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# Relationship Between Sleep Duration and Body Mass Index Depends on Age

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**Objective:** Sleep duration is associated with obesity and cardiometabolic disease. It is unclear, though, how these relationship differs across age groups.

**Methods:** Data from 2007 to 2008 National Health and Nutrition Examination Survey (NHANES) were used, including respondents aged 16+ with complete data ( $N = 5,607$ ). Sleep duration and age were evaluated by self-report, and body mass index (BMI) was assessed objectively. Sleep duration was evaluated continuously and categorically [very short ( $\leq 4$  h), short (5-6 h), and long ( $\geq 9$  h) versus average (7-8 h)]. Age was also evaluated continuously and categorically [adolescent (16-17 years), young adult (18-29 years), early middle age (30-49 years), late middle age (50-64 years), and older adult ( $\geq 65$  years)].

**Results:** There was a significant interaction with age for both continuous ( $P_{\text{interaction}} = 0.014$ ) and categorical ( $P_{\text{interaction}} = 0.035$ ) sleep duration. A pseudo-linear relationship was seen among the youngest respondents, with the highest BMI associated with the shortest sleepers and the lowest BMI associated with the longest sleepers. This relationship became U-shaped in middle-age, and less of a relationship was seen among the oldest respondents.

**Conclusions:** These findings may provide insights for clinical recommendations and could help to guide mechanistic research regarding the sleep-obesity relationship.

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## Introduction

Obesity is a major global health problem, and in the US the prevalence has increased at an alarming rate. Obesity is a major risk factor for cardiometabolic disease and other adverse health outcomes, many of which are linked to the leading causes of death in the population. Substantial research has clarified the role of behavioral factors in the etiology of obesity—particularly diet and exercise. However, it is recognized that other health behaviors are also important (1). More recently, sleep has been identified as a health behavior that may play a role in obesity as well (2).

Associations between sleep duration and obesity are well-characterized (3). Empirical evidence suggests a strong association between habitual sleep duration and obesity. Proposed mechanisms for this relationship include insulin and glucose dysregulation (4), an orexigenic pattern due to decreased leptin and/or increased ghrelin (5), increased caloric consumption or other dietary changes (6), increased systemic inflammation (7), or decreased physical activity, perhaps due to increased daytime

sleepiness (8). These and other pathways may explain the mechanisms underlying why short sleep may cause increased body weight.

Despite the general agreement across studies that there is an association between sleep duration and obesity (3), there is some notable inconsistency regarding the nature of this relationship. Some studies tend to show a relatively linear negative association between sleep duration and adiposity/obesity (9,10); however, others show a U-shaped association that implicates both short and long sleep duration (11), similar in pattern to the frequently observed relationship between sleep duration and mortality (12). These inconsistencies across studies may be due to differences in measurement approaches for both sleep and obesity/adiposity, differences in adjustment for potential confounders, and differences in the characteristics of study populations, particularly among observational studies.

Since body mass, and associated chronic disease, generally reflects years of accumulated morbidity, it is possible that the relationship

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between sleep duration and body mass may differ across age groups. For example, obesity in young adulthood may reflect more proximal lifestyle and health factors, one of which may be short sleep duration. In addition, childhood obesity may reflect parenting behaviors and availability of calorific foods rather than lifestyle factors. Conversely, obesity in older age may reflect decades of accumulated risk factors, which, in aggregate, outweigh any effect of short sleep duration. For example, the comorbidities which tend to develop with aging may mitigate obesity effects on the causal pathways mentioned above. Thus, the effects of sleep duration on obesity may vary with aging, as has been shown for certain neurocognitive outcomes (13). Further, there is a possibility that hormonal influences (e.g., menopause in women and lower testosterone levels in men) may impact this relationship in the older age population.

The present study assesses whether the cross-sectional association between sleep duration and body mass index (BMI) differs as a function of age. Specifically, it is hypothesized that this sleep duration–BMI relationship will not be linear, but with differing patterns of association across age groups. To assess this possibility, the current analysis explores data from the 2007–2008 National Health and Nutrition Examination Survey (NHANES), a cross-sectional, nationally representative cohort that assessed self-reported sleep duration and objectively determined BMI.

## Methods

### Data source

Participants included respondents to the 2007–2008 NHANES, a national survey conducted by the Centers for Disease Control and Prevention to assess the health and nutritional characteristics of the US population (14). The NHANES data, methodology, surveys, manuals, and procedures have been previously reported and are available online (<http://www.cdc.gov/nchs/nhanes>). Participants responded to questionnaires assessing demographic, socioeconomic, health, and other domains during face-to-face, in-home interviews. To supplement self-report data, physical examination data were gathered in mobile medical facilities. Blacks/African Americans, Hispanics/Latinos, and adults over 60 years were over-sampled to increase the power to detect differences in these groups. The NHANES is designed to ensure generalizability to the entire population across age groups. Given the complexity of the survey design, coupled with variable probabilities of selection, the data used in the following analyses were also weighted to control for representativeness, by following the procedures outlined in the current NHANES Analytic and Reporting Guidelines (15). Presently, data on adults ages 16–80+ years with complete data on our variables of interest were analyzed. All respondents provided informed consent.

