Article

Associations between Sleep Duration and Body Mass Index in the US Adult Population

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Abstract:

Introduction: This is a secondary data analysis of the association between sleep duration and BMI in the adult population, while controlling for confounders that may not have been thoroughly accounted for in previous cross-sectional studies.

Methods: The 2013-2014 United States' National Health and Nutrition Examination (NHANES) cross-sectional survey data was used to extract the sample of N=21,329 adults between the ages of 20 and 79 with a BMI of 50 kg/m^2or less. The sample was weighted to achieve national representativeness. Multivariable linear regression models were used to examine the relationship between BMI and sleep-hours, while controlling for sociodemographic characteristics, lifestyle, and health status. Confounding variables included respondent's sex, age, race, household income, education level, participation in moderate/vigorous physical activity, alcohol use, depression screening score, and perception of health status. Multivariable linear regression results are reported for the overall sample and by age groups.

Results: Mean BMI and the prevalence of obesity were higher in those with both short (0-6h) and long (10h or more) sleep as compared to those with normal (7-9h) sleep. The overall model (R^2=9.2%) showed that sleep duration was negatively associated with BMI (β=-0.114, p=.002), while controlling for confounding factors. The association between the number of hours of sleep and body mass index (BMI) is most detrimental in adults with annual incomes below $75,000 (β= -0.942, p<.001). However, the regression models by age group showed that sleep duration and BMI were positively associated in younger adults (β=0.234, p=.010), negatively associated in middle-age (β= -0.172, p<.001) and, not associated in the older adults (p=.250); the model explains the highest proportion of variance (R^2=11.8%) in the middle age group (30 to 64 years old). In all age groups, higher incomes are associated with lower average body mass index.

Discussion: The association between sleep duration and BMI adds to the existing body of evidence indicating that obesity is a disease with complex interactions and the number of hours of sleep is a potential risk factor, especially in families with lower annual incomes.

Keywords: sleep, obesity, socioeconomic, chronic disease, depression

INTRODUCTION

The obesity epidemic in the US contributes to an increased incidence of chronic health conditions, including type 2 diabetes, cardiovascular disease, degenerative joint disease, and malignancies (Ogilvie & Patel, 2017). It also coincides with a general reduction in sleep-hours, raising questions of a possible association between number of hours of sleep and body mass index (Patel et al., 2008). Indeed, over the past 50 years, Americans have lost 1.5 to 2h of sleep (Cappuccio et al., 2008). Several expert panels recommend that adults receive seven to nine hours of uninterrupted nightly sleep, but these guidelines have been poorly

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followed (Cooper, Neufeld, Dolezal, & Martin, 2018; Ford et al., 2014; Ogilvie & Patel, 2017). In 2014, more than one-third of the American adult population (33.8%) did not meet these recommendations (Ogilvie & Patel, 2017).

The research supporting a relationship between short sleep and obesity in adults is conflicting and potentially explained by confounders (Ogilvie & Patel, 2017). While most cross-sectional studies demonstrated an association between sleep and obesity, results from cohort studies have been mixed (Patel & Hu, 2008; Vgontzas et al., 2014). The pathophysiologic link between insufficient sleep and an increased BMI is not well understood; it may involve changes in appetite, physical activity, and thermoregulation among those with a sleep deficit (Patel & Hu, 2008). Insufficient sleep may also have deleterious metabolic effects on insulin sensitivity, glucose regulation, and inflammatory markers that predispose to weight gain (Marshall, Glozier, & Grunstein, 2008). Experimental studies have shown sleep restriction to result in dysregulation of the so-called hunger hormones of ghrelin and leptin (Marshall et al., 2008; Sun et al., 2015).

The most significant associations between sleep and obesity were found in studies focused on children (Patel & Hu, 2008). In adults, the evidence is less clear; while most cross-sectional studies demonstrated an association between short sleep and obesity (Patel, Malhotra, White, Gottlieb, & Hu, 2006), a few have had mixed results, such as reporting an association in men, but not in women (Sun et al., 2015). Cohort studies' results have been inconsistent; some found an association between sleep and BMI across all demographic groups (Patel et al., 2006; Sayon-Orea et al., 2013; Xiao, Arem, Moore, Hollenbeck, & Matthews, 2013), while others reported, for example, an increased risk of obesity in younger women, but not in older women (Theorell-Haglow, Berglund, Berne, & Lindberg, 2014). Other studies found no association between sleep and obesity (Vgontzas et al., 2014) or no association after adjustment for confounding variables (Tamakoshi, 2004). Further, some studies reported a significant curvilinear relationship, with the lowest risk found at 7-8h of sleep and odds rising for shorter and longer sleep durations (Marshall et al., 2008).

