



Original Contribution

A Large Prospective Investigation of Sleep Duration, Weight Change, and Obesity in the NIH-AARP Diet and Health Study Cohort

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The relationship between sleep and obesity or weight gain in adults, particularly older populations, remains unclear. In a cohort of 83,377 US men and women aged 51–72 years, we prospectively investigated the association between self-reported sleep duration and weight change over an average of 7.5 years of follow-up (1995–2004). Participants were free of cancer, heart disease, and stroke at baseline and throughout the follow-up. We observed an inverse association between sleep duration per night and weight gain in both men (P for trend = 0.02) and women (P for trend < 0.001). Compared with 7–8 hours of sleep, shorter sleep (<5 hours or 5–6 hours) was associated with more weight gain (in kilograms; men: for <5 hours, β = 0.66, 95% confidence interval (CI): 0.19, 1.13, and for 5–6 hours, β = 0.12, 95% CI: –0.02, 0.26; women: for <5 hours, β = 0.43, 95% CI: 0.00, 0.86, and for 5–6 hours, β = 0.23, 95% CI: 0.08, 0.37). Among men and women who were not obese at baseline, participants who reported less than 5 hours of sleep per night had an approximately 40% higher risk of developing obesity than did those who reported 7–8 hours of sleep (for men, odds ratio = 1.45, 95% CI: 1.06, 1.99; for women, odds ratio = 1.37, 95% CI: 1.04, 1.79). The association between short sleep and excess weight gain was generally consistent across different categories of age, educational level, smoking status, baseline body mass index, and physical activity level.

body mass index; obesity; sleep

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio.

Over the past decades, the increase in the prevalence of obesity (1) in the US population paralleled the decrease in nighttime sleep duration (2), suggesting the possibility that shortened sleep time may contribute to the obesity epidemic (3). Sleep duration is inversely associated with weight gain and the risk of obesity in children and adolescents; however, the relationship in adults, especially in middle-aged and older populations, remains unclear (4–6).

Many earlier studies in which the sleep–weight relationship in adults was examined were cross-sectional, making causal inference difficult (7). To date, 12 prospective studies have evaluated the relationship between sleep duration and weight gain or obesity in middle-to-older-aged populations, with mixed results. Seven studies reported an elevated risk of excess weight gain or obesity among persons with short

sleep durations (8–14), particularly in women, whereas the rest found no association (15–19).

Chronic conditions such as cancer and cardiovascular diseases can be powerful confounders, as they can affect both sleep pattern (20, 21) and body weight (22). Additionally, people may develop chronic diseases as a result of sleep deprivation (23, 24) and experience subsequent weight change that may not reflect the influence of sleep in a healthy population. Therefore, chronic conditions that are prevalent at baseline or that develop during follow-up could severely alter the sleep–weight association, particularly in older adults in whom these conditions are common. We are not aware of any studies that have excluded participants with chronic conditions at baseline and in the follow-up or that performed subgroup analyses by disease status. Moreover, as noted in previous reviews (7, 25),

the sleep–weight relationship can be influenced by many other factors, such as age, smoking status, alcohol consumption, caloric intake, daytime napping, physical activity level, and sedentary behaviors. Although most studies have included multiple confounders in their analyses, few studies had the power to conduct stratified analyses to evaluate the association of sleep with weight in different subgroups.

We prospectively investigated sleep duration in relation to weight change and the risk of developing obesity in a large cohort of middle-to-older-aged US men and women. We restricted our study to participants who were free of heart disease, stroke, and cancer at baseline and throughout the follow-up. We further examined the associations in subgroups of different ages, educational levels, smoking statuses, baseline body mass indexes (BMIs), and physical activity levels.

MATERIALS AND METHODS

Study population

The National Institutes of Health–AARP (NIH–AARP) Diet and Health Study recruited AARP members who were 50 to 71 years of age and resided in 1 of 6 US states (California, Florida, Louisiana, New Jersey, North Carolina, and Pennsylvania) or 2 metropolitan areas (Atlanta, Georgia, and Detroit, Michigan) in 1995–1996. Details of the study have been reported previously (26). In total, 566,399 participants satisfactorily completed the baseline questionnaire. Within 6 months of the baseline, a risk factor questionnaire was mailed to each member of the cohort, and in 2004–2006, a follow-up questionnaire was mailed to baseline participants. Habitual nighttime sleep duration in the past year was reported in the risk factor questionnaire, whereas body weight was reported in both the baseline questionnaire and the follow-up questionnaire.

Of the 221,189 people who completed all 3 questionnaires, we excluded those who reported missing or extreme BMIs (measured as weight in kilograms divided by height in meters squared) (<15 or >50) either at baseline or in 2004 (missing: $n = 43,958$; extreme: $n = 5,166$) or had no information on sleep duration ($n = 528$). We further excluded participants who had heart disease ($n = 20,840$), stroke ($n = 1,116$), or cancer ($n = 6,430$) at baseline, who reported having developed heart disease ($n = 26,520$) or stroke ($n = 3,463$) in the follow-up questionnaire, and who were diagnosed with cancer (ascertained from the state cancer registry or self-reported in 2004) during follow-up ($n = 25,581$). Finally, we excluded those who had at least 1 questionnaire filled out by a proxy respondent ($n = 4,210$). The final analytic sample consisted of 43,176 men and 40,201 women. The study was approved by the National Cancer Institute Special Studies Institutional Review Board.

