A Longitudinal Examination of Cumulative Short Sleep and Body Mass throughout Adolescence and Early Adulthood

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Running Head: Cumulative Short Sleep

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ABSTRACT

Numerous cross-sectional studies have identified an inverse association between sleep duration and body mass among adolescents and young adults. However, prior research has not examined the association between cumulative exposure to short sleep throughout adolescence and early adulthood on body mass index in early adulthood. This requires further exploration, because the mechanisms theorized to link sleep duration and body mass suggest that chronic exposure to short sleep is likely to be more strongly linked to excess body mass than acute exposure to short sleep. We use data from four waves of the National Longitudinal Study of Adolescent Health to examine the association between cumulative exposure to short sleep and body mass index in Wave 4. Chronic exposure to short sleep across waves is associated with substantially increased body mass in Wave 4, even when adjusting for cross-sectional sleep hours. Indeed, those who report short sleep in all four waves have BMIs that are 3 units higher on average than those who slept for the recommended duration across waves—an effect that is larger than the black-white difference in BMI. Our findings suggest that chronic exposure to short sleep in the population may have a profound impact on obesity.

Short sleep duration among children and adolescents is persistently associated with adverse health outcomes, including poor cardiovascular and cognitive functioning, depression, and elevated body mass.[1-4] Evidence of a decline in average sleep time among U.S. children and adolescents has led some scholars to suggest that short sleep might be a significant contributor to the U.S. obesity epidemic among children and adolescents,[5-6] and to promote additional sleep in order to help prevent or overcome obesity.[7]

Despite the persistent association between short sleep, obesity and other adverse health outcomes, several important limitations of previous research warrant mention. For instance, many studies that find an association between short sleep and childhood obesity are based on analyses of cross-sectional data.[6, 8-10] At this point, there are relatively few prospective studies that could provide stronger evidence about causal links between short sleep and health outcomes.[11-13] Notably, those prospective studies employ various indicators of short sleep duration, most of which do not account for the cumulative exposure to short sleep during the ages where substantial weight gain and obesity often emerge.

Our first aim is to develop age- and sex-specific measures of cumulative short sleep duration based on a careful examination of 13 years of prospective data from the National Longitudinal Study of Adolescent Health (Add Health). Although it is widely known that children require more sleep than adolescents, who in turn need more sleep than adults, there is no consensus about the appropriate amount of sleep for these populations. The Centers for Disease Control cites the National Sleep Foundation recommendations of 10 to 11 hours of sleep for children aged 5 to 10, 8.5 to 9.25 hours for children aged 10 to 17, and 7 to 9 hours for adults,[14] although the National Sleep Foundation offers no peer-reviewed evidence to support their recommendations. Clinicians and sleep researchers commonly define short sleep among children as anything less than 7 hours per night, but the empirical underpinnings for this cutoff are unclear and they do not account for variable sleep needs across ages. The lack of validated, evidence-based measures of short sleep in adolescence and early adulthood reflect the general lack of consensus regarding sleep requirements in these populations. Consequently, as Matricciani and colleagues emphasize, "sleep recommendations are still being issued in the acknowledged absence of meaningful evidence."[15:553]

Our second aim is to examine associations between the cumulative exposure to short sleep duration throughout adolescence and markers of health in early adulthood. Although we emphasize associations between short sleep and body mass, we also extend our analyses to include related indicators of metabolic and cardiovascular functioning, as well as cognitive and affective outcomes. Several pathways hypothesized to link short sleep to adverse health outcomes—such as hormonal dysregulation and changes in food consumption and physical activity behaviors—suggest that repeated exposure to short sleep may have more profound implications for health than acute episodes of short sleep. Thus, we anticipate that cumulative measures of short sleep duration will have stronger associations with body mass and other markers of health than cross-sectional measures of short sleep. If research supports this hypothesis, it would provide compelling evidence that adequate sleep through adolescence and early adulthood is vital for optimal health, including lower risks of obesity.

DATA AND METHODS

We use restricted-use data from all four panels of the National Longitudinal Study of Adolescent Health (Add Health), collected in 1995 (Wave 1), 1996 (Wave 2), 2001 to 2002 (Wave 3), and 2008-2009 (Wave 4). In 1994-1995, Add Health administered in-school questionnaires to a nationally representative sample of 90,118 adolescents in grades 7-12 from

132 schools. About 17 students from each school were randomly selected from strata defined by grade and sex to participate in more comprehensive in-home interviews, resulting in 20,745 students with detailed data in Wave 1, with a response rate of 79%. The restricted-use Add Health data permit access to certain variables not available in the public-use data, as well a larger sample size with greater statistical power.