The Nurses' Health Study data collected from a cohort of 68,183 women 16 years or older showed that, over time, those who slept 5h or less gained 1.14 kg more than women with seven to eight hours of sleep (Patel et al., 2006). The association between longer periods of sleep and obesity may be explained by confounding variables, such as depression, other health conditions, and low socioeconomic status (Ogilvie & Patel, 2017). This cross-sectional secondary analysis evaluates the association between sleep duration and BMI in the US adult population while controlling for known and other potential confounders.

METHODOLOGY

Study population

This is a secondary data analysis of the 2013-2014 National Health and Nutrition Examination Survey (NHANES). The NHANES (CDC, 2013-2014) uses a cross-sectional survey design for which a probability sample is selected annually. The probabilistic sampling technique was developed by the primary investigators at the United States' National Center for Health Statistics (Ford et al., 2014). The anonymized data is publicly available for download on the website of the Centers for Disease Control and Prevention (CDC). The NHANES surveys are collected through home interviews, while subsequent physical examinations and laboratory biospecimen were collected via mobile centers (Ford et al., 2014).

The sample is intended to be nationally representative, and thus, it must be weighted. The sampling weight variable [WTMEC2YR], included in the data publicly available for download, calibrates the sample proportions to reflect the proportions of various groups in the United States' (US) national population at the time the sample was randomly extracted. In this study, the sampling weight variable was divided by a factor of 10,000, to ensure the representativity of the sample for the 2013 to 2014 US population, while avoiding a dataset of hundreds of millions of records that would have rendered unreliable the results of the tests known to be sensitive to the sample size (ex, the chi-square test of independence). The study includes all of the records for the adults ages 20 to 79, with a BMI of up to 50, who had a valid response on the sleep variable. In total, there were 43,198 adult participants between the ages of 20 and 79 who had BMI data in the 2013-2014 cycle, of which only 21,329 had data on BMI and on sleep.

Sleep

The exposure in this study is the nightly sleep duration. The 2013-2014 NHANES survey included a question about the number of hours of sleep per night. The question asked was: "How much sleep do you usually get at night on weekdays or workdays?"; the variable name is [SLD010H]. The number of hours of sleep was capped at 12; thus, all responses of 12 hours or more were recorded as 12 hours. For this study, for the purpose to develop comparable exposure groups, we recoded this variable into a new ordinal variable with three categories of sleep: short (0 to 6 hours), normal (7 to 9 hours), and long (10 to 12 or more hours), using the National Sleep Foundation guidelines.

Obesity

The disease in this study is obesity as measured by the body mass index (kg/m2). The 2013-2014 NHANES survey includes the body mass index (BMI) as a previously computed variable [BMXBMI]. Obesity, which is defined as a BMI of 30 or greater, has more than doubled from 15% in the late 1970's to 35% of men and 40% of women in 2014 (Cooper et al., 2018; Patel et al., 2008; Patel & Hu, 2008). Body mass index was recoded into an ordinal variable with three categories: underweight/ normal weight (BMI less than 25), overweight (25 to 29.9), and obese (30 or greater). Individuals with a BMI score above 50 kg/m2 were considered outliers and were excluded from the analyses.

Confounding Factors

The potential confounding variables that were identified during the literature review were prepared for analyses as described below:

Age (Cho, Cho, Hur, & Shin, 2018) was collected as a numeric variable capped at 80; the older adults with ages 80 or older are grouped with the 80-year-old people; thus, all adults 80 or older were excluded from this study. Age was used as numeric variable in the overall regression. Age as an ordinal variable with three categories (young adults 20 to 29, middle-age adults 30 to 64, and older adults ages 65 to 79) was used to report on bivariate relationships and as a stratification criterion for regression models

Sex (Bjorvatn et al., 2007; Lauderdale et al., 2009) was measured as male or female.