Assessment of sleep duration and covariates

In the risk factor questionnaire, participants were asked to report the amount of time they slept at night in a typical 24-hour period over the past 12 months. They were asked to choose from “less than 5 hours,” “5–6 hours,” “7–8 hours,” and “9 or more hours” or leave the answer blank. In the follow-up questionnaire, the participants were asked to report the average number of hours they spent sleeping, at night or during the day, and

the choices were “none,” “less than 3 hours,” “3–4 hours,” “5–6 hours,” “7–8 hours,” “9–10 hours,” “11–12 hours,” and “more than 12 hours.”

Other information ascertained from the baseline and risk factor questionnaire included demographic characteristics; lifestyle factors, such as napping, physical activity level, sedentary behavior, and smoking history; medical history; dietary intake; and the use of menopausal hormone therapy in women.

Assessment of height, weight, and weight change

Current height (in inches and feet) and weight (in pounds) were reported in the baseline questionnaire, and current weight was reported again in the follow-up questionnaire. We calculated BMI at baseline and at the end of follow-up. We additionally calculated the change in weight (kg) between the 2 time points. We defined obesity as having a BMI of 30 or higher.

Statistical analysis

We examined categories of sleep duration and continuous measures of baseline BMI and weight change using multivariate linear regression. We used multivariate logistic regression to calculate the odds ratio and 95% confidence interval for developing obesity among subjects who were not obese at baseline and who gained 5 kg or more of body weight. In the models, we adjusted for age at baseline (50–<55, 55–<60, 60–<65, 65–<70, or ≥ 70 years), race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, or Asian, Pacific Islander, American Indian/Alaskan Native, or other), marital status (married, widowed, divorced, separated, or never married), educational level (less than 12 years, 12 years, post–high school education, some college, or college/post graduate), self-reported health (excellent, very good, good, fair, or poor), smoking status (never, former, or current smoker), alcohol consumption (continuous), and coffee consumption (continuous). In models concerning weight change or development of obesity, we further adjusted for baseline BMI (continuous). We considered episodes of vigorous physical activity (never/rarely, ≤ 3 times/month, 1–2 times/week, 3–4 times/week, or ≥ 5 times/week), overall time spent sitting (<3 , 3–4, 5–6, 7–8, or ≥ 9 hour/day), total caloric intake (continuous), and the intakes (continuous) of fruits and vegetables, whole grains, and total fat as both potential confounders and mediators and included them in separate models. Adjustment for daytime napping, use of hormonal therapy in women, history of depression, and self-reported diabetes at baseline did not alter the results, and these variables were not included in the model. In subgroup analyses, we evaluated the sleep–weight association by different ages, educational levels, smoking statuses, baseline BMIs, physical activity levels, and levels of sedentary behavior.

Tests for linear trend were performed by modeling a numeric value for each sleep category (1 for <5 hours, 2 for 5–6 hours, 3 for 7–8 hours, and 4 for ≥ 9 hours). Tests for interaction were performed using the likelihood-ratio test, comparing the fit of models with a cross-product term between sleep duration and the covariate of interest to those of models without this term. All P values are 2-sided. All analyses were conducted using SAS, version 9.3 (SAS Institute, Inc., Cary, North Carolina).

Table 1. Baseline Characteristics of 83,377 Men and Women With No Heart Disease, Stroke, or Cancer at Baseline and Throughout Follow-up, by Sleep Duration Category, National Institutes of Health-AARP Diet and Health Study, 1995–1996