### Measures

**Sleep duration.** Sleep duration was assessed with the survey item, “How much sleep do you usually get at night on weekdays or workdays?” Thus, the data do not reflect weekend sleep. Responses were coded in whole numbers. This variable was used for the continuous measure of sleep duration. Sleep duration categories were also computed. Based on previous studies, responses were categorized as “very short” ( $\leq 4$  h), short (5–6 h), average (7–8 h), or long ( $\geq 9$  h). These categories were based on existing literature examining

cardiovascular and metabolic consequences of habitual sleep duration and experimental sleep restriction (16). Although the NHANES sleep duration item is a retrospective self-report (and not an objective or prospective measure of habitual sleep), it has demonstrated utility in many studies.

**Body mass index.** Body mass index (BMI) was computed using objectively measured height and weight recorded during a physical exam. The details of this assessment are reported in the Anthropometry Procedures Manual (17).

**Age.** Age was assessed via self-report. In analyses, age was considered both continuously (to document linear relationships) and categorically (to document nonlinear relationships). Both approaches were chosen *a priori*. Categorical analyses of age examined late adolescents (16–17 years), young adults (18–29 years), younger middle-aged adults (30–49 years), older middle-aged adults (50–64 years), and older adults ( $\geq 65$  years) separately.

**Covariates.** The present study adjusted for potential confounding factors by including the following covariates: Demographic variables included sex, race/ethnicity (Non-Hispanic White, Black/African-American, Mexican-American, Other Hispanic/Latino, or Asian/Other), and marital status (Married, Widowed, Divorced, Separated, Never Married, or Living with Partner), as these factors are known to affect sleep behaviors as well as health outcomes. Socioeconomic factors suspected to affect sleep and health outcomes were also entered as covariates, including education level (less than high school, high school, some college, college graduate) and income to poverty ratio (computed using household income, household size, and federal poverty level). Exercise (minutes of moderate and/or vigorous activity, assessed using standard NHANES methodology) was included as a covariate in all models due to the presence of exercise as a potential confounder, related to both sleep and BMI. Other health risk factors included smoking (number of smoking days in the past 30 days), alcohol (measured as average number of drinks per day over the past 12 months) and both total daily caloric intake and food variety [gathered from detailed dietary interviews (18)]. Depression was included as a dichotomized variable comparing those that felt down, depressed, or hopeless in the past 2 weeks to those that did not.

### Statistical analyses

In analyses, age and sleep duration were considered as both continuous and categorical measures, in order to model both linear and nonlinear relationships. Relationships were first examined using categorical age groups (using both continuous and categorical sleep variables), and then relationships were examined using age as a continuous variable (using both continuous and categorical sleep variables).

Univariate comparisons across age groups for all variables were evaluated using ANOVA or  $\chi^2$  as appropriate. Then, linear regression analyses evaluated differences in BMI associated with sleep duration (as a continuous variable and as a categorical variable, using 7–8 h as reference), stratified across categorical age groups. These analyses were performed in three stages: Model 1 was unadjusted, Model 2 adjusted for sex, race/ethnicity, marital status, income to poverty ratio, education, and exercise, and Model 3 included all Model 2 variables and total caloric intake, food variety, alcohol, and smoking. To examine the relationships with age as a continuous variable, linear regression

analyses examined a sleep duration by age interaction on BMI using both continuous and categorical sleep duration variables. Significant interactions were plotted using three-dimensional graphs for the continuous by continuous interaction and stratified line graphs for the categorical by continuous interaction. Since these relationships may differ for men and women, we performed secondary analyses separately for men and women, as well.

Since BMI among adolescents and younger adults may be better represented by BMI  $z$  scores, we performed a secondary analysis, repeating all tests using BMI  $z$  scores instead of BMI. BMI  $z$  scores for participants  $\leq 20$  years old were created based on Growth Charts from 2000 using the standardized method (19).  $Z$  scores for the rest of the sample were created by subtracting the within-sample mean BMI from each participant's value and dividing by the standard deviation.

Two-tailed  $P$  values of  $< 0.05$  were used as the threshold for the determination of significance. All statistical calculations were performed using STATA/SE version 12 (STATA Corp, College Station, TX).