Race (Ford et al., 2014; Jean-Louis, 2014; Xiao et al., 2013) was coded as Non-Hispanic White, Non-Hispanic Black, Non-Hispanic Asian, Hispanic, and Other/Multi-racial. For the multivariable linear regression, race was recoded into a binary variable *White*, with (1) for White, and (0) for non-White respondents.

Annual Family Income (Singh, 2005) is available as an ordinal variable with 12 valid categories, which was recoded into a binary variable coded as (0) if less than $75,000 and as (1) for incomes of $75,000 or greater.

Education Level (Sun et al., 2015; Xiao et al., 2013) is available for all adults ages 20 or older and was measured as an ordinal variable with five valid categories, which was recoded into an ordinal variable with three categories: (1) less than high school, (2) high school, and (3) greater than high school). For the regression analysis, a binary education variable separated respondents with at least high school education (1) from those with less than high school education (0).

Physical Exercise (Maugeri et al., 2018; Theorell-Haglow et al., 2014): Five variables were used to develop a binary variable to measure participation in moderate or vigorous physical activities, coded as (1) for participation in moderate or vigorous activities and coded as (0) for no participation in moderate or vigorous activities. If respondents answered 'yes' to any of these five they were coded with (1) and if they answered 'no' they were coded with (0). The five variables are: [PAQ605] Does your work involve vigorous-intensity activity that causes large increases in breathing or heart rate like carrying or lifting heavy loads, digging or construction work for at least 10 minutes continuously?"; [PAQ620] "Does your work involve moderate-intensity activity that causes small increases in breathing or heart rate such as brisk walking or carrying light loads for at least 10 minutes continuously?"; [PAQ635] "In a typical week, do you walk or use a bicycle for at least 10 minutes continuously to get to and from places?"; [PAQ650] "In a typical week, do you do any vigorous-intensity sports, fitness, or recreational activities that cause large increases in breathing or heart rate like running or basketball for at least 10 minutes continuously?"; and [PAQ665] "In a typical week, do you do any moderate-intensity sports, fitness, or recreational activities that cause a small increase in breathing or heart rate such as brisk walking, bicycling, swimming, or volleyball for at least 10 minutes continuously?"

Depression (Tamakoshi, 2004; Theorell-Haglow et al., 2014): The symptom items of the PHQ-9 scale are measured using questions, such as: "Over the last 2 weeks, how often have you been bothered by the following problems: little interest or pleasure in doing things? Would you say..." (0) not at all, (1) sometimes, (2) often, and (3) all of the time). Specifically, the nine items measured the following problems: [DPQ010] little interest or pleasure in doing things; [DPQ020] feeling down, depressed, or hopeless; [DPQ030] trouble falling or staying asleep, or sleeping too much; [DPQ040] feeling tired or having little energy; [DPQ050] poor appetite or overeating; [DPQ060] feeling bad about yourself; [DPQ070] trouble concentrating on things; [DPQ080] moving or speaking slowly or too fast; [DPQ090] thoughts you would be better off dead. A summed score ranging from 0 to 27 was computed for all respondents with complete responses to these nine items. The reliability analysis showed that Cronbach's α for the summed depression score is α=0.839. The overall score was then recoded into an ordinal variable with three categories: (1) 0 to 4 indicating minimal or no risk for depression, (2) 5 to 9 indicating a mild risk for depression, and (3) 10 to 27 indicated a higher risk to be diagnosed with depression. A binary variable was computed based on the summed score as (0) for scores less than 10 indicating no /minimal/mild risk to be diagnosed with depression and (1) for scores of 10 or above, which indicate an increased risk to be diagnosed for depression and the need to be seen by a physician.

Perceived Health (Kripke, Garfinkel, Wingard, Klauber, & Marler, 2002; Xiao et al., 2013) condition was measured with the standard question "Would you say your health in general is... excellent, very good, good, fair, or poor". For the bivariate analyses, the original variable was recoded into an ordinal variable with three categories (very good or excellent, good, and fair or poor), while for the multivariable regression it was recoded into a binary variable where (1) is excellent or very good health condition and (0) is for good, fair, or poor health condition.