Characteristic	Sleep Duration, hours															
	Men (n = 43,176)								Women (n = 40,201)							
	<5 (n = 804)		5–6 (n = 13,015)		7–8 (n = 28,159)		≥9 (n = 1,198)		<5 (n = 1,019)		5–6 (n = 12,845)		7–8 (n = 25,071)		≥9 (n = 1,266)	
	Mean (SD)	%	Mean (SD)	%	Mean (SD)	%	Mean (SD)	%	Mean (SD)	%	Mean (SD)	%	Mean (SD)	%	Mean (SD)	%
Baseline body mass index ^a																
15–18.4		0.3		0.4		0.5		0.5		1.2		1.1		1.2		1.0
18.5–24.9		26.9		29.1		34.2		33.8		32.2		43.1		48.1		44.3
25–29.9		44.3		49.3		48.7		47.3		34.8		33.0		32.3		31.0
30–34.9		19.5		16.5		13.4		15.2		18.3		14.8		12.6		14.9
35–50		9.1		4.7		3.2		3.3		13.5		7.9		5.9		8.8
Weight change, kg	1.0 (8.3)		0.5 (7.3)		0.3 (6.5)		0.3 (6.7)		1.1 (8.4)		1.2 (7.3)		1.0 (6.7)		0.4 (7.4)	
≥5-kg weight gain	23.4		18.7		15.6		17.1		26.6		22.8		19.9		19.5	
Age at baseline, years																
50–<55		20.3		19.2		15.1		10.0		17.7		17.2		16.4		15.9
55–<60		30.6		29.0		25.9		20.5		25.9		26.6		26.0		23.1
60–<65		25.9		27.0		28.5		31.7		26.9		27.5		28.7		29.6
65–71		23.3		24.9		30.5		37.8		39.5		28.8		28.9		31.4
White, non-Hispanic	85.0		90.3		94.9		95.7		84.3		88.4		94.2		94.7	
College and postcollege education	38.1		50.4		56.4		53.6		22.9		32.1		37.7		38.9	
Married	79.2		84.1		86.9		82.4		35.8		41.9		49.9		53.2	
Self-reported excellent health	17.0		22.4		26.7		23.0		14.9		19.8		24.2		20.9	
Current smoker	11.1		9.0		7.1		7.1		11.1		12.1		10.2		8.4	
Physical activity ≥5 times/week	21.7		21.0		22.4		21.2		16.7		17.7		17.8		16.8	
Sitting <3 hour/day	23.5		18.7		17.2		17.7		25.5		22.2		20.3		20.5	
Current MHT use	N/A		N/A		N/A		N/A		36.6		44.6		49.3		50.9	
Coffee intake, g/day	826 (752)		852 (679)		812 (637)		758 (660)		692 (691)		705 (621)		703 (585)		623 (587)	
Alcohol intake, g/day	18.8 (50.2)		16.3 (41.5)		18.0 (39.3)		27.5 (51.6)		4.5 (15.6)		5.5 (17.1)		6.5 (16.3)		9.5 (22.4)	
Fruits and vegetables, servings/day	7.7 (5.4)		7.1 (4.2)		7.0 (3.8)		6.8 (4.1)		7.6 (5.4)		6.9 (4.1)		6.6 (3.7)		6.7 (4.1)	
Whole grains, servings/day	1.3 (1.1)		1.3 (1.0)		1.3 (1.0)		1.3 (1.0)		1.1 (0.9)		1.1 (0.8)		1.1 (0.8)		1.1 (0.8)	
Total fat, g/day	76.5 (48.9)		69.8 (42.1)		68.3 (34.3)		72.1 (36.0)		57.3 (41.5)		53.3 (30.7)		50.9 (26.6)		54.7 (33.2)	
Total energy, kcal/day	2,235 (1218)		2,046 (997)		2,017 (825)		2,138 (901)		1,699 (991)		1,585 (711)		1,535 (618)		1,629 (762)	

Abbreviations: MHT, menopausal hormonal therapy; N/A, not applicable; SD, standard deviation.

^a Weight (kg)/height (m)².

Table 2. Cross-sectional Associations of Sleep Duration With Body Mass Index and Obesity^a at Baseline, by Sex, National Institutes of Health-AARP Diet and Health Study, 1995–1996

Model	Body Mass Index								P for Trend	
	Sleep Duration, hours									
	<5		5–6		7–8		≥9			
	β	95% CI	β	95% CI	β	95% CI	β	95% CI		
Men										
Model 1 ^b	1.37	1.10, 1.64	0.55	0.47, 0.63	0	Referent	0.22	−0.01, 0.44	<0.001	
Model 2 ^c	0.97	0.71, 1.24	0.43	0.35, 0.51	0	Referent	0.12	−0.09, 0.34	<0.001	
Model 3 ^d	0.88	0.62, 1.14	0.40	0.32, 0.48	0	Referent	0.03	−0.19, 0.24	<0.001	
Women										
Model 1 ^b	2.05	1.73, 2.37	0.60	0.49, 0.71	0	Referent	0.68	0.39, 0.97	<0.001	
Model 2 ^c	1.03	0.72, 1.33	0.23	0.13, 0.34	0	Referent	0.45	0.18, 0.72	<0.001	
Model 3 ^d	1.01	0.72, 1.31	0.21	0.11, 0.31	0	Referent	0.31	0.04, 0.57	<0.001	
	Obesity								P for Trend	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI		
Men										
Model 1 ^b	1.96	1.68, 2.30	1.32	1.25, 1.39	1	Referent	1.18	1.02, 1.38	<0.001	
Model 2 ^c	1.6	1.36, 1.88	1.24	1.18, 1.31	1	Referent	1.12	0.96, 1.31	<0.001	
Model 3 ^d	1.53	1.29, 1.81	1.23	1.16, 1.30	1	Referent	1.06	0.91, 1.24	<0.001	
Women										
Model 1 ^b	2.06	1.80, 2.36	1.30	1.23, 1.37	1	Referent	1.38	1.21, 1.57	<0.001	
Model 2 ^c	1.45	1.26, 1.68	1.13	1.07, 1.20	1	Referent	1.28	1.11, 1.47	<0.001	
Model 3 ^d	1.49	1.28, 1.73	1.13	1.07, 1.19	1	Referent	1.21	1.05, 1.40	<0.001	

Abbreviations: CI, confidence interval; OR, odds ratio.

^a Defined as a body mass index (weight (kg)/height (m)²) of 30 or higher.

^b Adjusted for age.

