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Original article

Associations of allostatic load with sleep apnea, insomnia, short sleep duration, and other sleep disturbances: findings from the National Health and Nutrition Examination Survey 2005 to 2008

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ABSTRACT

Purpose: To examine whether allostatic load (AL), a measure of cumulative physiologic dysregulation across biological systems, was associated with sleep apnea, insomnia, and other sleep disturbances.
Methods: Data from the National Health and Nutrition Examination Survey 2005–2008 were used. AL was measured using nine biomarkers representing cardiovascular, inflammatory, and metabolic system functioning. A total of 3330 US adults aged 18 years and older were included in this study.
Results: The prevalence of high AL (AL score ≥3) was the highest among African Americans (26.3%), followed by Hispanic Americans (20.3%), whites (17.7%), and other racial/ethnic group (13.8%). After adjustment for sociodemographic and lifestyle factors, high AL was significantly associated with sleep apnea (odds ratio [OR], 1.92; 95% confidence interval [CI], 1.40–2.63), snoring (OR, 2.20; 95% CI, 1.79–2.69), snorting/stop breathing (OR, 2.16; 95% CI, 1.46–3.21), prolonged sleep latency (OR, 1.42; 95% CI, 1.08–1.88), short sleep duration (<6 hours) (OR, 1.35; 95% CI, 1.00–1.82), and diagnosed sleep disorder (OR, 2.26; 95% CI, 1.66–3.08). There was no clear evidence that observed associations varied by sociodemographic characteristics.
Conclusions: This study suggests significant associations of high AL with sleep apnea, sleep apnea symptoms, insomnia component, short sleep duration, and diagnosed sleep disorder among US adults.

Introduction

Quality sleep is fundamental for health and wellness. Increasing epidemiologic studies have linked sleep characteristics such as short sleep duration and poor sleep to obesity [1], hypertension [2], diabetes [3], cardiovascular disease [4,5], mortality [6], and decreased health-related quality of life [7]. Additionally, sleep research and health disparities have been prioritized by the Institute of Medicine and Healthy People 2020 [8,9]. Allostatic load (AL) is a multisystem construct theorized to quantify stress-induced biological risk, defined as the cumulative dysregulation of biological systems with prolonged or poorly regulated responses to internal and external stressors [10]. Several studies including one recent systematic review have shown that elevated AL is associated with cardiovascular diseases [11,12], chronic fatigue [13], pain [14], declines in health and cognition [15], and mortality [16,17]. Differences in AL may reflect the accumulation of physiological changes induced by differences in exposure to chronic stress, and thus might provide a mechanistic link for understanding the differential burden of life stressors and health disparities [18]. AL has been proposed as a possible mechanism contributing to health disparities observed in racial/ethnic minority groups [19]. Recent research has demonstrated that African Americans exhibit higher levels of AL than other racial/ethnic groups [20–22].

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However, only limited research has been conducted on possible associations between AL and sleep disturbances (e.g., poor sleep quality). Some researchers have proposed that poor sleep might act as a neurobiological and physiological stressor that could impair neurophysiological functions and lead to allostatic changes throughout the body by increasing proinflammatory cytokines, oxidative stress, and evening cortisol and insulin concentrations [23,24]. Other researchers consider sleep as a component of AL [21,25]. Recurrent or chronic stress attributable from environmental and social factors can alter physiological functioning and behavior (e.g., sleep) which may lead to increased AL in a vicious cycle [26,27]. There might be bidirectional associations between AL and sleep disturbances. Prolonged sleep deprivation, poor sleep quality, and sleep apnea-associated stresses may contribute to AL and in turn high AL might contribute to sleep disturbances. To our knowledge, no research findings to date have been reported assessing any associations between AL and sleep characteristics, and certainly none of previous studies were based on national survey data.

Using nationally representative data, we examined whether AL severed as a predictor of insufficient sleep or sleep disturbances. We conducted stratified analyses to evaluate whether the associations between AL and sleep disturbances varied by sex, race/ethnicity, and country of birth. We hypothesized that AL would be significantly associated with sleep apnea, insomnia, short sleep duration, and other sleep disturbances. We also hypothesized that such associations would be stronger for African and Hispanic Americans.