Alcohol Use (Vgontzas et al., 2014) was measured by asking: "In the past 12 months, how often did you drink any type of alcoholic beverage? PROBE: How many days per week, per month, or per year did you drink? The information provided in two variables, one for the number of days [ALQ120Q] and the other for the unit of measurement [ALQ120U], were used to compute a new variable measuring the number of days when the respondent drank any type of alcohol beverage in the past year. A binary variable was computed with (0) none or one day, and (1) drank 2 or more days.

Statistical analysis

The groups with short, normal, and long sleep were contrasted and compared on relevant variables in terms of traditional univariate statistics (percentages or means and standard deviations), as shown in Table 1. Traditional bivariate statistics were used to test the relationship between the exposure and the disease, between the exposure and the confounding factors, and between the confounding factors and the disease. Table 2 reports on the crosstabulation analyses with $\chi 2$ test of independence to compare the three groups measuring the exposure (short, normal, and long sleep-hours) across relevant categorical variables, and on the analyses of variance (ANOVA) used to compare the three exposure groups on their average age, BMI, and depression score. In addition, the results of the bivariate correlation between the numeric variables (age, BMI, depression score, and sleep measured in hours) are also reported. Finally, a simple unadjusted linear regression was used to estimate the ordinary least square coefficients for sleep-hours used to predict the BMI (kg/m^2).

The multivariable regression model estimates the average BMI by sleep-hours, while controlling for the confounding variables identified during the bivariate analyses to be significantly related to the disease; these confounding variables include respondent's age in years, and a series of binary variables coded as (1) if they have the measured characteristics: high school education or above, income of $75,000 or above, participates in moderate or vigorous physical exercise, with a depression score of 10 or above, drank alcohol on two or more days within the past 12-month, and is in excellent of very good health condition. An overall multivariable regression model used age as numeric, while a stratified multivariable regression led to separate models for each of the three age groups. The sex of the respondent was excluded from the final model because it was not statistically significant. The most parsimonious overall and age-group regression models are reported here. All statistical tests were two-sided, using 95% confidence intervals and a significance level of α=.05. Thus, all p-values that are less than α=.05 are reported as statistically significant. The data analyses were conducted with IBM SPSS 26.0.

RESULTS

The weighted 2013-2014 NHANES dataset of 43,198 participants included N=21,329 respondents with valid data on both the BMI and the sleep duration. Table 1 reports the valid number of records for each variable and for each category of the categorical variables and the means and standard deviations for the numeric variables. The final sample size is N=21,329.

The average age in the sample of 21,329 respondents is 46 years, with a standard deviation (SD) of 15.9 years. Of these, 10,398 (48.8%) are men and 10,931 (51.2%) are women; 13,830 (64.8%) are non-Hispanic White. Majority of the respondents in the sample have greater than high school education (13,539 or 63.5%), and most have annual family incomes below $75,000 (11,977 or 56.1%). Almost a third of the sample (5,325 or 30.4%) drank alcohol on two or more days within the past 12 months. Majority of the respondents engage in moderate to vigorous physical exercise (16,582 or 77.7%) and 81.6 percent perceive their health to be good or better; 40.8 percent perceive their health to be very good or excellent and another 40.8 percent stated that they are in good health. The average BMI was 28.8 (SD=6.3) with a median of 27.9; with 29.7% being underweight or with normal weight, 32.9% being overweight, and 37.4% obese. The majority of participants (62.1%) had the recommended seven to nine hours of sleep per night, while 35.4% had six or fewer hours of sleep, and 2.4% had 10 hours or more hours of sleep.

