = 0.13$) at Wave 1 and –0.15 ($SD = 0.20$) at Wave 2, suggesting small effect sizes, and the effect size of the difference relative to the maximum level of predicted distress was –0.37 ($SD = 0.38$) at Wave 1 and –0.48 ($SD = 0.63$) at Wave 2, indicating medium effect sizes.

To estimate the associations of age, gender, and symptomatology with optima, we conducted three two-level (i.e., waves within individuals) models. Each index of youth symptomatology (i.e., internalizing, externalizing, and total) was examined as the predictor of individual differences in sleep optima in a separate model, along with age and gender as additional predictors and a random intercept at the person level. As shown in Table 4,

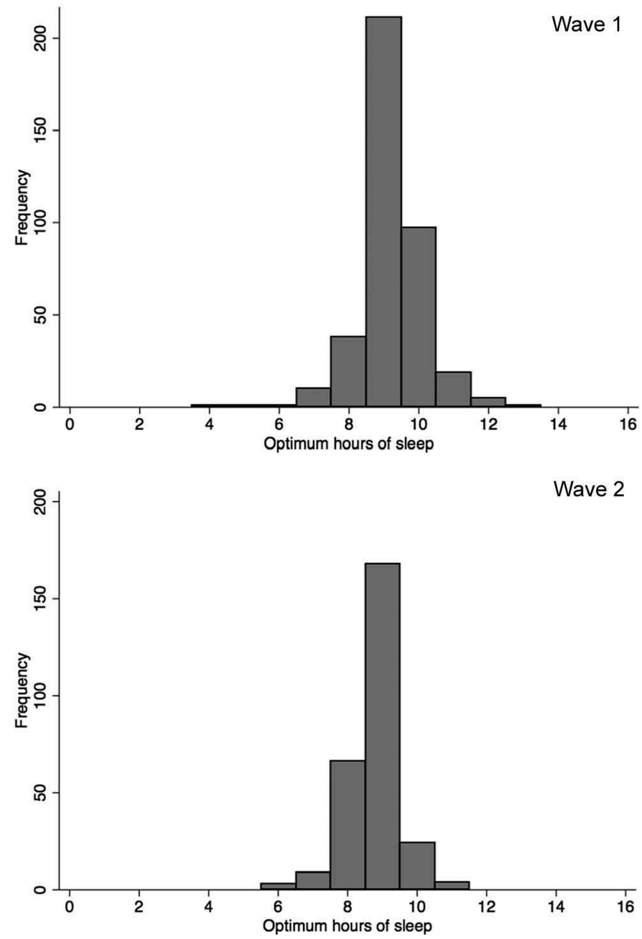

FIGURE 1 Histograms showing distribution of winsorized sleep optima for each wave.

TABLE 4
Two-Level Linear Associations Between Each Measure of Symptomatology as the Predictor and Optimum Hours of Sleep Duration as the Outcome, Controlling for Age and Gender

	Internalizing Symptoms		*Externalizing Symptoms*		*Total Symptoms*	
	Coeff.	*SE*	*Coeff.*	*SE*	*Coeff.*	*SE*
Intercept	9.04***	0.03	9.04***	0.04	9.04***	0.04
Symptoms	0.02***	0.004	0.005	0.005	0.01**	0.002
Age	−0.16***	0.04	−0.17***	0.04	−0.16***	0.04
Gender	0.04	0.04	0.07	0.04	0.06	0.04

Note: The dependent variable is always sleep optimum. Column heads refer to the specific measure of symptomatology used as the predictor. Age is coded in years and grand mean centered. Internalizing, externalizing, and total symptoms are grand mean centered. Adolescent gender is effect coded −1 = male, 1 = female. Coeff. = coefficient.