## Results

### Sample characteristics

Characteristics of the sample are reported in Table 1. All cases were weighted, resulting in a sample that was nationally representative. Sociodemographic, socioeconomic, and health variables were differentially distributed across age groups, justifying their inclusion as covariates. In addition, sleep duration (continuous and categorical) differed by age group, with the longest sleep duration in the youngest group (16- to 17-year-olds) and the shortest sleep duration in the 50- to 64-year-olds. Figure 1 depicts the distribution of sleep duration across age groups. Figure 1(A) depicts continuous sleep duration, and Figure 1(B) depicts sleep duration category.

The sample was not evenly distributed across age groups. For the 16-17 group, there were  $N = 272$  individuals (4.85% of the sample, adjusted to 3.82% after weighting). For the 18-29 group, there were  $N = 1,016$  individuals (18.12% of the sample, adjusted to 21.12% after weighting). For the 30-49 group there were  $N = 1,748$  individuals (31.18%, adjusted to 36.86% after weighting). For the 50-64 group, there were  $N = 1,293$  individuals (23.05%, adjusted to 23.48% after weighting). Finally for those 65 and older, there were  $N = 1,278$  individuals (22.79% of the sample, adjusted to 14.71% after weighting).

### Linear relationships with continuous sleep duration

Results from linear regression analyses can be found in Table 2. In unadjusted analyses, shorter sleep duration was associated with higher BMI, but only among those in the 18-29 and 30-49 years age groups. No significant linear relationship was detected among other age groups. This pattern was maintained in adjusted analyses (which include sociodemographics) and fully adjusted analyses (which include sociodemographics and health risk factors). A linear relationship between sleep duration and BMI was also observed for 16- to 17-year-olds in the adjusted analysis only. These findings are displayed graphically in Figure 2, where filled markers indicate a relationship with  $P < 0.05$ .

### Linear relationships with categorical sleep duration

Results from linear regression analyses with sleep duration categories can be found in Table 3. Among 18- to 29-year-olds, in unadjusted analyses, elevated BMI was seen in very short ( $\leq 4$  h) and short (5-6 h) sleepers, and lower BMI was seen in long (9+ h) sleepers. In adjusted and fully adjusted analyses, the relationships for short and very short sleep were maintained, though slightly attenuated. The finding for long sleep was no longer significant in these models ( $P < 0.10$ ). Among 30- to 49-year-olds, short sleep duration (5-6 h) was associated with elevated BMI in all models. No other significant relationships were found.

### Interactions between sleep duration and age

Sleep duration by age interaction terms in the fully adjusted model were significant for both sleep duration variables. Thus, the relationship between sleep duration and BMI depended on age for both continuous ( $P_{\text{interaction}} = 0.014$ ) and categorical ( $P_{\text{interaction}} = 0.035$ ) sleep duration. The relationship between continuous sleep duration and BMI relative to age is depicted in Figure 3. As seen in this figure, a pseudolinear relationship is seen among the youngest respondents, with the highest BMI associated with the shortest sleepers and the lowest BMI associated with the longest sleepers. This relationship flattens out and becomes slightly concave in middle age, with elevated BMI in both shorter and longer sleepers, and less of a relationship is seen among the oldest respondents.

An alternate pattern is seen in Figure 4, which depicts this relationship using sleep duration categories. In this figure, the pseudolinear relationship can be seen here as well, with the highest BMI in the shortest sleepers and the lowest BMI in the long sleepers. This finding progresses into a slightly U-shaped relationship in middle age respondents. Among the oldest respondents, there is little difference in BMI among sleep duration categories, except that the very short sleepers have nominally higher BMIs as compared to all of the other groups.

To test statistically these patterns, a *post hoc* exploratory analysis was conducted (Figure 5). BMI values and 95% confidence intervals (CI) were plotted against values from 7-8 h sleepers for each age. When the CI does not cross the marker for 7-8 h (the "0" line), that age group could be described as having a higher or lower BMI than the 7-8 h sleepers. This figure demonstrates that although the very short sleepers (panel A) had consistently higher BMI values than the 7-8 h sleepers, groups only differed among the younger respondents (perhaps due to power limitations). For the short sleepers (panel B), smaller, but more consistent differences were seen across age groups). The long sleepers (panel C) did demonstrate lower BMI values for younger respondents and higher BMI values for middle-aged respondents, but these differences were not statistically significant.