Table 1: Descriptive Statistics for US Adults Ages 20-79 (NHANES 2013-2014)

Variable	**N (valid)**	**Percent Valid** ***Mean (SD)***
Sex (%)	21,329	100.00
Male	10,398	48.8
Female	10,931	51.2
Race (%)	21,329	100.00
Non-Hispanic White	13,830	64.8
Non-Hispanic Black	2,459	11.5
Non-Hispanic Asian	1,195	5.6
Hispanic	3,260	15.3
Other Race	586	2.7
Age (years)	21,329	*45.96 (15.9)*
Age groups (%)	21,329	100.00
20-29	4,210	19.7
30-64	13,928	65.3
65+	3,192	15.0
Household income (%)	19,693	92.30
Low ≤ $25,000	4,106	19.2
Medium $25,000 to < $75,000	7,871	36.9
High ≥$75,000	7,716	36.2
Education (%)	21324	99.97
Less than High school	3,231	15.2
High school / GED	4559	21.4
Greater than high school	13,533	63.5
General health condition (%)	19,901	93.30
Excellent/ very good	8,123	40.8
Good	8,117	40.8
Fair/Poor	3,660	18.4
Alcohol 2+ days in past 12-month (%)	5,325	30.4
Vigorous/moderate activities (%)	16,582	77.7
Depression score (0-27)	19,825	*3.10 (4.24)*
Depression risk (%)	19,825	92.90
None (0)	6,575	33.2
Low (1-4)	8,664	43.7
Medium (5-9)	2,903	14.6
High (10-27)	1,683	8.5
Sleep (hours)	21,329	*6.92 (1.34)*
Sleep-hours (%)	21,329	100.00
Short (0-6)	7,563	35.5
Normal (7-9)	13,254	62.1
Long (10-12)	512	2.4
BMI (kg/m²)	21,340	*28.8 (6.34)*
BMI categories (%)	21,329	100.00
Normal/underweight	6,339	29.7
Overweight	7,012	32.9
Obese	7,979	37.4

Table 2 displays the results of the crosstabulation analyses testing the associations between the sleep-hours (column) and all other categorical variables relevant to the study (rows). Moreover, each of the three sleep-hour groups reports the means of the relevant numeric variables (age, BMI, and depression scores), along with the F-test and its p-value, obtained with the One-Way ANOVA comparison of means test. The columns report the proportion of respondents who have a specific characteristic in the total sample; then, for each exposure group (low, normal, and long sleep-hours), and in the last two columns, it reports the results of the statistical test, the value and its p-value.

The first χ^2 test of independence shows that the differences in proportions of men and women across the three sleep-hours groups were not significant ($\chi^2(2) = 2.13$, $p = .345$), and thus, there is no association between the sex of the respondent and the number of hours of sleep. Next, significant differences were found across race ($\chi^2(8) = 426.34$, $p < .001$) which showed that the non-Hispanic whites were more likely to have seven to nine hours of sleep than all other race groups; hence, a binary variable comparing the non-Hispanic Whites with all other race or ethnic groups was computed and included in the multivariable regression. Additional crosstabulation analyses showed that the group with longer sleep-hours have a significantly greater observed than expected proportion of younger (23.6% vs. 19.7%) and older (20.1% vs. 15%) participants ($\chi^2(4) = 182.735$, $p < .001$) as compared to the middle-age group (56.3% vs. 65.3%). Further, the group with normal hours of sleep is more likely to have a greater than expected proportion of individuals with higher education ($\chi^2(4) = 283.884$, $p < .001$) and with annual incomes greater than $75,000 ($\chi^2(4) = 284.173$, $p < .001$). Moreover, they are more likely to perceive their health to be excellent or very good ($\chi^2(4) = 438.095$, $p < .001$), more likely to engage in moderate or vigorous physical activities ($\chi^2(2) = 32.036$, $p < .001$), although they are more likely to have had two or more drinks in the past 12-month period ($\chi^2(2) = 202.513$, $p < .001$). It is also noteworthy that people who sleep normal or long hours are more likely to have more days when they drank alcohol than those who sleep fewer hours.

One-Way ANOVA also identified significant differences across the three exposure groups in the average body mass index scores ($F(2, 21326) = 32.396$, $p < .001$) with a higher average BMI in the short (0-6h) and long sleep (10-12h) groups than in the group with normal sleep-hours (7-9h). Specifically, the group with normal sleep-hours has a significantly ($p < .001$) lower BMI average (28.5 kg/m^2) than the groups with short or long sleep; and, Tukey B post-hoc test showed that the groups with short (29.3 kg/m^2) and long (29.1 kg/m^2) sleep-hours were not statistically different from each other ($p = .469$). Finally, a third One-Way ANOVA test compared the three groups on their average depression scores; a significant difference was found ($F(2, 19822) = 24.321$, $p < .001$) between the group with normal sleep-hours and the short ($p < .001$) and respectively long ($p < .001$) sleep groups. Posthoc Dunnett T3 test showed no significant difference between the groups with short and long sleep-hours ($p = .277$).