Methods

Data set and study population

Data were obtained from continuous biennial cycles of the National Health and Nutrition Examination Survey (NHANES) during 2005 to 2008. The NHANES is a stratified multistage probability survey conducted by the Department of Health and Human Services in the noninstitutionalized population and administered by the National Center for Health Statistics. The NHANES incorporates a series of cross-sectional surveys providing health and nutrition data on a nationally representative sample. Using a computer-assisted personal interview system, trained interviewers interviewed participants in their homes to collect sociodemographic data and sleep-related information. Questionnaires that included assessment of sleep habits, sleep quality, and sleep disorders were administered by interviewers in the homes of participants aged 16 years or older. Participants were also asked to visit the NHANES Mobile Examination Center, where they completed additional questionnaires, underwent physical examinations, and provided a blood sample for laboratory measurements. Measured weight and height were used to calculate body mass index. All survey information is confidential and approved by the National Center for Health Statistics Institutional Review Board. Detailed information on the study design and data collection are described on the NHANES website http://www.cdc.gov/nchs/nhanes.htm, and a number of NHANES articles have been published elsewhere [28,29].

In this study, participants aged 18 years or older with complete sleep data were included. Participants were excluded from this study if they were aged 18 years (1397 participants with sleep information aged 16 to 17 years, because of our interest in an adult population aged 18 years or older), pregnant (428 participants, because of associated changes in sleep physiology), or for whom incomplete data on AL existed (1475 participants). A total of 3330 individuals were included as our analytic sample in this study.

Sleep characteristics

Sleep characteristics, which were classified on the basis of participant self-reports, included sleep apnea; sleep apnea symptoms such as habitual snoring, snorting, or stop breathing; insomnia; short sleep duration; and any sleep disorder diagnosed by a physician or other health professional. Sleep apnea was defined based on an affirmative answer to the following question: “Have you ever been told by a doctor or other health professional that you have a sleep disorder: sleep apnea?”

Regarding sleep apnea symptoms of habitual snoring and snorting/stop breathing, the following two questions were asked: (1) “In the past 12 months, how often did you snore while you were sleeping?” (snoring) and (2) “In the past 12 months, how often did you snort, gasp, or stop breathing while you were asleep?” (snorting or stop breathing). Participants who answered “frequently (five or more nights per week)” were considered as having “habitual snoring” and “snorting/stop breathing,” respectively, whereas those with response “never,” “rarely (1–2 nights/week),” or “occasionally (3–4 nights/week)” were considered as having no snoring or snorting/stop breathing, respectively.

Insomnia symptoms were based on the following standard questions: (1) “trouble falling asleep” (prolonged sleep latency), (2) “waking up during the night and had trouble getting back to sleep” (frequent nocturnal awakenings), (3) “waking up too early in the morning and unable to get back to sleep” (early morning awakening), and (4) “feeling unrested during the day, no matter how many hours of sleep had” (unrefreshed sleep). Responses to each insomnia symptom were collapsed as follows: occurring 2to 4 times per month or less (considered a negligible symptom), 5 to 15 times per month (some level of insomnia or mild or moderate insomnia), and more than 15 times/month (severe insomnia).

The study also collected data on functional impairments related to daytime sleepiness, including difficulties carrying out specific regular daily activities over the last month: (1) “concentrating on the things,” (2) “remembering things,” (3) “getting things done because too sleepy or tired to drive or take public transportation,” (4) “performing employed or volunteer work or attending school,” (5) “working on a hobby, for example, sewing, collecting, gardening,” and (6) “taking care of financial affairs and doing paperwork.” In this study, insomnia (yes/no) was defined by using the National Heart, Lung, and Blood Institute Working Group definition as one of the four insomnia symptoms plus at least one self-reported daytime functional impairment due to lack of sleep [30]. This approach has been used in other NHANES research [29].

Sleep duration was identified based on participants’ responses to the question: “How much sleep do you usually get at night on weekdays or workdays?” Previous studies have defined short habitual sleep using two cutpoints: less than 7 hours and less than 6 hours per week-night [29,31]. We found similar results using both cut-points. In this study, we reported findings based on the cut-point: sleep less than 6 hours per night (yes/no). AL was not related to long sleep duration ($\geq$9 hours per night) in this study (data not shown).

Diagnosed sleep disorder was based on the question: “Have you ever been told by a doctor or other health professional that you have a sleep disorder?” Those with the response “yes” were considered as having a diagnosed sleep disorder.