**$p < .01$. ***$p < .001$.

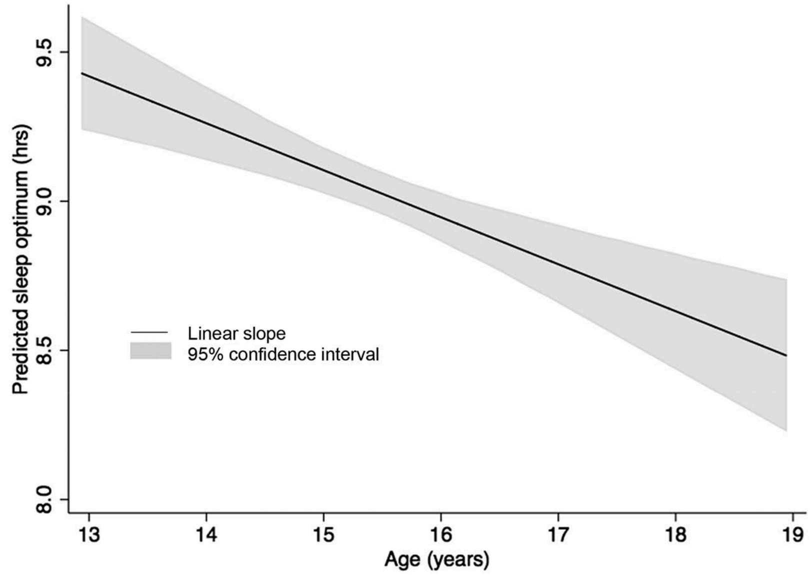

FIGURE 2 Age differences in predicted sleep optima for daily mood. *Note*: Model controls for grand mean centered internalizing symptoms and effect coded gender (−1 = male, 1 = female).

youth who reported more internalizing and total symptoms needed more hours of sleep to experience their minimum level of distress the following day. Externalizing symptoms were not associated with sleep optima. Younger adolescents needed more sleep in order to experience their minimum level of distress, as shown in Figure 2, with the greater uncertainty of the estimates for the youngest and oldest ages represented by the wider confidence intervals. Gender did not predict sleep optima. Gender and age did not significantly moderate any of the associations between adolescent symptomatology and sleep optima.

To examine whether the association between internalizing symptoms and sleep optima was clinically meaningful, we converted raw scores of internalizing symptoms into t scores and dichotomized the variable by the clinical cutoff point, $t = 64$. In Wave 1, 58 of 385 youths (15.1%) reported symptom levels above the cutoff ($t \geq 64$), and in Wave 2, 30 of 254 youths (11.8%) reported clinically significant levels. We examined this binary variable (0 = nonclinical; 1 = clinically significant) as a predictor of sleep optima, along with age and gender as additional predictors and a random intercept at the person level. As shown in Figure 3, those who reported clinically significant levels of internalizing

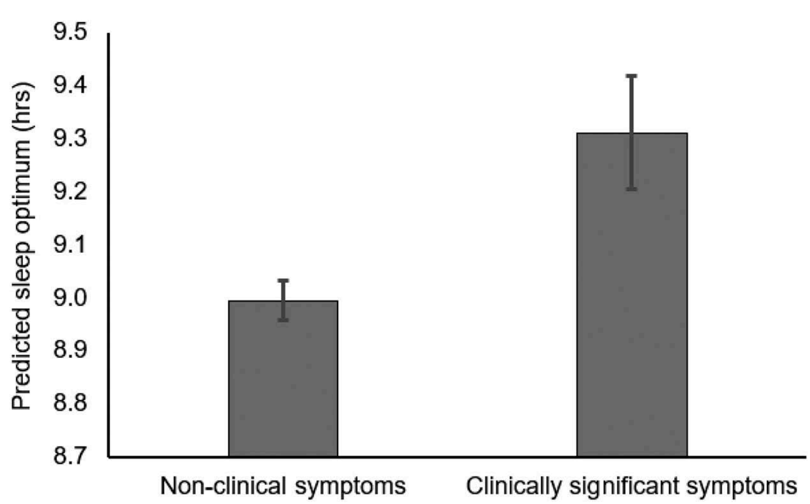

FIGURE 3 Point estimates of sleep optima for daily mood by clinical severity of internalizing symptoms. *Note*: t score < 64 for nonclinical levels of internalizing symptoms and t score ≥ 64 for clinically significant levels. Error bars represent standard errors around point estimates. Model controls for grand mean centered age and effect coded gender (–1 = male, 1 = female).

symptoms needed 0.32 hr more sleep than nonclinical youths to experience their minimum level of distress the following day (b = 0.32, SE = 0.10, t = 3.17, p = .002). Consistent with prior models, age was negatively associated with sleep optima (b = –0.16, SE = 0.04, t = –4.54, p < .001). Gender was significantly associated with sleep optima, such that female adolescents needed more sleep than male adolescents (b = –0.07, SE = 0.04, t = 2.09, p = .037).