Bivariate Pearson R correlation analyses revealed weak negative correlations between the number of hours of sleep and BMI ($R = -.058$, $p < .001$); between the number of hours of sleep and depression ($R = -.118$, $p < .001$); between the number of days when drank alcohol and depression ($R = -.075$, $p < .001$); and, between alcohol use and body mass index ($R = -.153$, $p < .001$) while significant weak positive correlations were found between BMI and depression ($R = .107$, $p < .001$), and between the number of hours of sleep and the number of days in the past 12-month period when drank alcohol ($R = .088$, $p < .001$).

Table 2. Characteristics of Adults Ages 20-79 by Sleep-hours (NHANES 2013-2014)

Variable	Total	Sleep-hours			χ^2/ F	P
		0-6h	7-9h	10-12h		
Female (%)	51.2	50.6	51.7	50.4	2.3	.319
Race (%)					427.9	<.001
Non-Hispanic White	64.8	58.0	69.0	59.0		
Non-Hispanic Black	11.5	16.2	8.7	16.6		
Non-Hispanic Asian	5.6	5.4	5.9	2.0		
Hispanic	15.3	16.6	14.4	18.6		
Other Race	2.7	3.8	2.1	3.9		
Age (years) Mean (SD)	46.0 (15.9)	44.7 (14.7)	46.6 (16.4)	48.9 (18.2)	42.7	<.001
Age groups (%)					182.7	<.001
20-29	19.7	19.1	20.0	23.6		
30-64	65.3	70.0	62.9	56.3		
65+	15.0	10.9	17.1	20.1		
Household income (%)					284.2	<.001
Low ≤ $25k	20.8	22.8	18.9	43.6		
Medium $25k to < $75k	40.0	42.6	38.5	39.0		
High ≥$75k	39.2	34.7	42.6	17.4		
Education (%)					283.9	<.001
Less than High school	15.2	15.6	14.0	37.1		
High school / GED	21.4	24.3	19.8	20.1		
Greater than high school	63.5	60.1	66.2	42.8		
General health condition (%)					438.1	<.001
Excellent/ very good	40.8	32.8	45.8	30.9		
Good	40.8	43.4	39.3	39.5		
Fair/Poor	18.4	23.8	14.9	29.6		
Alcohol 2+ days /year (%)	30.4	23.8	34.0	34.3	202.5	<.001
Vigorous/moderate activities (%)	77.7	77.1	78.5	68.4	32.1	<.001
Depression score Mean (SD)	3.10 (4.2)	3.91 (4.7)	2.59 (3.8)	4.48 (5.9)	244.3	<.001
Depression risk (%)					504.5	<.001
None (0)	33.2	27.6	36.2	36.0		
Low (1-4)	43.7	41.1	45.6	31.6		
Medium (5-9)	14.6	19.7	11.7	16.3		
High (10-27)	8.5	11.6	6.4	16.0		
BMI (kg/m²) Mean (SD)	28.8 (6.3)	29.3 (6.5)	28.5 (6.2)	29.2 (6.8)	32.4	<.001
BMI categories (%)					80.1	<.001
Normal/underweight	29.7	28.0	30.9	26.0		
Overweight	32.9	30.9	34.0	32.6		
Obese	37.4	41.2	35.1	41.4		

Finally, the association test between the categorical version of the body mass index and of the depression score show that the three exposure groups are significantly different from each other. Specifically, the group with normal sleep-hours has a significantly lower proportion of obese individuals than the other two groups ($\chi^2(4)$ =80.115, p<.001), and a significantly lower proportion of individuals with a large number of depression symptoms ($\chi^2(4)$ =504.457, p<.001). The One-Way ANOVA comparison of means tests showed that the group with 10 or more hours of sleep were on average 48.9 years old, about two years older than the group with normal hours of sleep, and four years older than the group with short sleep. All three exposure groups were significantly different from each other in their average ages (F (2, 21326) = 42.702, p<.001), as shown by the Dunnett's T3 post-hoc tests (p<.05).