Allostatic load

AL levels were measured using nine biomarkers representing cardiovascular, inflammatory, and metabolic system functioning [32].The nine biomarkers and their corresponding cutoffs were indicated as: (1) systolic blood pressure 140 mm Hg or more, (2)

diastolic blood pressure 90 mm Hg or more, (3) heart rate 90 beats/minute or more, (4) total cholesterol level 240 mg/dL or more, (5) high-density lipoprotein cholesterol less than 40 mg/dL, (6) body mass index 30 kg/m^2 or more, (7) glycosylated hemoglobin 6.4% or more, (8) C-reactive protein 0.3 mg/dL or more, and (9) albumin less than 3.8 g/dL. Each cutoff was coded as a dichotomous variable (1, if the respondent had indicated the condition; 0, if otherwise). The AL score was defined as the sum of the indicators for the nine components and was then converted into a dichotomous variable, with high AL defined as the AL score 3 or more. The same cutoff values and measures have been used with the NHANES data set in previous studies [32–34].

Covariates

Sociodemographic characteristics

Participants' sociodemographic characteristics included sex, age, race/ethnicity, marital status, education, poverty income ratio (PIR), and country of birth. Participants were grouped into three age categories: young (18–39 years), middle-aged (40–59 years), and old group (≥60 years). Based on self-reported information, participants were categorized as whites, African Americans, Hispanic Americans, and other racial/ethnic group. Education levels were grouped into three categories: "less than high school" (<12 years of education), "high school," and "greater than high school" (>12 years of education). PIR divides family income by the poverty threshold, taking into account family size. As such PIR represents adjusted income, which is more informative about available resources than income alone [14]. PIR was categorized as three levels: low income (PIR < 1, below the poverty threshold), middle (PIR: 1–2), and high income (PIR ≥ 3). The question "In what country were you born?" was used to categorize respondents as "US-born" or "foreign-born".

Lifestyle factors

Participants were asked the following questions about their participation in sport(s), exercise, or any other recreational activities: (1) "Over the past 30 days, did you do any vigorous activities for at least 10 minutes that caused heavy sweating or large increases in breathing or heart rate?"; (2) "Over the past 30 days, did you do any moderate activities for at least 10 minutes that cause only light sweating or a slight to moderate increase in breathing or heart rate?." Participants were grouped into two categories: without physical activity participation (individuals did not participate in any moderate or vigorous recreational activities) and with physical activity participation (individuals participated in moderate and/or vigorous recreational activities). Alcohol consumption and cigarette smoking were also asked and included as covariates in this study (yes vs. no).

Statistical analysis

The primary exposure variable was AL, whereas the outcome variables were sleep apnea, sleep apnea symptoms of snoring and snorting/stop breathing, insomnia, short sleep duration, and any sleep disorder diagnosed by a physician or other health professional. AL was examined both as a continuous and a dichotomous variable (high AL, defined as the AL score ≥ 3; low AL, defined as the AL score < 3). We used χ^2 tests to examine any differences in the distribution of elevated AL across sociodemographic, lifestyle, and sleep characteristics. Multivariable logistic regression models were fit to examine the associations between AL and sleep parameters with adjustment for sociodemographic and lifestyle factors. Odds ratios (ORs) and 95% confidence intervals (95% CIs) were calculated. We further conducted stratified analyses to test whether the AL-sleep associations varied by sex, race/ethnicity, and country of birth. Interaction terms were included and tested in separate models. Our sensitivity analysis showed that the sample included in the study was not significantly different from the entire NHANES population.

All statistical analyses were conducted in SAS (version 9.3; SAS Institute, Inc., Cary, NC). Survey-related commands including sampling design variables and sampling weights were applied to account for the complex multistage sampling design. Statistical significance was set at two-tailed *P* less than .05.

Results

Prevalence of high AL and sleep characteristics

Approximately 21.1% of the US adults had high AL. There was no significant sex difference in the prevalence of high AL (Table 1). The

Table 1
Sociodemographic and lifestyle characteristics of 3330 US adults in the National Health and Nutrition Examination Survey 2005 to 2008, according to AL status