Variables

Our primary outcome measure is body mass index in Wave 4, which we derive from measured heights and weights and calculate as: (weight in pounds)/(height in inches squared)*703. Our key predictor is the cumulative exposure to short sleep across all four waves of Add Health. In Waves 1 and 2, Add Health asks how much sleep, in hours, respondents usually get. In Waves 3 and 4, Add Health asks respondents what hour and minute they usually go to sleep and then wake up on days that they attend work or school-related activities. Waves 3-4 also inquire about sleep duration for days that participants do not have to get up at a certain time. We multiply sleep hours on work or school days by 5/7 and on weekends by 2/7, and then add the resulting figures to create a weekly average of usual sleep hours. Wave 3 and 4 data occasionally yield negative sleep hours or implausibly high sleep hours (e.g., 16+ hours) for 3% and 5% of observations, respectively. Most misreports occurred among those who reported “12” as the hour of waking or sleep onset, suggesting that some respondents confused 12am and 12pm. Correcting these misreports resulted in correlations in sleep hours across Waves 3 and 4 that were consistent with those observed across Waves 1 and 2.

We adjust for variables that are exogenous and that are likely to be correlated with sleep duration, body mass, or both. A dichotomous variable captures the respondent’s sex. Race/ethnicity is coded categorically as non-Hispanic white (referent), non-Hispanic black, Hispanic, Asian, Native American, and other. Age at Wave 4 is measured in years (and fractions of years) and is included as a continuous variable in the models. Subsequent models will adjust for parent or early life characteristics, such as parents' education and family structure during childhood.

Analyses

Given the absence of clear recommendations about what level of sleep is associated with optimal health and functioning among adolescents and young adults, we measure cumulative sleep in three ways. First, we give each respondent in each wave a 1 if they meet the age-specific standards for necessary sleep levels reported by the Centers for Disease Control and the National Sleep Foundation (the "NSF standard"), and a 0 otherwise.[14] Summing the items across waves results in a 5-point scale, with 0 indicating that the respondent meets the recommendations in all 4 waves, and 4 indicating that respondents fail to meet those recommendations in any of the waves. Second, we follow prior clinical sleep research and give adolescents in each wave a 1 if they sleep less than 7 hours (the "clinical standard"), and a 0 otherwise. Again, summing these four items results in a 5-point scale.

Third, we calculate the degree to which participants slept less than the average, at a given age, in each wave. We pool observations from all four waves, so that each respondent contributes one observation for each wave in which s/he is interviewed. Then we estimate a hierarchical linear model (with observations nested within respondents) that predicts the average level of sleep by age, sex, race/ethnicity, and the wave of observation. To flexibly model the association between age and sleep, we include cubic splines for age, with knots at ages 15, 20, 25 (an additional knot at age 30 did not improve the model fit, so we dropped that term). We sum the within-respondent and between-respondent variances from the model, then take the square root of that quantity to estimate a standard deviation for sleep duration, conditional on the other variables in the model. Next, we calculate a total residual (based on within-respondent and between-respondent residuals) and divide it by the conditional standard deviation to create a standardized variable. Residuals smaller than negative 1 indicate that the participant's average sleep is at least one standard deviation below their age and sex peers. In our analyses, adolescents who satisfy this definition for short sleep are coded as 1 (the "model-based standard"), or 0 otherwise. Summing the four indicators across the four waves again creates a 5-point scale, where higher values indicate more consistent exposure to short sleep across waves.

We use ordinary least squares regression to estimate the association between our measures of cumulative short sleep and body mass from Wave 4, while adjusting for age, sex, and race/ethnicity. We also estimate models that examine the cross-sectional association between short-sleep and body mass in Wave 4 to examine whether the cumulative short sleep measures fit the data better than the cross-sectional sleep measure. All models use Wave 4 survey weights, and account for the complex sampling frame used by Add Health.