A simple unadjusted linear regression, which was performed to predict participants' BMI based on their hours of sleep alone found a significant relationship (F (1, 21327) = 71.204, p < .001) albeit a very small yet significant coefficient of determination R^2 =0.3%. The regression equation for the unadjusted model is:

(1) $Y'_{BMI} = 30.703 + (-0.273)*sleephours$

The multivariable regression (see Table 3) model predicts the body mass index from the number of hours of sleep, while controlling for all of the confounding variables found to be significantly associated with obesity as measured by the BMI. Specifically, all measures presented in Table 1, except the sex of the respondent (p=.368) and race (p=.618) were included. Due to missing values, the sample size for the regression analysis is N=16,327 participants. A squared term was computed for the number of hours of sleep to test whether the relationship between sleep-hours and BMI was u-shaped or curvilinear. The squared term was not statistically significant, and thus, the relationship between obesity and the number of hours of sleep per night is linear, not curvilinear.

The multivariable regression equation for the overall final, best fit, most parsimonious model (that includes only significant effects) is:

(2) $Y'_{BMI} = 29.863 + .036*age + .978*education + (-.942)*income75k + (-1.263)*exercise +$

$+ (-.008)*alcohol + (-2.353)*besthealth + .045*depression + (-.114)*sleephours.$

The multivariable regression model shows that BMI decreases on average by 0.114 kg/m^2 for each extra hour of sleep (F (8, 16318) = 207.403, p < .001, with R^2=9.2%); however, only 0.1 percent of the total amount of variation in the BMI is explained by the number of sleep-hours. The demographic and socioeconomic variables show that as people age the BMI increases by an average of 0.036 kg/m^{2}per year. When adjusting for all other variables in equation, individuals with at least a high school education tend to have a BMI average that is about 0.978 kg/m^2 higher than their counterparts; however, individuals with annual incomes of at least $75,000, have a BMI that is on average 0.942 kg/m^2 lower than their counterparts. As expected, individuals who participate in moderate or vigorous physical activities (β=-1.263 kg/m^2, p<.001) and individuals who perceive their health to be very good or excellent (β=-2.353 kg/m^2, p<.001) have a significantly lower BMI average than those who do not. Finally, individuals with a higher depression score tend to have a significantly higher BMI (β=0.045 kg/m^2, p<.001).

Table 3. Predicting BMI: Multivariable Unstandardized Regression Coefficients

Variables	Coefficient	Std Error	t	P
Constant	29.863	.334	89.373	<.001
Age (years)	0.036	.003	11.869	<.001
High school or greater	0.978	.147	6.670	<.001
Household income $75k+	-0.942	.103	-9.185	<.001
Moderate/Vigorous exercise	-1.263	.120	-10.522	<.001
Alcohol drinking days/year	-0.008	.001	-15.383	<.001
Excellent/Very good health	-2.353	.103	-22.865	<.001
Depression score 10+	0.045	.012	3.790	<.001
Sleeping (hours)	-0.114	.036	-3.133	.002

R^2 = 9.2%

To better understand the relationship between the number of hours of sleep and BMI, both significantly different across the life course, a stratified regression analysis was conducted using age groups as a stratification criterion. Table 4 presents the unstandardized regression coefficients for the three main age groups: 20 to 29, 30 to 64, and 65 to 79, including the same sample of N= 16,327 individuals with a BMI no greater than 50kg/m^2. All else be equal, for one additional hour of sleep, the BMI increases an average of 0.234 kg/m^2 (p<.001) in younger adults, decreases an average by 0.172 kg/m^2 (p<.001) in middle-age adults, and it makes no difference in older adults (p=.250). The stratified regression model supports most of the findings of the overall regression.