### Stratification by sex

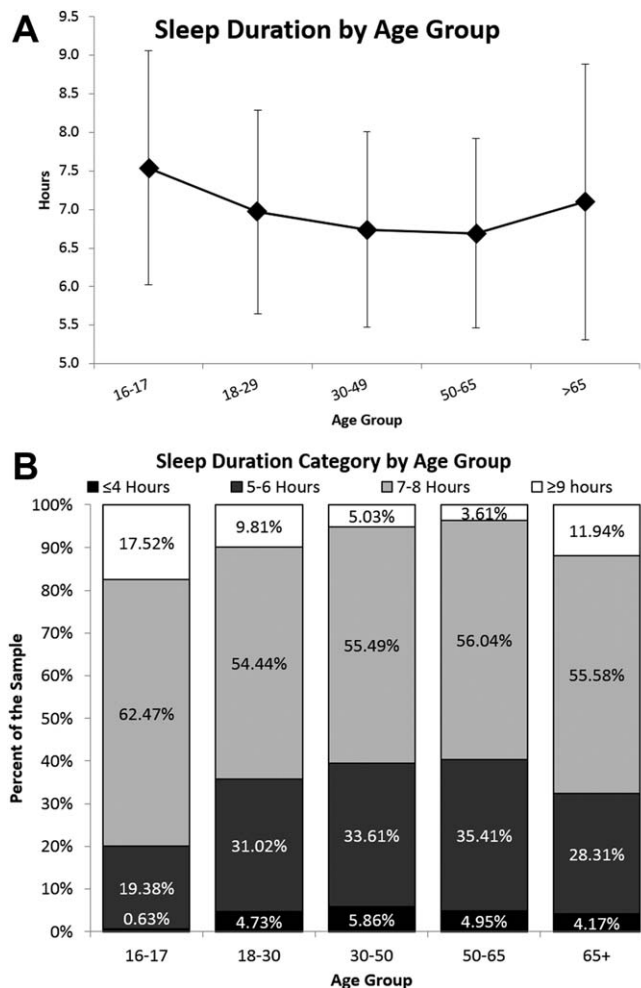
Prior to stratification, interaction terms were computed for continuous and categorical sleep duration and are reported in Supporting Information Table 1. Although none of the interactions were significant (thus mathematically not justifying stratification), we performed exploratory stratified analyses. Although not statistically significant, a trend towards a stronger relationship between sleep and BMI was

**TABLE 1** Characteristics of the analytic sample, overall and stratified by age

Variable	Category	Overall sample	Stratification by age group				P*	
			16-17	18-29	30-49	50-64		≥65
Age	Years	100%	3.82%	21.12%	36.86%	23.48%	14.71%	
	kg/m <sup>2</sup>	44.3 ± 17.5	16.4 ± 0.6	23.6 ± 3.2	40.1 ± 5.2	56.1 ± 4.3	73.4 ± 6.6	<0.0001
BMI	z score	28.3 ± 6.7	24.1 ± 6.1	27.1 ± 6.7	28.7 ± 6.1	29.5 ± 6.5	28.3 ± 7.1	<0.0001
	Nonobese	-0.01 ± 1.02	0.56 ± 1.26	-0.08 ± 1.04	-0.05 ± 0.91	0.07 ± 0.98	-0.12 ± 1.07	<0.0001
Obese	Obese	67.54%	83.44%	74.40%	66.42%	59.97%	68.45%	<0.0001
	Hours	32.46%	16.56%	25.60%	33.58%	40.03%	31.55%	<0.0001
Sleep duration groups	Hours	6.86 ± 1.38	7.54 ± 1.52	6.97 ± 1.32	6.74 ± 1.27	6.69 ± 1.23	7.10 ± 1.79	<0.0001
	≤4 h	4.96%	0.63%	4.73%	5.86%	4.95%	4.17%	<0.0001
Gender	5-6 h	32.16%	19.38%	31.02%	33.61%	35.41%	28.31%	
	7-8 h	55.68%	62.47%	54.44%	55.49%	56.04%	55.58%	
Race	≥9 h	7.20%	17.52%	9.81%	5.03%	3.61%	11.94%	
	Female	51.61%	53.13%	48.58%	51.80%	50.92%	56.19%	0.0954
Marital status	Male	48.39%	46.87%	51.42%	48.20%	49.08%	43.81%	
	White	70.00%	66.58%	63.49%	66.59%	73.85%	82.65%	<0.0001
Income to poverty	Hispanic	12.94%	15.57%	17.83%	15.35%	8.60%	6.14%	
	Black	11.25%	14.44%	12.86%	12.09%	9.99%	7.99%	
Education	Other	5.81%	3.41%	5.82%	5.97%	7.56%	3.22%	
	Married	54.90%	0.00%	26.17%	64.49%	69.15%	57.13%	<0.0001
Energy intake	Widowed	5.23%	0.00%	0.00%	0.69%	3.40%	27.18%	
	Divorced	9.81%	0.00%	2.14%	11.28%	14.33%	10.73%	
Alcohol	Separated	2.36%	0.00%	1.71%	3.05%	2.95%	1.08%	
	Never married	20.86%	100.00%	53.51%	12.76%	7.26%	2.79%	
Smoking	Living with partner	6.85%	0.00%	16.48%	7.73%	2.91%	1.09%	
	Minutes	166 ± 220	186 ± 211	217 ± 217	186 ± 224	139 ± 187	84 ± 182	<0.0001
Number of foods	Ratio	3.01 ± 1.65	2.77 ± 1.86	2.51 ± 1.52	3.09 ± 1.52	3.59 ± 1.58	2.64 ± 1.80	<0.0001
	Less than high school	23.08%	94.08%	19.98%	19.42%	16.91%	28.37%	<0.0001
Depression	High school graduate	23.57%	1.75%	23.06%	22.51%	25.29%	29.82%	
	Some college	29.32%	4.17%	39.24%	29.19%	29.47%	21.63%	
Depression	College graduate	24.03%	0.00%	17.72%	28.88%	28.33%	20.18%	
	kcal	2,180 ± 1,040	2,180 ± 1,071	2,399 ± 1,131	2,292 ± 954	2,116 ± 975	1,695 ± 787	<0.0001
Smoking	Drinks/day past 12 months	1.92 ± 2.65	N/A	3.303 ± 2.941	2.226 ± 2.633	1.469 ± 1.933	0.760 ± 1.316	<0.0001
	Days smoked past 30 days	5.88 ± 11.62	N/A	7.599 ± 11.261	7.072 ± 11.494	5.637 ± 11.460	2.561 ± 10.361	<0.0001
Depression	#	16.8 ± 6.3	13.0 ± 5.6	15.1 ± 5.6	16.8 ± 5.7	18.1 ± 6.2	18.2 ± 7.5	<0.0001
	Yes	23.82%	N/A	22.74%	26.79%	21.64%	21.50%	