^c Adjusted for age, race/ethnicity, marital status, educational level, self-reported health, smoking status, alcohol consumption, and coffee consumption.

^d Adjusted for variables in model 2 and physical activity level, overall time spent sitting, total caloric intake, and the intake of fruits and vegetables, whole grains, and total fat.

RESULTS

At baseline, 65.2% of men and 62.3% of women reported sleeping 7–8 hours every night. Compared with these people, those with shorter sleep durations were more likely to be current smokers and to report less than 3 hours of overall time spent sitting and were less likely to be white, to be college educated, or to report excellent health. Participants who slept for shorter periods also consumed more fruits and vegetables, fat, and total energy. Men who reported less than 7 hours of sleep per night were younger and had higher coffee intakes, whereas women who slept less than 7 hours were less likely to be married or to use menopausal hormonal therapy (Table 1). There was an interaction between sleep duration and sex in relation to weight change, with borderline statistical significance (*P* for interaction = 0.07); therefore, we report results separately for men and women.

Table 2 shows the cross-sectional relationship of sleep duration with BMI and obesity in men and women. In the age-adjusted model, compared with participants with 7–8 hours of sleep per

night, both short (<5 hours or 5–6 hours) and long (≥9 hours) sleepers of both sexes had significantly higher BMIs and were more likely to be obese. After adjustment for potential confounders, the associations remained statistically significant for short sleepers among both men and women and long sleepers among women but not men.

On average, men and women in all sleep categories gained weight during follow-up. We found a significant inverse association between sleep duration and changes in body weight in both men (*P* for trend = 0.02) and women (*P* for trend < 0.001) (Table 3). Compared with participants who reported 7–8 hours of sleep per night, men and women who reported less than 5 hours of sleep gained 0.66 kg (95% confidence interval (CI): 0.19, 1.13) and 0.43 kg (95% CI: 0.00, 0.86) more weight, respectively. Approximately one-fifth of the population experienced a weight gain of 5 kg or more. We found that getting less than 5 hours of sleep at night was associated with an approximately 30% increase in the odds of gaining 5 kg or more as compared with 7–8 hours of sleep in both men and women (Table 4). Further adjustment for potential mediators, including

Table 3. Associations Between Baseline Sleep Duration and Weight Change From 1995 to 2004, by Sex, National Institutes of Health-AARP Diet and Health Study

Weight Change, kg	Sleep Duration, hours								P for Trend	
	<5		5–6		7–8		≥9			
	β ^a	95% CI	β ^a	95% CI	β	95% CI	β ^a	95% CI		
Men										
Model 1 ^b	0.85	0.38, 1.32	0.20	0.06, 0.34	0	Referent	0.24	−0.15, 0.62	0.001	
Model 2 ^c	0.66	0.19, 1.13	0.12	−0.02, 0.26	0	Referent	0.21	−0.18, 0.59	0.03	
Model 3 ^d	0.64	0.17, 1.12	0.12	−0.02, 0.26	0	Referent	0.20	−0.19, 0.59	0.04	
Women										
Model 1 ^b	0.58	0.15, 1.01	0.33	0.18, 0.47	0	Referent	−0.42	−0.80, −0.03	<0.001	
Model 2 ^c	0.43	0.00, 0.86	0.23	0.08, 0.37	0	Referent	−0.27	−0.66, 0.11	0.001	
Model 3 ^d	0.41	−0.02, 0.84	0.22	0.07, 0.37	0	Referent	−0.26	−0.64, 0.13	0.002	

Abbreviation: CI, confidence interval.

^a Average difference in weight change for sleep duration category compared to the reference category.

^b Adjusted for age and baseline body mass index (weight (kg)/height (m)²).

^c Adjusted for age, baseline body mass index, race/ethnicity, marital status, educational level, self-reported health, smoking status, alcohol consumption, and coffee consumption.

^d Adjusted for variables in model 2 and potential mediators, including physical activity level, overall time spent sitting, total caloric intake, and the intake of fruits and vegetables, whole grains, and total fat.

physical activity level, overall time spent sitting, and dietary intakes of total calories, fruits and vegetables, whole grains, and total fat, had little impact on the results. We performed a sensitivity analysis by excluding participants who reported napping during the day at baseline or who reported to have at least 1 intentional weight loss in the follow-up questionnaire, and the association between short sleep at night and weight gain remained unchanged, although the sample sizes were substantially smaller (data not shown). Furthermore, we considered that participants who consistently reported a sleep duration in the

same category in both questionnaires might have had baseline information that better reflected their long-term sleep habits. When we restricted our analysis to these participants, the results were similar (data not shown).