Characteristic	*N*	Low AL* (*n* = 2627) % (SE)	High AL* (*n* = 703) % (SE)	*P* value†
Sex				
Men	1749	82.4 (1.0)	17.6 (1.0)	.260
Women	1581	80.6 (1.4)	19.4 (1.4)	
Age (yrs)				
18–39	1273	87.1 (1.3)	12.9 (1.3)	<.001
40–59	1115	78.1 (1.6)	21.9 (1.6)	
≥60	942	77.3 (1.8)	22.7 (1.8)	
Race/ethnicity				
White	1593	82.3 (1.1)	17.7 (1.1)	<.001
African American	712	73.6 (1.9)	26.3 (1.9)	
Hispanic American	635	79.7 (2.0)	20.3 (2.0)	
Other	390	86.1 (2.2)	13.8 (2.2)	
Marital status				
Married/living with a partner	2121	82.3 (1.0)	17.7 (1.0)	<.001
Widowed/separated/divorced	557	71.6 (2.4)	28.4 (2.4)	
Single	652	86.7 (1.7)	13.3 (1.7)	
Education level				
<High school	892	74.4 (1.0)	25.6 (1.6)	<.001
High school	861	78.4 (1.6)	21.6 (1.6)	
>High school	1577	85.5 (1.1)	14.9 (1.1)	
Poverty income ratio				
<1	757	79.8 (2.2)	20.2 (2.2)	.086
1–2	1286	79.3 (1.4)	20.7 (1.4)	
≥3	1287	83.4 (1.4)	16.6 (1.4)	
Country of birth				
US-born	2618	80.7 (1.0)	19.3 (1.0)	<.001
Foreign-born	712	86.9 (1.1)	13.1 (1.1)	
Physical activity participation‡				
No	1462	74.1 (1.4)	25.9 (1.4)	<.001
Yes	1868	86.0 (1.1)	14.0 (1.1)	
Alcohol consumption				
No	2002	79.5 (1.3)	20.5 (1.3)	.002
Yes	1328	84.0 (1.0)	16.0 (1.0)	
Cigarette smoking				
No	2637	81.8 (1.0)	18.2 (1.0)	.557
Yes	693	80.5 (2.1)	19.5 (2.1)	

SE = standard error.

* AL was measured using the following nine components and their corresponding cutoffs: (1) systolic blood pressure 140 mm Hg or more, (2) diastolic blood pressure 90 mm Hg or more, (3) heart rate 90 beats/minute or more, (4) total cholesterol level 240 mg/dL or more, (5) high-density lipoprotein cholesterol less than 40 mg/dL (6) body mass index 30 kg/m^2 or more, (7) glycosylated hemoglobin 6.4% or more, (8) C-reactive protein 0.3 mg/dL or more, and (9) albumin less than 3.8 g/dL. Each cutoff was coded as a dichotomous variable, and the AL score was defined as the sum of the indicators for the nine components. High AL was defined as the AL score 3 or more, whereas low AL was defined as the AL score less than 3.

† χ^2 test was conducted.

‡ Insomnia (yes/no) was defined by using the National Heart, Lung, and Blood Institute Working Group definition as one of the four insomnia symptoms plus at least one self-reported daytime functional impairment due to lack of sleep.

prevalence of high AL was higher among participants aged 60 years or older than in the youngest age group (aged 18–39 years), was higher among widowed, separated, or divorced individuals than among those married or living with a partner, and was higher for US-born than for foreign-born individuals. Participants with less than high school of education levels were more likely to have high AL than those with high school or more than high school of education levels. We did not find significant differences in the prevalence of high AL across PIR categories. The prevalence of high AL was the highest among African Americans (26.3%), followed by Hispanic Americans (20.3%), whites (17.7%), and other racial/ethnic group (13.8%). Those with high education levels and recreational activity participation had a lower prevalence of high AL than their counterparts.

As shown in Table 2, the prevalence of high AL was higher among adults with diagnosed sleep apnea, snoring, snorting/stop breathing, insomnia, short sleep duration (<6 hours), diagnosed sleep disorder than those without sleep disturbances.

Table 2
Sleep characteristics of 3330 US adults in the National Health and Nutrition Examination Survey 2005 to 2008, according to AL status