RESULTS

Figure 1 shows the average amount of sleep, by age and at the average of the other covariates in the model, from the hierarchical linear regression model (solid line). The red dashed line shows the threshold for short sleep based on National Sleep Foundation (NSF) standards. The NSF standard shows a sharp drop-off of 1.5 hours at age 17 that does not likely reflect a clear biological threshold. Notably, based on the NSF standard, at ages 15 and 16 the average Add Health respondent is a short sleeper. The green dashed line shows the clinical standard for short sleep—less than 7 hours at all ages, which fails to take into account age differences in average sleep needs. Based on the average hours of sleep by age, the clinical standard is a severely low threshold during adolescence, but indicates only modestly short sleep among young adults. Finally, the dashed black line shows our model-based standard of one standard deviation below the mean.

(Figure 1 about here)

Table 1 shows means and percentages of the study variables. By Wave 4, the average study participant has a body mass of 29.1, is 28.8 years old, and sleeps an average of 7.7 hours per night. Regularly getting recommended amounts of sleep is uncommon based on any of the three standards we examine. Just 50% met the clinical standard (7 or more hours of sleep), 17% met the National Sleep Foundation standard, and 62% met the model-based standard for adequate sleep in all four waves. Also notably, very few respondents were short sleepers in all four of the waves. Just 1% failed to meet the clinical standard, 4% failed to meet National Sleep Foundation recommendations, and 0.4% failed to meet the model-based standard for the minimum acceptable amount of sleep across all four waves.

(Table 1 about here)

Table 2 presents unstandardized linear regression coefficients from models that predict BMI in wave 4. Model 1 includes demographic variables. Body mass increases with age, does not differ for males and females, and is higher among blacks and Hispanics, relative to whites. In addition to demographic information, Model 2 includes variables indicating the number of waves that respondents failed to meet the clinical standard for adequate sleep (i.e., less than 7 hours of sleep). Compared to those who meet the clinical standard in all four waves, those who do not meet the standard in one wave averaged .75 more BMI units, those who did not meet the standard in 2 waves averaged 1.9 more BMI units, those who did not meet the standard in 3 waves averaged 1.4 more BMI units, and those did not meet the standard of at least 7 hours of sleep in all four waves averaged 3.0 more BMI units; these are all statistically significant differences.

(Table 2 about here)

Model 3 includes indicator variables for the number of waves in which respondents failed to meet National Sleep Foundation (NSF) standards. Compared to those who met NSF standards for adequate sleep in all four waves, those who did not meet that standard in one or two waves did not have significantly higher BMIs, those who failed to meet NSF standards for three waves averaged 1.3 more BMI units, and those who failed to meet the NSF standards for all four waves averaged 2.0 more BMI units.

In Model 4, we replace extant measures of short sleep with indicator variables derived from our model-based standard. This model shows that compared to respondents who met our model-based age specific sleep standard across all four waves, those who did not meet the standard in one wave averaged .91 more BMI units, those who did not meet the standard in two waves averaged 1.7 more BMI units, those who did not meet the standard in three waves averaged 1.5 more BMI units, and those who did not meet the standard amount of sleep in four waves averaged 3.4 more BMI units. For comparison purposes, we note that blacks average BMIs of 2.4 units higher than whites in the same model.

Model 5 examines the cross sectional association between sleep hours and BMI in Wave 4, and finds that each additional hour of sleep is associated with 0.36 less BMI units. Model 6 further includes sleep-squared to account for any nonlinearity in the association between sleep hours and BMI. Increasing sleep duration is inversely associated with BMI until sleep duration reaches about 9.6 (=-1.672/(2*0.087)) hours, whereupon additional hours of sleep are associated with increasing BMIs.

Models 7 and 8 include both cross-sectional and cumulative measures of sleep to identify which is more closely associated with BMI in Wave 4. In both cases, the cross-sectional measure of sleep duration fall from significance, but the indicator variables for cumulative sleep exposure remain statistically significant.

DISCUSSION

The cumulative exposure to short sleep has a substantial and graded association with body mass. The dose-response association we identified is consistent with the notion that sleep duration is causally associated with body mass, although we cannot rule out the possibility of unobserved confounders with observational data. Our results are also consistent with both behavioral and hormonal mechanisms that highlight the importance of cumulative short sleep rather than acute bouts of short sleep—although our data cannot test those mechanisms directly—and imply a relatively long latency period between short sleep and excess body mass. Our findings, which suggest much stronger effects of short sleep duration than previous studies of adolescents, merit extension and replication.