Next, we evaluated the association between developing obesity and sleep duration among men and women who were not obese at baseline (Figure 1). The association was inversely linear among women (*P* for trend <0.001), with both less than 5 hours and 5–6 hours of sleep associated with significantly increased odds of obesity (for <5 hours, OR = 1.37, 95% CI:

Table 4. Prospective Odds Ratios and 95% Confidence Intervals of Baseline Sleep Duration and a Weight Gain of 5 kg or More From 1995 to 2004, by Sex, National Institutes of Health-AARP Diet and Health Study

Model	Sleep Duration, hours								P for Trend	
	<5		5–6		7–8		≥9			
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI		
Men										
Model 1 ^a	1.43	1.22, 1.71	1.14	1.08, 1.21	1	Referent	1.20	1.03, 1.40	<0.001	
Model 2 ^b	1.29	1.08, 1.53	1.10	1.04, 1.16	1	Referent	1.17	1.00, 1.36	0.002	
Model 3 ^c	1.27	1.07, 1.52	1.10	1.04, 1.16	1	Referent	1.16	0.99, 1.36	0.002	
Women										
Model 1 ^a	1.39	1.20, 1.61	1.17	1.11, 1.23	1	Referent	0.98	0.85, 1.13	<0.001	
Model 2 ^b	1.30	1.12, 1.51	1.12	1.06, 1.18	1	Referent	1.02	0.88, 1.17	<0.001	
Model 3 ^c	1.30	1.12, 1.51	1.12	1.06, 1.18	1	Referent	1.02	0.88, 1.17	<0.001	

Abbreviation: CI, confidence interval; OR, odds ratio.

^a Adjusted for age and baseline body mass index (weight (kg)/height (m)²).

^b Adjusted for age, baseline body mass index, race/ethnicity, marital status, educational level, self-reported health, smoking status, alcohol consumption, and coffee consumption.

^c Adjusted for variables in model 2 and potential mediators including physical activity level, overall time spent sitting, total caloric intake, and the intake of fruits and vegetables, whole grains, and total fat.

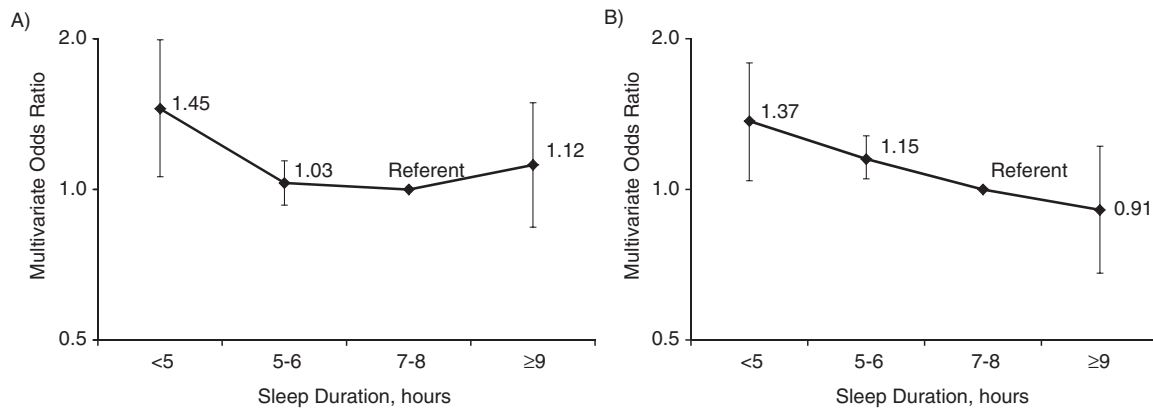


Figure 1. Multivariate odds ratios and 95% confidence interval for developing obesity during follow-up for categories of sleep duration in (A) men and (B) women in the National Institutes of Health-AARP Diet and Health Study, 1995–1996. The analysis included men ($n = 35,319$) and women ($n = 32,025$) who were not obese at baseline. The number of participants who developed obesity in less than 5 hours, 5–6 hours, 7–8 hours, and 9 or more hours sleep categories were: 62 (10.8%), 792 (7.7%), 1448 (6.2%), and 68 (7.0%) in men and 89 (12.8%), 921 (9.3%), 1,530 (7.5%), and 66 (6.8%) in women, respectively. Multivariate models were adjusted for age, baseline body mass index, race/ethnicity, marital status, educational level, self-reported health, smoking status, alcohol consumption, and coffee consumption. P for trend = 0.25 for men and <0.0001 for women.

1.04, 1.79, and for 5–6 hours, OR = 1.15, 95% CI: 1.05, 1.28). Among men, only the category of less than 5 hours of sleep was associated with significantly increased odds of obesity (OR = 1.45, 95% CI: 1.06, 1.99), and no associations were observed for 5–6 hours and ≥ 9 hours sleep (for 5–6 hours, OR = 1.03, 95% CI: 0.93, 1.14, and for ≥ 9 hours, OR = 1.12, 95% CI: 0.84, 1.49).

In subgroup analyses, we examined the odds of gaining 5 kg or more in relation to sleep duration by age, educational level, smoking status, baseline BMI, physical activity level, and overall time spent sitting (Table 5 for men and Table 6 for women). We found an increased odds of a weight gain of 5 kg or more in the short-sleep categories in almost all strata. There was a significant interaction between sleep and smoking in men ($P = 0.05$) and between sleep and baseline BMI ($P = 0.03$) and sleep and overall time spent sitting ($P = 0.03$) in women. The increased odds of gaining 5 kg or more with short sleep appeared to be higher among men who were smokers and women who had lower baseline BMI or who reported less than 3 hour/day sitting.