Table 4. Predicting BMI: Multivariable Unstandardized Regression Coefficients by Age Groups

Variables	Age 20-29 N=3167	P_{20-29}	Age 30-64 N=10601	P_{30-64}	Age 65-79 N=2560	P_{65-79}
Constant	25.076	<.001	33.083	<.001	29.656	<.001
High school or greater	1.494	<.001	0.939	<.001	0.925	.007
Household income $75k+	-1.187	<.001	-1.226	<.001	-0.529	.039
Moderate/Vigorous exercise	0.850	.015	-1.638	<.001	-1.837	<.001
Alcohol drinking days/year	-0.013	<.001	-0.007	<.001	-0.009	<.001
Excellent/Very good health	-1.560	<.001	-2.818	<.001	-0.901	.001
Depression score 10+	0.076	.016	0.036	.009	0.068	.024
Sleeping (hours)	0.234	.010	-0.172	<.001	0.104	.250
R^2	*4.9%*		*11.8%*		*8.2%*	

Participants with higher education tend to have a higher average BMI, yet individuals with higher annual incomes tend to have significantly lower average BMIs; this is true for all age groups. The difference made by alcohol drinking was also similar across groups; one additional day of drinking alcohol is associated with a slightly lower BMI ($p<.001$). Individuals in the middle age group who perceive their health condition to be excellent or very good have a lower average BMI (β=-2.818 kg/m^2, $p<.001$) than the younger group (β=-1.56 kg/m^2, $p<.001$) or the older group (β=-0.901 kg/m^2, $p<.001$) when compared to their counterparts, which are respondents with perceived good, fair, or poor health. Respondents who have a higher number of depression symptoms (a score of 10 to 27) have significantly higher BMIs than those with depression scores below 10; specifically, the average BMI was higher by 0.076 kg/m^2 (p=.016) in younger adults, by 0.036 kg/m^2 (p=.009) in middle aged adults, and by 0.068 kg/m^2 ($p<.001$) in older adults. Interestingly, physical activity in the younger group was associated with higher average BMI (β=0.850 kg/m^2, p=.015), which may be due to heavier muscle mass, which may indicate that BMI is not the best measure of obesity in younger people who exercise moderately or vigorously. The coefficients of determination indicate that the model explains the most variance in middle aged adults (R^2=11.8%) and the least in the younger adults (R^2=4.8%).

DISCUSSION

This study examined the relationship between sleep and body mass while accounting for known and potential confounders. The relationship between the number of hours of sleep and BMI was similar across gender and race, but was significantly different across age groups. Specifically, sleep duration had a direct proportional relationship with BMI in younger adults (ages 20 to 29) and an inverse linear relationship with BMI in middle age adults (ages 30 to 64), while adjusting for education, household income, alcohol use, exercise, depression, and perception of health condition. However, no association was found between the number of hours of sleep and BMI in older adults (ages 65 to 79). Further, the association between sleep and BMI in the young group (20-29) was positive, indicating an increase in the BMI with every additional hour of sleep. This last finding differs from other studies, likely due to differences in population definition; some studies defined young adults as ages 32 to 49 years old, others as ages 20 to 39 years (Ford et al., 2014; Gangwisch, 2005), while in this study the younger group was defined as people between the ages of 20 to 29 years. Conversely, the association found between the number of hours of sleep and BMI in middle-age adults was negative, indicating that the BMI decreases with every additional hour of sleep; this finding echoes the results of other cross-sectional studies conducted over the last 15 years (Cooper et al., 2018; Ford et al., 2014; Gangwisch, 2005). The lack of a statistical relationship between the number of hours of sleep and BMI in older adults is similar to the mixed results of some previous research (Patel & Hu, 2008; Vgontzas et al., 2014).

A major strength of this study is the use of a large, nationally representative sample. Furthermore, the sleep variable used here, although self-reported, has construct validity (Ogilvie & Patel, 2017) demonstrated by a moderate correlation with polysomnography and actigraphy. The weaknesses include the inability to establish directionality inherent in a cross-sectional design and the limitations associated with secondary data analyses. Future investigations may improve our understanding of the relationship between BMI and sleep by following long-term changes in the BMI while objectively monitoring sleep-hours.

CONCLUSION

The association between sleep and BMI is particularly concerning given that 36% of the NHANES sample reported short sleep . The significantly higher average body mass index in the groups with short and long sleep-hours as compared to the group with normal sleep-hours warrants further investigation. The results of this study underscore the concerns about the recently noted reduction in the number of hours of sleep per night (Cappuccio et al., 2008), which may have significant implications for population health, given its association with obesity, a well-known risk factor for poor physical and mental health in general.

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