Notably, the persistent failure to meet National Sleep Foundation standards for adequate sleep is more weakly associated with BMI in early adulthood than either the clinical or model-based standards for assessing adequate sleep at different ages. Sleeping less than 7 hours or 1 or more standard deviations less than age-specific peers is persistently associated with higher BMI. Our results suggest that National Sleep Foundation standards may not clearly map on to the level of sleep that confers protection against overweight or obesity among adolescents or young adults in the United States.

The strengths of our study include the use of a large, nationally representative cohort of adolescents and young adults in the United States. Further, Add Health data provide repeated indicators of sleep duration as well as objective measures of height and weight from study participants. Nevertheless, some limitations warrant mention. Sleep duration is self-reported in each wave; although self-reports in each wave are preferable to retrospective reports, they may imperfectly reflect actual sleep duration. However, the respondents with higher BMIs who are most likely to experience sleep apnea, may be most likely to over-state their sleep duration, which would tend to bias our results toward the null.[16]

The next steps in our analyses include the following. First, we will develop a rigorous imputation model and will use multiple imputation to re-capture the substantial number of individuals who are missing data on key variables in the four waves, or who simply did not participate in certain waves. Second, we will consider a variety of secondary outcomes, including biomarkers of cardiovascular function (e.g., blood pressure), metabolic function (e.g., glycosilated hemoglobin or long-tem blood sugar regulation—an indicator of diabetes), inflammation (e.g., C-reactive protein, Epstein Bar virus reactivity), and affective disorders (e.g., depression). Sleep duration, body mass, or both have been linked to those indicators in cross-sectional studies—identifying an association with cumulative sleep would further bolster evidence in favor of a causal association between sleep and health. Third, we will identify and adjust for additional confounders from early life (e.g., parents' education, parents' marital status).

In sum, the cumulative exposure to short sleep appears to be a major risk factor for elevated BMIs. Future research could work to better understand the biological and behavioral pathways that drive that association, and include additional potential confounders.

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Table 1: Means and proportions of study variables, Wave 4 of the Add Health data

Body mass index		29.1
Age		28.8
Male (=1)		0.51
Race/Ethnicity		
Non-Hispanic White		0.67
Non-Hispanic Black		0.16
Hispanic		0.12
Asian		0.03
Native American		0.01
Other		0.01
Did not meet the clinical standard: number of waves		
	0	0.50
	1	0.30
	2	0.14
	3	0.05
	4	0.01
Did not meet the NSF standard: number of waves		
	0	0.17
	1	0.29
	2	0.34
	3	0.15
	4	0.04
Did not meet the model-based standard: number of waves		
	0	0.62
	1	0.26
	2	0.09
	3	0.03
	4	0.004
Sleep hours in Wave 4		7.7

Table 2: Linear regression coefficients for the association between cumulative sleep measures and body mass index

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Age	0.199***	0.157**	0.271***	0.207***	0.190***	0.189***	0.162**	0.207***
Male (=1)	-0.207	-0.180	-0.165	-0.072	-0.370*	-0.365*	-0.201	-0.131
Race/Ethnicity								
Non-Hispanic White								
Non-Hispanic Black	2.265***	2.333***	2.448***	2.418***	2.223***	2.135***	2.315***	2.399***
Hispanic	1.336***	1.201***	1.203***	1.216***	1.363***	1.355***	1.201***	1.214***
Asian	-1.822***	-2.228***	-2.172***	-2.072***	-1.892***	-1.877***	-2.225***	-2.101***
Native American	3.685	4.674*	4.848**	4.649*	3.666	3.568	4.628*	4.603*
Other	-1.229	-1.045	-0.917	-0.962	-1.263	-1.297*	-1.049	-0.968
Did not meet the clinical standard: number of waves								
0		ref.					ref.	
1		0.724***					0.651**	
2		1.854***					1.720***	
3		1.396***					1.210**	
4		2.965**					2.715**	
Did not meet the NSF standard: number of waves								
0			ref.					
1			0.126					
2			0.300					
3			1.313***					
4			2.039***					
Did not meet the model-based standard: number of waves								
0				ref.				ref.
1				0.913***				0.795**
2				1.649***				1.433***
3				1.509*				1.175
4				3.408**				2.932*
Sleep hours in Wave 4					-0.357***	-1.672***	-0.580	-0.576
Sleep hours in Wave 4, Squared						0.087**	0.033	0.029
Intercept	22.998***	23.709***	20.612***	22.340***	26.086***	30.940***	26.067***	25.125***
N (unweighted)	14,788	9,254	9,254	9,254	14,725	14,725	9,254	9,254
R-squared	0.020	0.031	0.028	0.029	0.024	0.026	0.031	0.030