Finally, we examined the relationship of prevalent disease at baseline and the development of incident disease during follow-up with sleep-weight association in this population by comparing the results obtained in our final analytic cohort to those in participants who were excluded because of chronic conditions. Specifically, we examined the association between sleep duration and a weight gain of 5 kg or more among participants who had prevalent cardiovascular disease and cancer or who developed these conditions during follow-up (Web Table 1, available at <http://aje.oxfordjournals.org/>). Overall, we found no association between sleep duration and weight change in these men and women. Moreover, as these participants were removed from the study cohort, the association between less than 5 hours of sleep and increased odds of gaining 5 kg or more was strengthened (Web Table 2).

DISCUSSION

In the present large prospective study of men and women who were 50–71 years of age at baseline, we found an inverse association between sleep duration and BMI. During follow-up, men and women who reported a typical sleep duration of 6 hours or less per night reported gaining more weight, after controlling for multiple factors. Among participants who were not obese at baseline, sleeping less than 5 hours was associated with a nearly 40% increase in the risk of developing obesity compared with sleeping 7–8 hours each night.

The observed association between short sleep and higher weight gain in women was most comparable to that from the Nurse's Health Study (9), the largest study to-date on the sleep-weight association in adults ($n = 68,183$). In that study, investigators reported a 0.78-kg higher weight gain in women with 5 or fewer hours of sleep and a 0.53-kg higher weight gain in women with 6 hours of sleep. Similar associations were confirmed in 3 other studies conducted in Japan (8), Spain (11), and Finland (14), although the latter 2 reported no association among men. To date, 3 studies have found a link between short sleep and higher weight gain in men, and all were conducted in Japanese populations (8, 12, 13). Five cohort studies (15–19) found no association between sleep and weight change in men or women, including 2 studies that objectively measured sleep variables using actigraphy (18, 19). Compared with studies with positive findings, those showing no association tended to be smaller (range, 310–8,000 participants).

Our findings in subgroup analyses suggested that the association between short sleep and weight gain was generally consistent across subpopulations. However, multiple factors, such as smoking status, sedentary behavior, and baseline BMI might influence the association between sleep duration and weight change. Particularly, we found a stronger association between

Table 5. Prospective Odds Ratios and 95% Confidence Intervals of Baseline Sleep Duration and a Weight Gain of 5 kg or More From 1995 to 2004 Among Men, by Subgroup, National Institutes of Health-AARP Diet and Health Study

Subgroup	Sleep Duration, hours								P for Trend
	<5		5–6		7–8		≥9		
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	
Age, years ^a									
50–<55	1.35	0.96, 1.90	1.08	0.96, 1.22	1	Referent	0.90	0.58, 1.39	0.05
55–<60	1.31	0.98, 1.76	1.11	1.00, 1.22	1	Referent	1.21	0.89, 1.64	0.05
60–<65	1.20	0.84, 1.72	1.15	1.03, 1.28	1	Referent	1.35	1.03, 1.77	0.14
65–71	1.23	0.80, 1.90	1.05	0.92, 1.19	1	Referent	1.08	0.80, 1.47	0.48
P for interaction				0.68					
Educational level ^a									
Less than college	1.65	1.25, 2.18	1.15	1.03, 1.28	1	Referent	1.27	0.95, 1.70	0.003
Some college or higher	1.06	0.84, 1.33	1.09	1.02, 1.16	1	Referent	1.11	0.92, 1.35	0.07
P for interaction				0.43					
Smoking status ^b									
Never	1.20	0.87, 1.64	1.08	0.98, 1.20	1	Referent	1.12	0.84, 1.51	0.14
Former	1.33	1.05, 1.69	1.13	1.04, 1.21	1	Referent	1.16	0.95, 1.43	0.004
Current	1.44	0.91, 2.27	1.10	0.93, 1.30	1	Referent	1.03	0.62, 1.70	0.11
P for interaction				0.05					
Baseline body mass index ^{a,c}									
15–24.9	1.47	1.03, 2.09	1.20	1.08, 1.34	1	Referent	1.52	1.16, 1.99	0.01
25–29.9	1.28	0.99, 1.66	1.07	0.98, 1.15	1	Referent	1.09	0.86, 1.37	0.08
30–50	1.14	0.84, 1.55	1.04	0.93, 1.17	1	Referent	0.91	0.64, 1.28	0.24
P for interaction				0.24					
Physical activity level ^a									
≤3 times/month	1.19	0.89, 1.60	1.13	1.02, 1.26	1	Referent	1.39	1.06, 1.83	0.18
1–4 times/week	1.19	0.90, 1.56	1.06	0.98, 1.15	1	Referent	1.08	0.86, 1.37	0.13
≥5 times/week	1.70	1.19, 2.44	1.12	0.99, 1.27	1	Referent	1.07	0.75, 1.52	0.01
P for interaction				0.12					
Overall time spent sitting ^a									
<3 hour/day	1.24	0.85, 1.80	1.09	0.95, 1.24	1	Referent	0.84	0.56, 1.29	0.08
3–6 hour/day	1.4	1.11, 1.77	1.07	0.99, 1.16	1	Referent	1.28	1.04, 1.56	0.09
≥7 hour/day	1.13	0.79, 1.61	1.17	1.05, 1.30	1	Referent	1.15	0.83, 1.58	0.02
P for interaction				0.80					

Abbreviation: CI, confidence interval; OR, odds ratio.