Values presented as mean ± standard deviation or percent. Alcohol, smoking, and depression were not measured in the youngest age group. \*P value from ANOVA or  $\chi^2$ , as appropriate.





**Figure 1** (A) Sleep duration assessed as a continuous variable across age groups. (B) Proportion of the sample in each sleep duration category in each age group.

observed in women compared to the men when stratifying by sex, as can be seen in Supporting Information Tables 2 and 3. Since interaction terms were not significant, these results should be interpreted with appropriate caution, though.

### Analysis of BMI z scores

Analyses of BMI z scores for the complete sample are reported in Supporting Information Tables 4 and 5. Supporting Information Table 4 shows that continuous sleep duration was associated with BMI z scores among the 18-29 and 30-49 age groups. Supporting Information Table 5 shows that sleep duration of ≤4 h was associated with significantly higher BMI z scores among those age 16-17 and 18-29, and sleep duration of 5-6 h was associated with higher BMI z scores among those age 18-29 and 30-49.

Sex-stratified results for analysis of BMI z scores are reported in Supporting Information Tables 6, 7, and 8. Supporting Information Table 6 shows that there were no significant interactions, so interpretation of stratified analyses were performed with caution. Stratified analyses suggested a trend towards significance; as with BMI, relationships with BMI z scores were generally stronger among women. As above, sex-stratified results (reported in Supporting Information Tables 7 and 8) should be interpreted with appropriate caution.

### Discussion

This study examined data from 2007 to 2008 NHANES to determine whether the relationship between sleep duration and BMI varies based on age. Sleep duration was assessed both continuously and categorically. In both cases, significant interactions were observed. *Post hoc* analyses of these interactions identified a pattern such that younger adults demonstrate a relatively linear negative association between sleep duration and BMI, middle-aged adults show a more U-shaped relationship, and older adults show a more attenuated relationship, with a possible association only for very short sleep duration.

### Sleep duration and BMI patterns associated with age

The present study examined age as both a continuous and categorical variable. This approach was taken because many previous studies of sleep across the lifespan have used age as a continuous variable, to chart differences in sleep by year. However, many previous studies have also shown that the relationship between sleep and age is nonlinear, and there may be important relationships that differ between adolescents, young adults, middle-aged adults, and older adults. For example, sleep need is greater among adolescents,

**TABLE 2** Linear regression results of relationships between sleep duration and BMI, stratified by age group

Model	16-17, β (95% CI)	18-29, β (95% CI)	30-49, β (95% CI)	50-64, β (95% CI)	≥65, β (95% CI)
Unadjusted	-0.47 (-1.07, 0.14)	*** -0.75 (-1.12 to -0.38)	** -0.36 (-0.64 to -0.09)	-0.27 (-0.63 to 0.10)	-0.25 (-0.52 to 0.03)
Adjusted <sup>a</sup>	* -0.57 (-1.13, -0.01)	*** -0.82 (-1.25 to -0.39)	* -0.35 (-0.63 to -0.06)	-0.26 (-0.65 to 0.13)	-0.26 (-0.55 to 0.02)
Fully adjusted <sup>b</sup>	-0.54 (-1.10, 0.01)	*** -0.75 (-1.20, -0.31)	* -0.31 (-0.62, -0.00)	-0.34 (-0.73, 0.05)	-0.17 (-0.47, 0.13)

β values reflect difference in BMI for each increased hour of sleep.