* p<.1; ** p<.05; *** p<.01

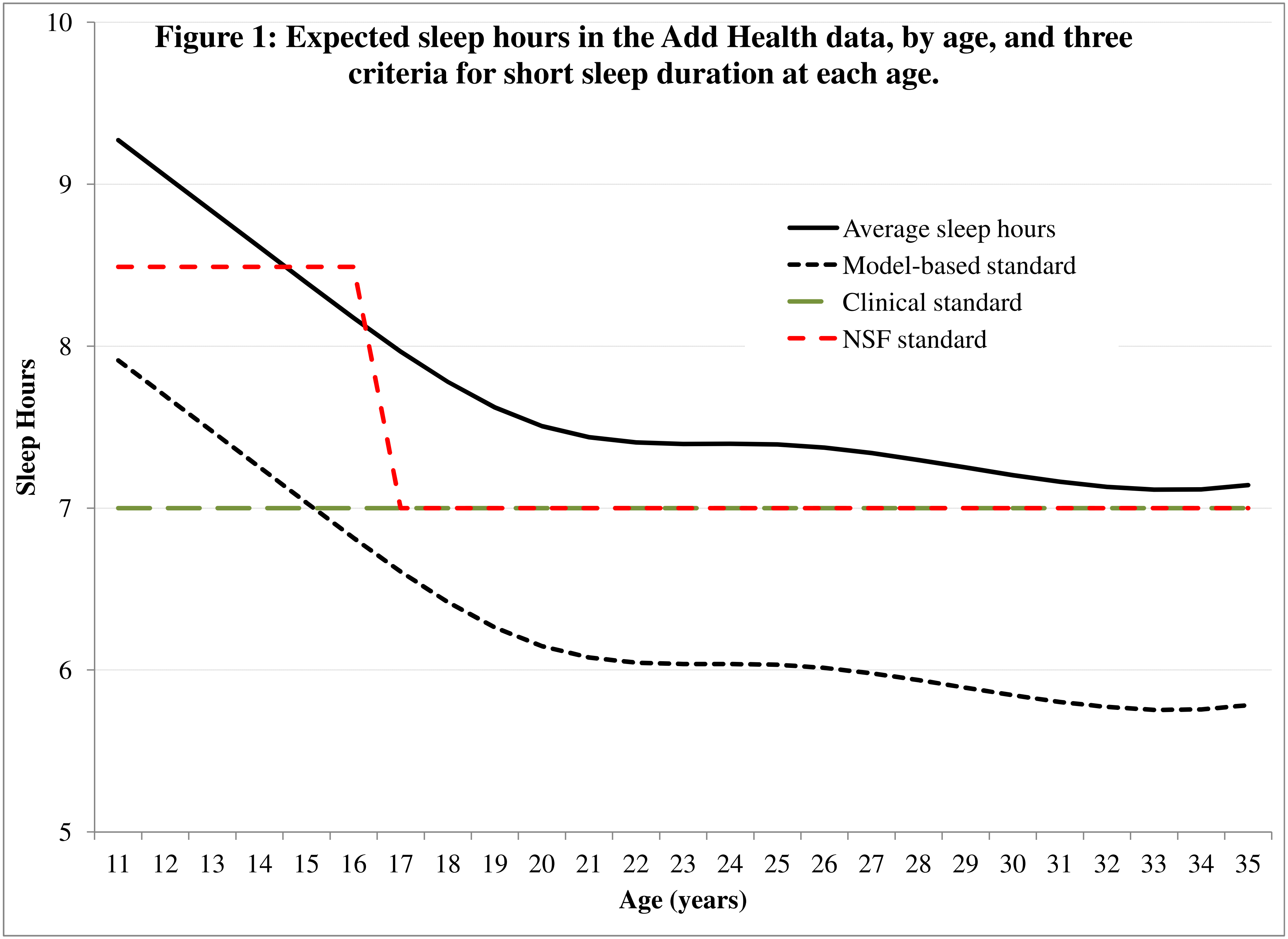
Figure 1: Expected sleep hours in the Add Health data, by age, and three criteria for short sleep duration at each age.
Sleep Hours
10
9
8
7
6
5
Average sleep hours
Model-based standard
Clinical standard
NSF standard
11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
Age (years)