^a Adjusted for age, baseline body mass index, race/ethnicity, marital status, educational level, self-reported health, smoking status, alcohol consumption, and coffee consumption.

^b Adjusted for all variables above except for smoking status.

^c Weight (kg)/height (m)².

reduced sleep and weight gain among women with a baseline BMI less than 25. This was consistent with the finding by Patel et al. (9), who also reported a higher elevated risk for obesity among women with normal baseline BMI when compared with overweight women. We are not aware of any other prospective study that examined the relationship of short sleep with weight gain by lifestyle factors, such as smoking and exercise. Our finding of significant interactions between sleep and smoking and sleep and sedentary behavior suggested

that people with certain behaviors might be more susceptible to weight change associated with sleep, and it is important to investigate the combined effect of sleep and other lifestyle factors on body weight.

There has been considerable heterogeneity among previous studies regarding the sleep–weight relationship among adults who reported more than 8 hours of sleep per night. A U-shaped association with greater weight gain among long sleepers was observed in several studies (10–12), whereas

Table 6. Prospective Odds Ratios and 95% Confidence Intervals of Baseline Sleep Duration and a Weight Gain of 5 kg or More From 1995 to 2004 Among Women, by Subgroup, National Institutes of Health-AARP Diet and Health Study

Subgroup	Sleep Duration, hours								P for Trend
	<5		5–6		7–8		≥9		
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	
Age, years ^a									
50–<55	1.36	0.99, 1.88	1.18	1.06, 1.33	1	Referent	0.94	0.68, 1.30	0.001
55–<60	1.15	0.87, 1.52	1.08	0.98, 1.19	1	Referent	0.88	0.66, 1.18	0.04
60–<65	1.37	1.03, 1.82	1.21	1.09, 1.34	1	Referent	1.04	0.79, 1.37	<0.001
65–71	1.4	1.04, 1.88	1.05	0.93, 1.18	1	Referent	1.23	0.93, 1.63	0.31
P for interaction				0.55					
Educational level ^a									
Less than college	1.4	1.14, 1.73	1.12	1.03, 1.22	1	Referent	0.91	0.70, 1.17	<0.001
Some college or higher	1.28	1.03, 1.59	1.13	1.05, 1.21	1	Referent	1.06	0.88, 1.26	<0.001
P for interaction				0.76					
Smoking status ^b									
Never	1.36	1.10, 1.69	1.18	1.09, 1.28	1	Referent	1.01	0.82, 1.26	<0.001
Former	1.23	0.97, 1.56	1.09	1.00, 1.19	1	Referent	1.09	0.87, 1.35	0.05
Current	1.37	0.92, 2.06	1.03	0.89, 1.19	1	Referent	0.78	0.49, 1.24	0.17
P for interaction				0.88					
Baseline body mass index ^{a,c}									
15–24.9	1.47	1.13, 1.90	1.16	1.06, 1.26	1	Referent	1.33	1.07, 1.64	0.004
25–29.9	1.34	1.05, 1.70	1.11	1.01, 1.21	1	Referent	0.78	0.60, 1.03	<0.001
30–50	1.16	0.89, 1.51	1.11	0.99, 1.24	1	Referent	0.91	0.68, 1.23	0.03
P for interaction				0.03					
Physical activity level ^a									
≤3 times/month	1.22	0.96, 1.54	1.04	0.95, 1.14	1	Referent	0.87	0.69, 1.11	0.06
1–4 times/week	1.41	1.13, 1.76	1.21	1.12, 1.30	1	Referent	1.01	0.81, 1.26	<0.001
≥5 times/week	1.15	0.79, 1.66	1.11	0.98, 1.27	1	Referent	1.28	0.91, 1.80	0.33
P for interaction				0.19					
Overall time spent sitting ^a									
<3 hour/day	1.56	1.16, 2.09	1.22	1.09, 1.37	1	Referent	0.97	0.59, 1.36	<0.001
3–6 hour/day	1.22	0.99, 1.49	1.12	1.04, 1.20	1	Referent	1.05	0.86, 1.28	0.002
≥7 hour/day	1.31	0.96, 1.77	1.07	0.97, 1.19	1	Referent	0.99	0.75, 1.29	0.06
P for interaction				0.03					

Abbreviation: CI, confidence interval; OR, odds ratio.

^a Adjusted for age, baseline body mass index, race/ethnicity, marital status, educational level, self-reported health, smoking status, alcohol consumption, and coffee consumption.

^b Adjusted for all variables above except for smoking status.

^c Weight (kg)/height (m)².

the others reported an L-shaped relation, finding no association with the long sleep categories (9, 14). Only one study, which used data from the National Health and Nutrition Examination Survey I, found that more than 9 hours sleep was associated with a lower increase in BMI, but the results were not statistically significant (17). In our study, we found generally no relationship between 9 or more hours of sleep at night and weight gain or risk of obesity in men. However, among female long sleepers, there seemed to be a trend of less weight gain

or lower risk of obesity, although we did not have more refined categories of sleep duration beyond 9 hours and thus were not able to evaluate the effect of long sleep in more detail.