Characteristic	*N*	Low AL* ($n = 2627$) % (SE)	High AL* ($n = 703$) % (SE)	*P* value†
Sleep apnea				
No	2895	83.4 (0.9)	16.6 (0.9)	<.001
Yes	435	69.3 (2.6)	30.6 (2.6)	
Sleep apnea symptoms				
Snoring				
No	2232	86.0 (1.0)	14.0 (1.0)	<.001
Yes	1098	72.3 (1.2)	27.7 (1.4)	
Snorting/stop breathing				
No	3120	82.8 (0.9)	17.2 (0.9)	<.001
Yes	210	64.7 (3.9)	35.2 (3.9)	
Insomnia‡				
No	3109	82.1 (0.9)	17.9 (0.9)	.002
Yes	221	72.8 (3.6)	27.2 (3.6)	
Components of insomnia				
Prolonged sleep latency				
No	2763	82.8 (0.9)	17.2 (0.9)	<.001
Yes	567	75.5 (1.9)	24.5 (1.9)	
Frequent nocturnal awakenings				
No	2667	81.9 (1.0)	18.1 (1.0)	.267
Yes	663	80.0 (1.6)	20.0 (1.6)	
Early morning awakening				
No	2753	82.1 (0.9)	17.9 (0.9)	.041
Yes	575	78.9 (1.6)	21.1 (1.6)	
Unrefreshed sleep				
No	2449	82.0 (0.9)	17.9 (0.9)	.283
Yes	881	80.3 (1.6)	19.7 (1.7)	
Short sleep duration				
≥6 h	2793	82.6 (1.0)	17.4 (1.0)	.001
<6 h	537	75.3 (2.0)	24.7 (2.0)	
Diagnosed sleep disorder				
No	3076	82.8 (0.9)	17.2 (0.9)	<.001
Yes	254	65.5 (2.9)	34.5 (2.9)	

SE = standard error.

* AL was measured using the following nine components and their corresponding cutoffs: (1) systolic blood pressure 140 mm Hg or more, (2) diastolic blood pressure 90 mm Hg or more, (3) heart rate 90 beats/minute or more, (4) total cholesterol level 240 mg/dL or more, (5) high-density lipoprotein cholesterol less than 40 mg/dL (6) body mass index 30 kg/m^2 or more, (7) glycosylated hemoglobin 6.4% or more, (8) C-reactive protein 0.3 mg/dL or more, and (9) albumin 3.8 g/dL or more. Each cutoff was coded as a dichotomous variable, and the AL score was defined as the sum of the indicators for the nine components. High AL was defined as the AL score 3 or more, whereas low AL was defined as the AL score less than 3.

† χ^2 test was conducted.

‡ Insomnia (yes/no) was defined by using the National Heart, Lung, and Blood Institute Working Group definition as one of the four insomnia symptoms plus at least one self-reported daytime functional impairment due to lack of sleep.

Figure 1, A shows that the mean AL score was high for African Americans, followed by Hispanic Americans, and whites. Individuals in other racial/ethnic group had the lowest AL score. The mean AL score was the highest among African American women, whereas the mean AL score was the lowest in other racial/ethnic women (Fig. 1, B). The elevated mean AL score in African Americans was solely due to African American women.

Table 3 shows that African Americans had a higher prevalence of insomnia and short sleep duration compared with other racial/ethnic groups (both $P < .05$). There were no significant differences in the distributions of sleep apnea, sleep apnea symptoms of snoring and snorting, and diagnosed sleep disorder across racial/ethnic groups.

Associations between high AL and sleep characteristics: mean differences

As shown in Figure 2, adults with sleep apnea, sleep apnea symptoms of snoring and snorting/stop breathing, insomnia, short sleep duration, and diagnosed sleep disorder had higher mean AL scores than those without these sleep disturbances (all $P < .001$).

Associations between high AL and sleep characteristics: logistic regression analysis

Table 4 shows the results of logistic regression models for the associations between AL and sleep characteristics. High AL was associated with sleep apnea (OR, 1.92; 95% CI, 1.40–2.63), insomnia (OR, 1.70; 95% CI, 1.16–2.47), and short sleep duration (OR, 1.35; 95% CI, 1.00–1.82), controlling for age, sex, race/ethnicity, marital status, education, PIR, country of birth, physical activity participation, alcohol consumption, and cigarette smoking. Individuals with a high AL were about two times as likely to have snoring (OR, 2.20; 95% CI, 1.79–2.69), snorting/stop breathing (OR, 2.16; 95% CI, 1.46–3.21), and diagnosed sleep disorder (OR, 2.26; 95% CI, 1.66–3.08). High AL was related to increased risk for prolonged sleep latency (one of the insomnia components), the adjusted OR was 1.42 (95% CI, 1.08–1.88). High AL was not associated with other components of insomnia, including frequent nocturnal awakenings, early morning awakening, or unrefreshed sleep.