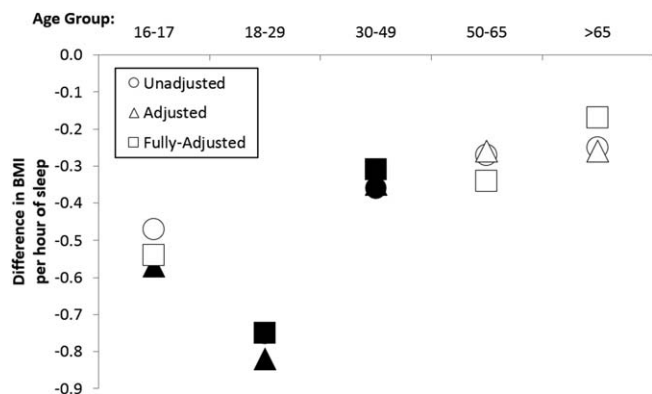
\*P < 0.05.

\*\*P < 0.01.

\*\*\*P < 0.001.

<sup>a</sup>Adjusted analyses include sex, race/ethnicity, marital status, exercise, income to poverty ratio, and education.

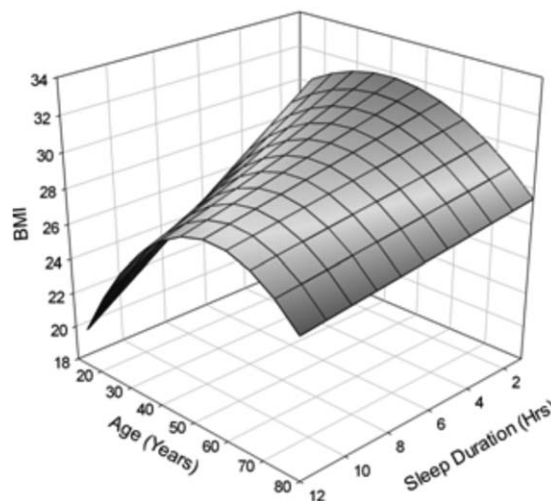
<sup>b</sup>Adjusted for sex, race/ethnicity, marital status, exercise, income to poverty ratio, education, total caloric intake, alcohol, smoking, number of foods in diet, and depression.



**Figure 2** Graphical depiction of regression results showing the relationship between continuous BMI per hour of sleep, stratified by age group. Filled symbols represent statistically significant findings.

subjective sleep disturbances peak in young adults, some sleep problems peak in middle age, women experience severe sleep problems due to menopause, and objective sleep disturbances are well-documented in the elderly. Given that 18- to 29-year-olds tend to sleep more than older adults, the relationship between sleep and BMI could be most pronounced in this age group since short sleep compared to a longer sleep duration would be proportionally more sleep restriction than when total sleep time tends to be lower (as in middle/older adults). Also, exposure to different types of stress at different ages may play a role in both short sleep and higher BMI among various age groups (20).

It is notable that the relationship in middle adulthood reflects a U-shaped association, such that long sleep is also associated with



**Figure 3** Three-dimensional plot of regression results for the relationship between sleep duration and BMI, and how this varies by age, with all factors expressed as continuous variables.

higher BMI. This age range may be associated with hormonal changes in both men and women, though this relationship may be more pronounced in women (21). The present study attempted to account for variables known to affect sleep and health outcomes, but it is plausible that unknown covariates (i.e., residual confounding) were not accounted for in the analysis.

It is plausible that the reason for attenuated results among older adults reflects accumulated morbidity, such that effects of sleep on body weight have already manifest or other accumulated effects on BMI