We believe that one of the unique advantages of the present study was that we were able to evaluate the sleep–weight association in a relatively healthy older population that was free of cancer and cardiovascular diseases throughout the study. Patients with cancer and cardiovascular diseases are known to have disrupted sleep (20, 21) and may experience either unintended

or intended weight loss due to the disease, medical treatment, or self-determination for better disease management (22); therefore, prevalent chronic conditions at baseline may confound and mask the sleep–weight association. Failure to exclude people who developed these conditions during the follow-up period could also have an impact. Sleep at baseline may be associated with in-study incidence of comorbid conditions, such as cardiovascular diseases and cancer (23, 24). If these comorbid conditions then cause weight-loss, it would introduce bias into the sleep–weight gain association.

These problems are particularly relevant for investigations of middle-aged and elderly people, given the high prevalence of chronic diseases in these populations. Interestingly, although it was generally established that short sleep is associated with obesity in younger populations, several studies have suggested that this association might become weaker or even diminish with increased age (17, 27). We did not detect an interaction with age. The increased risk of gaining 5 kg or more among short sleepers appeared to be fairly stable across all age groups. Possibly, the lack of an interaction in our study reflects the fact that we have removed the effect of chronic conditions, which may have biased results in some of the previous studies.

Although the exact pathways that link short sleep to weight gain and obesity remain to be determined, multiple mechanisms have been proposed (25, 28). It has been suggested that sleep deprivation may produce fatigue that leads to reduced physical activity levels and prolonged sedentary behavior, thereby curtailing energy expenditure (25). Short sleep may also promote an increased total caloric intake. Laboratory-based studies have shown that sleep restriction leads to changes in appetite-regulating hormones, including reductions in leptin and peptide YY, increases in ghrelin and insulin, and multiple alterations in glucose regulation (29–33). A recent study reported that 5 days of insufficient sleep increased food intake and led to weight gain in human subjects (34). In the present study, we adjusted for total calorie intake, diet, and physical activity level in our analysis, yet the associations between sleep and weight gain remained, which suggests that there may be other factors in play.

One such mechanism may involve the hypothalamic-pituitary-adrenal axis, a major neuroendocrine pathway that mediates stress response. Sleep restriction can activate the hypothalamic-pituitary-adrenal axis and lead to elevated levels of stress hormones such as cortisol, which not only increases food intake but also causes the accumulation of fat, especially the visceral fat tissue (25, 35, 36). Moreover, recently it has been postulated that melatonin, the pineal hormone central to the regulation of sleep and circadian rhythm, may mediate the effect of sleep on body weight (37). In animal studies, increased melatonin enhances the metabolic activity of brown adipose tissue, resulting in higher energy expenditure and reduced weight gain (38–40). Low levels of sleep reduce melatonin levels, which would be expected to reduce brown adipose tissue metabolic activity, possibly causing weight gain.

Our study has several strengths. First, this was a prospective study, and we were able to ascertain the temporal sequence of sleep and weight change, which could reduce the likelihood of reversal causation. Second, our large sample size allowed us to exclude participants with chronic conditions at baseline and throughout follow-up and still retain adequate statistical

power. Third, we performed subgroup analyses to examine the potential effects of other factors on the sleep–weight association, which have rarely been explored in previous studies. Fourth, we controlled for a large array of potential confounders, including demographic characteristics, diet, physical activity level, and other lifestyle factors. Lastly, we were able to perform sensitivity analyses to evaluate the impact of daytime napping and intentional weight loss and to restrict our analyses to participants who reported consistently on their sleep duration at the beginning and the end of the follow-up.

There are, however, several limitations of our study. Information on weight, height, and sleep duration were self-reported. Self-reported body weight and height are generally highly correlated with actual body weight and height (41), but self-reported and measured sleep duration are only moderately correlated (42), which may result in misclassification of exposure. Moreover, people with short sleep durations are more likely to over-report their sleep duration than are people with longer sleep durations (42), which may lead to differential bias in observed associations. Additionally, we only had sleep time and weight reported at 2 time points, and we were not able to capture fluctuations in between. The duration categories in the questionnaire were somewhat broad, which did not allow us to evaluate the effect of sleep duration in more refined categories. We also did not have information about sleep disorders, such as obstructive sleep apnea and chronic insomnia, which could also influence both sleep duration and body weight (43). Lastly, we only included people who lived to fill out the follow-up questionnaire, and we cannot generalize our findings to participants who died between the completion of the 2 questionnaires.

We found that a short sleep duration is associated with excess weight gain and obesity risk among older men and women. Given the increasingly high number of people with chronic sleep deficit in the population and the severity of obesity epidemic, the link between sleep and obesity deserves special attention. Future studies should aim to understand the behavioral and physiological mechanisms underlying the observed sleep associated weight gain, as well as to develop effective intervention strategies to achieve better weight management through improving sleep.

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