Stratified analysis

As shown in Table 5, the associations of high AL with sleep apnea, snoring, and diagnosed sleep disorder were statistically significant and similar for both men and women. Although the association between high AL and insomnia was significant for women (OR, 1.90; 95% CI, 1.10–3.44) but not for men (OR, 1.43; 95% CI, 0.83–2.46), the interaction term was not significant. The associations of high AL with sleep apnea, snorting, insomnia, short sleep duration, and diagnosed sleep disorder were statistically significant and stronger for whites but not for African Americans, Hispanic Americans, or other racial/ethnic group. However, interaction terms were not statistically significant. There were significant associations between high AL and habitual snoring across racial/ethnic groups. The associations of high AL with sleep disturbances did not vary by country of birth (data not shown in tables).

Discussion

Minority racial/ethnic and low socioeconomic groups tend to have a higher prevalence of sleep disturbances and are more likely to be exposed to stress or high AL, a measure of physiological

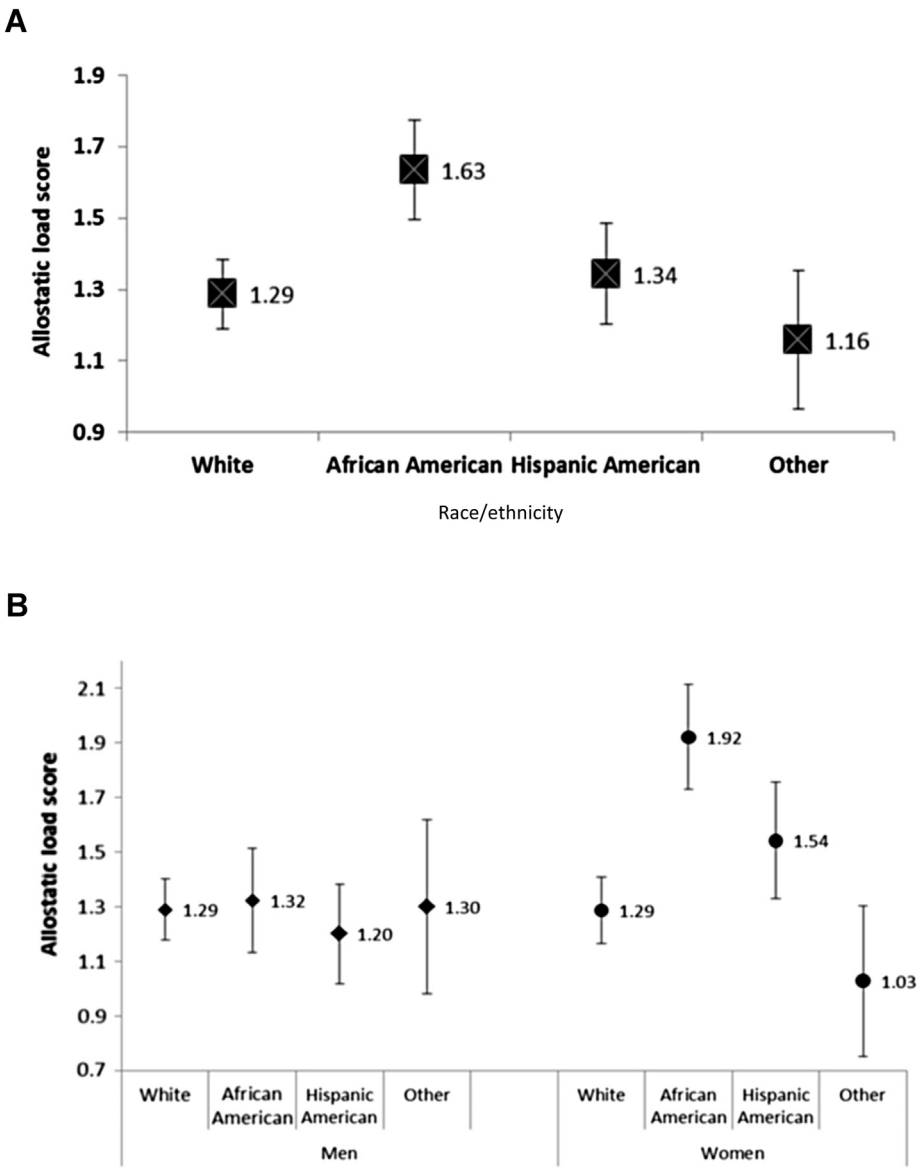

Fig. 1. Race/ethnicity distributions and mean AL scores among 3330 US adults in the National Health and Nutrition Examination Survey 2005 to 2008: means and 95% CI limits of means. (A) Both men and women. (B) For men and women separately.