**TABLE 3** Relationships between sleep duration category and BMI, stratified by age group

Model	Sleep category	16-17, β (95% CI)	18-29, β (95% CI)	30-49, β (95% CI)	50-64, β (95% CI)	≥65, β (95% CI)
Unadjusted	≤4 h	5.22 (−2.82, 13.27)	***4.32 (1.86, 6.78)	1.23 (−0.00, 2.46)	1.98 (−0.58, 4.54)	1.24 (−0.54, 3.01)
	5-6 h	1.48 (−0.61, 3.58)	*1.58 (0.35, 2.80)	**1.24 (0.42, 2.06)	0.46 (−0.54, 1.46)	0.76 (−0.23, 1.75)
	7-8 h	Reference	Reference	Reference	Reference	Reference
	≥9 h	0.30 (−2.18, 2.77)	*−1.43 (−2.78, −0.07)	0.31 (−1.64, 2.26)	0.13 (−1.79, 2.05)	−0.32 (−1.27, 0.63)
Adjusted <sup>a</sup>	≤4 h	5.08 (−1.91, 12.07)	**3.49 (0.89, 6.09)	0.77 (−0.48, 2.02)	1.71 (−1.05, 4.46)	1.38 (−0.34, 3.11)
	5-6 h	0.97 (−0.93, 2.87)	**2.13 (0.77, 3.48)	**1.16 (0.32, 2.00)	0.51 (−0.47, 1.49)	0.78 (−0.21, 1.77)
	7-8 h	Reference	Reference	Reference	Reference	Reference
	≥9 h	−0.14 (−2.61, 2.34)	−1.61 (−3.38, 0.15)	−0.02 (−1.95, 1.91)	0.16 (−1.71, 2.02)	−0.35 (−1.34, 0.63)
Fully adjusted <sup>b</sup>	≤4 h	4.91 (−2.03, 11.85)	2.35 (−0.32, 5.01)	0.44 (−0.92, 1.81)	2.12 (−0.71, 4.94)	1.30 (−0.48, 3.07)
	5-6 h	1.49 (−0.48, 3.47)	*1.87 (0.44, 3.30)	**1.22 (0.32, 2.11)	0.57 (−0.44, 1.59)	0.50 (−0.54, 1.54)
	7-8 h	Reference	Reference	Reference	Reference	Reference
	≥9 h	0.46 (−1.93, 2.86)	−1.84 (−3.72, 0.04)	0.01 (−2.06, 2.07)	0.33 (−1.54, 2.20)	−0.17 (−1.22, 0.89)

β values reflect difference in BMI for each sleep duration group, relative to 7-8 h.

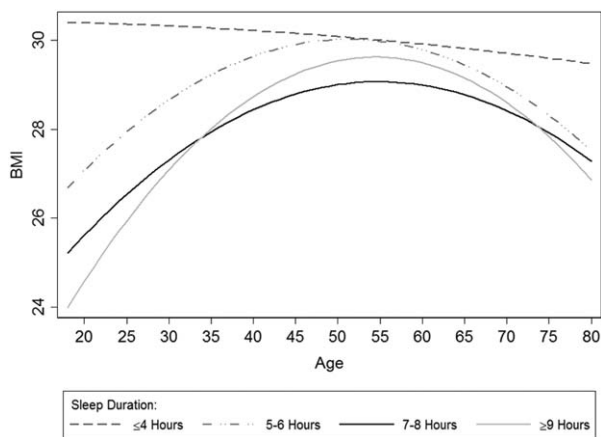
\*P < 0.05.

\*\*P < 0.01.

\*\*\*P < 0.001.

<sup>a</sup>Adjusted analyses include sex, race/ethnicity, marital status, exercise, income to poverty ratio, and education.

<sup>b</sup>Adjusted for sex, race/ethnicity, marital status, exercise, income to poverty ratio, education, total caloric intake, alcohol, smoking, number of foods in diet, and depression.



**Figure 4** Graphical representation of the relationship between categorical sleep duration and BMI as it relates to age. Age is on the X axis and BMI is on the Y axis, with separate lines for different sleep duration categories.

have overshadowed effects of current sleep. Also, adults who survive to old age tend to be healthier than those who have succumbed (i.e., survivor effects). Perhaps individuals with a lifetime of suboptimal sleep, especially in those for whom sleep would play a major impact in these factors, did not survive to older age. This notion is consistent with findings related to sleep apnea in the elderly where a protective effect of apnea has been postulated (22). Although untreated sleep apnea is associated with elevated cardiometabolic mortality risk, this risk is significantly attenuated in the elderly (23).

### Previous studies of sleep duration and BMI

Previous studies have found inconsistent results when examining sleep duration and BMI. After examining the ages of participants in the conflicting studies, varying age ranges and average ages of the participants may explain the varying results (24). Marshall et al. (24) examined inconsistent findings by age group and found similar age-related patterns.