DISCUSSION

Promoting healthy sleep habits during the adolescent years can be enhanced by building a strong empirical foundation for the specific durations recommended by public health and clinical sleep guidelines. The challenges of experimentally testing the impact of varying amounts of sleep at this age have led investigators to use naturalistic studies to make estimates of "optimum sleep," defined as the amount of sleep at which peak mental health and behavioral functioning is observed (Eide & Showalter, 2012; Fuligni et al., 2017). Our results highlight the importance of including the assessment of individual differences in optimum sleep in these efforts. Adolescents varied significantly in the magnitude of the association between nightly sleep and next-day mood and in the duration of nightly sleep after which they reported their lowest level of distress on the following day. Younger adolescents and those reporting greater internalizing and overall symptomatology had higher levels of optimum sleep, suggesting that they may need more sleep to achieve their own lowest level of psychological distress the following day. The fact that these results were obtained only for school nights highlights the relevance of this significant structural constraint for discussions of optimum sleep and sleep recommendations (Carskadon, 2011).

In terms of the magnitude and form of the association between nightly sleep and next-day distress, we observed a significant curvilinear association between sleep and distress. Estimating across the sample, adolescents reported greater levels of daily distress after nights in which they obtained either too little or too much sleep. These findings are consistent with the well-known link between sleep and internalizing symptomatology (Dahl & Harvey, 2007). Significant daily-level associations between sleep and mood have been observed in several previous studies (e.g., Barber et al., 2010; Cousins et al., 2011; Fuligni & Hardway, 2006; Galambos et al., 2009; Kouros & El-Sheikh, 2015), but this may be one of the first studies to estimate a nonlinear association at the daily level. Most important, our analyses allowed us to observe significant individual differences in the strength of the association between nightly sleep and distress, suggesting that adolescents vary in the importance or relevance of sleep for their daily mood. We were unable, however, to predict this variability as a function of adolescents' age, gender, and symptomatology. Future research needs to more deeply investigate the factors that may account for the differences across youth, because the variability suggests that some adolescents may be less likely to take up or respond to sleep enhancement efforts because sleep is less relevant for their daily functioning.

Variations in the amount of nightly sleep after which adolescents reported their lowest level of distress the next day were significantly predicted by youths' age and symptomatology. Across the sample, optimum sleep for daily mood averaged approximately 9 hr per night, an amount that falls in the range of commonly promoted sleep guidelines for this age period (National Sleep Foundation, 2017). The sizes of the average differences in daily distress following nights with optimum sleep as compared to adolescents' average and highest levels of daily distress were small and moderate in magnitude, respectively. Yet younger adolescents and those who reported higher levels of chronic internalizing and total symptomatology reported more sleep than their peers on the nights proceeding the days they experienced their lowest levels of psychological distress. The age differences support sleep guidelines that encourage more sleep among young adolescents (National Sleep Foundation, 2017). Our findings, particularly those regarding adolescents with clinically significant levels of internalizing symptoms, suggest that youth facing mental health issues may require even more sleep than is typically recommended in order to obtain their optimal level of daily psychological functioning. This possibility supports the use of sleep as a target of behavior change within intervention efforts geared toward reducing internalizing symptoms during the adolescent years (e.g., Waloszek et al., 2015).