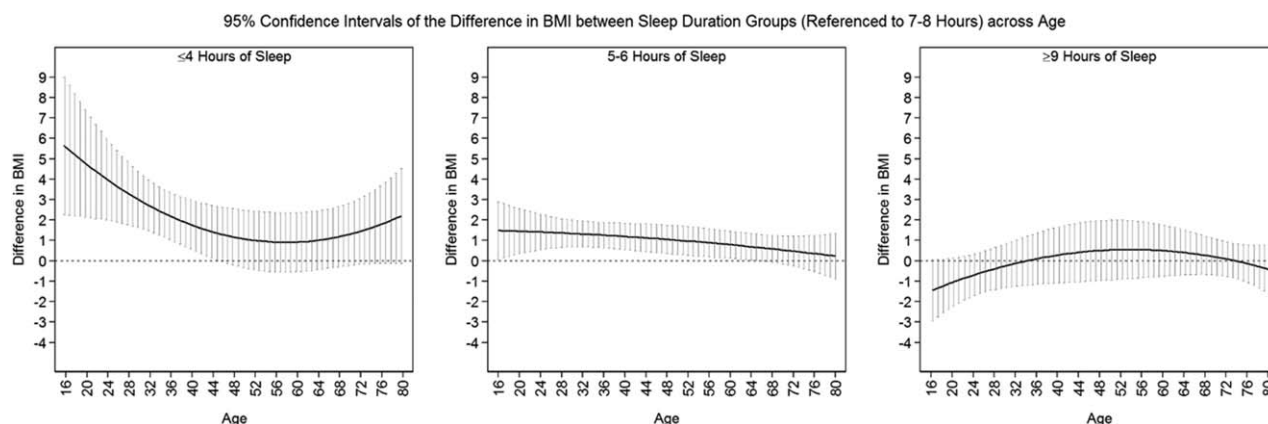
For instance, several studies had large age ranges such as: 17-65 ( $N = 64,110$ ) (25), 20-80 ( $N = 1,042$ ) (26), 20-92 ( $N = 1,203$ ) (27), 30-81 ( $N = 316$ ) (28), 30-102 ( $N = 1,116,936$ ) (29), and 17-83 ( $N = 4,793$ ) (30). Although a large age range may improve generalizability of the sample, the inclusion of age as a linear covariate may be obscuring the relationship between BMI and sleep duration. This notion may especially be the case for studies which included multiple age ranges, reflecting different patterns of association.

Studies that included greater numbers of younger participants tended to find a linear relationship (25,31-33). Studies with middle-aged participants more frequently found U-shaped associations between sleep duration and BMI/obesity (29,34,35) or at least found part of this U-shaped relationship with long sleepers having higher BMI (36). Nagai and colleagues (37) found that long sleep duration increased the risk of a participant’s gaining weight, but only if they already had obesity. Hasler and colleagues suggest that part of the relationship between short and/or long sleep and obesity may depend on age-related patterns of psychopathology (38). Previous research has shown that the relationship between sleep and weight decreased with age (39), which is also what was found in the current study.

### Limitations

There are several limitations with the current study. One is that this is a cross-sectional analysis, therefore we cannot make inferences with regards to causality. Future research should include a greater emphasis on longitudinal studies to examine how sleep and BMI vary by age within an individual over time. Multiple longitudinal cohorts with different ages of participants would help to corroborate and extend our findings. Mechanistic research is also critical to draw rigorous conclusions.

In addition, sleep duration was measured by a single self-report item. More reliable results could be achieved through objective means (e.g., actigraphy) or other prospective self-reports (e.g., sleep diaries). Also, asking for an overall sleep duration may be less accurate than using validated questionnaires that include measures of sleep duration, or getting multiple subjective sleep durations over several days or weeks (including weekends), or computing sleep duration based on sleep



**Figure 5** Separate plots of the relationship between sleep duration category (relative to 7-8 h sleepers) and BMI, across age groups, with 95% confidence intervals for each age. This shows how there are significant relationships, but only in certain age ranges.



timing (24,40). Nonetheless, we view a single self-reported sleep duration as a crucial variable clinically, since clinicians will typically intervene based on this information rather than more objectively obtained longitudinal data.

A third limitation is that there were relatively small sample sizes for both extreme sleep durations as well as extreme age groups. These power limitations resulted in unstable parameter estimates. Also, there could be additional factors affecting some of these smaller groups. As mentioned above, there might be something systematically different about middle-aged adults who are able to sleep nine or more hours a day, especially given that people in this age cohort tend to work, raise families, and otherwise maintain schedules where excessive sleep duration is unfeasible. Further research should seek underlying mechanisms and to acquire larger samples of participants from extreme sleep durations and age groups so as to maximize statistical predictions.

## Conclusion

This current study attempts to explain why there have been inconsistent results when examining sleep duration and BMI. The relationship between these two variables likely depends on age. In young adults, this relationship between sleep and BMI is linear, where more sleep is associated with lower BMI. However, this relationship changes for the middle-aged where 7-8 h of sleep is associated with the lowest BMI, and both short and long sleepers tend to have a higher BMI. In older adults, the association between sleep duration and BMI weakens. Due to the changing relationship among age, sleep and BMI, these data suggest that simply including age as a linear covariate may not most accurately account for this relationship. Researchers may need to consider stratification for different age groups. **O**

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