An estimate of optimum sleep duration for daily mood could not be estimated for the small percentage of youth who did not evidence a concave upward curvilinear association between sleep and mood. Given the higher level of symptomatology of this group, they may have been more likely to have clinical psychopathology and very different sleep patterns. Their sleep may have been more erratic and unpredictable, consistent with emerging evidence of the negative implications of sleep variability independent of sleep duration (Bei, Manber, Allen, Trinder, & Wiley, 2017; Fuligni & Hardway, 2006; Meltzer, 2017a). It is also possible that our 2-week sampling period was insufficient to accurately capture the complexity of the sleep patterns of these youth. Longer protocols and additional measures of sleep may be necessary for the segment of youth who do not demonstrate the more typical concave upward curvilinear association between sleep and daily functioning.

We estimated optimum sleep by predicting next day's mood from prior night's sleep, but there is evidence that the effects of daily sleep and mood are reciprocal (Cousins et al., 2011; Galambos et al., 2009; Kouros & El-Sheikh, 2015). The reciprocality raises interesting additional questions about optimum sleep, questions that focus more on sleep in reaction in daily events and experiences. As studies of the first-order questions regarding the existence of nonlinear associations between sleep and functioning begin to accrue, future research on optimum sleep can begin to address second-order questions that focus on how much sleep is optimal for recovering from daily events and experiences. Although notably more complex, such analyses would more fully recognize sleep as both a proactive and reactive health behavior in everyday life.

Sleep diary measures are moderately correlated with more objective wrist actigraphy measurements that infer sleep through movement (e.g., Matthews et al., 2014), but diaries may produce higher sleep duration estimates (Matthews et al., 2014; Short, Gradisar, Lack, Wright, & Carskadon, 2012). It is unclear whether the differing durations are due to an underestimate of awakenings by self-reports or an overestimate by actigraphy because of greater movement during sleep among adolescents (Johnson et al., 2007; Short et al., 2012). Nevertheless, future research should employ multiple measures to order to obtain converging evidence for public health and clinical recommendations. The reporting of the prior night's sleep duration on the subsequent evening at the same time of the daily mood items may have led to recall biases that produced error in the estimates. Another limitation is the use of a single reporter of sleep, daily distress, and symptomatology. Additional reporters of these factors would provide additional validity for the results, although other reporters (e.g., parents, teachers) may not have as good access to adolescents' sleep, distress, and symptoms as the adolescents themselves. Finally, the cross-sectional associations estimated in our study cannot determine the direction of causality between sleep and adjustment. Analyses of nonexperimental studies such as these should be seen as the first step, helping to isolate a limited range of potential optimal sleep durations that could be feasibly manipulated in experimental paradigms to provide a more definitive conclusion about causality.

Our analyses were based on a sample of youth from Mexican American backgrounds and potential ethnic differences in sleep and adolescent symptomatology highlight the need for replication of these analyses with adolescents from multiple ethnic and socioeconomic backgrounds. Studies of Mexican American and other Latino adolescents have been inconsistent in reporting whether these youth sleep more or about the same as their European American peers (Adam et al., 2007; Fuligni & Hardway, 2006; Park et al., 2016), and our prior analyses of achievement outcomes for the present sample obtained estimates of optimum sleep similar to those observed in a nationally representative sample (Eide & Showalter, 2012; Fuligni et al., 2017). African American youth, however, appear to obtain significantly less sleep than their peers (Adam et al., 2007; Matthews et al., 2014), and it is possible that findings may differ for this group. Future research should expand the diversity of populations being studied in order to determine the generalizability of estimates of individual differences in optimum sleep.

In conclusion, clinical and public health recommendations for adolescent sleep durations must allow for the possibility of individual differences in sleep need in order to be broadly applicable to diverse groups of youth. Continued research across different aspects of functioning that empirically tests for such individual differences could provide more confidence in such sleep recommendations, thereby enhancing the potential for their acceptance and success.

ACKNOWLEDGMENTS

We thank the participating families and Thomas Weisner for his contributions to the larger project.

FUNDING

The research was supported by funding from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (R01-HD057164) and the UCLA California Center for Population Research, which is supported by the National Institute of Child Health and Human Development (P2C-HD041022). The content does not necessarily represent the official views of the National Institute of Child Health and Human Development or the National Institutes of Health.

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