instability across biological systems from cumulative or repeated adaptation to stressors [17]. Using nationally representative data, we found a high prevalence of AL (21.1%) and racial/ethnic differences in AL among US adults. High AL was associated with sleep apnea, sleep apnea symptoms (snoring and snorting/stop breathing), insomnia, short sleep duration, and diagnosed sleep disorder. These associations were independent of sociodemographic and lifestyle factors. Short sleep duration was most prevalent in African Americans. To our knowledge, this is the first study to examine the associations between AL and sleep characteristics based on national survey data.

Increasing research has indicated the relationships between AL and sociodemographic, lifestyle, and genetic characteristics [17,20–22]. Several studies have investigated the racial/ethnic differences in AL levels [20–22]. A study of 129 US adults found that African Americans had higher AL scores than whites, and more African Americans had high AL (67.9%) than did whites (48.9%) [21]. The NHANES 1999 to 2004 data showed that African American women had the highest AL scores relative to other racial/ethnic groups [22]. Our study, based on the NHANES 2005–2008, found similar results, which expand on previous research by evaluating the AL-sleep association using the national survey data. The NHANES III (1988–1994) data demonstrated that lower individual socioeconomic status was associated with higher AL, and this association existed for all major racial/ethnic groups [35]. In this study, we found that being African Americans or Hispanic Americans, having less education, being older, widowed, separated, or divorced, and alcohol consumption were associated with high AL, whereas recreational physical activity participation was related to low AL. These results were consistent with previous findings [17,36]. Our findings add to the growing literature regarding AL and its risk factors.

Several studies have suggested that country of birth may explain some health disparities in the United States [29,37–39]. Seicean et al [29] reported that Mexican-born US immigrants had more favorable sleep patterns than the general US population. In a

Table 3
Distributions of sleep disturbances in the National Health and Nutrition Examination Survey 2005 to 2008, according to race/ethnicity

	White % (SE)	African American % (SE)	Hispanic American % (SE)	Other % (SE)	*P* value*
Total sample size	1593	712	635	390	
Sleep apnea					
No	86.2 (1.2)	85.8 (2.0)	90.2 (1.5)	87.1 (1.9)	.364
Yes	13.8 (1.2)	14.2 (2.0)	9.8 (1.5)	12.9 (1.9)	
Sleep apnea symptoms					
Snoring					
No	67.2 (1.6)	68.7 (1.8)	66.3 (1.7)	66.9 (3.4)	.45
Yes	32.8 (1.6)	31.3 (1.8)	33.7 (1.7)	33.1 (3.4)	
Snorting/stop breathing					
No	92.9 (0.9)	93.8 (0.9)	94.7 (1.3)	93.7 (1.4)	.605
Yes	7.1 (0.9)	6.2 (0.9)	5.3 (1.3)	6.3 (1.4)	
Insomnia†					
No	94.4 (0.6)	90.5 (1.4)	95.1 (1.0)	91.9 (1.6)	.013
Yes	5.6 (0.6)	9.5 (1.4)	4.9 (1.0)	8.1 (1.6)	
Short sleep duration					
≥6 h	87.4 (0.8)	72.1 (1.4)	90.0 (1.5)	82.6 (2.4)	<.001
<6 h	12.6 (0.8)	27.9 (1.4)	10.0 (1.5)	17.4 (2.4)	
Diagnosed sleep disorder					
No	92.5 (0.7)	91.0 (1.2)	95.9 (1.0)	92.2 (1.7)	.109
Yes	7.5 (0.7)	9.0 (1.2)	4.1 (1.0)	7.8 (1.7)	

SE = standard error.
* Rao-Scott χ^2 test was conducted.
† Insomnia (yes/no) was defined by using the National Heart, Lung, and Blood Institute Working Group definition as one of the four insomnia symptoms plus at least one self-reported daytime functional impairment due to lack of sleep.

population-based sample of adults living in Texas City, foreign-born Mexicans were the least likely group to score in the higher AL categories [20]. US-born Mexican Americans had higher AL scores than foreign-born Mexicans, and acculturation measures did not account for the difference. We found that the prevalence of high AL was higher for US-born than for foreign-born individuals, supporting the healthy immigrant hypothesis [20].

Although there has been an increasing number of studies on the association between AL and health outcomes [14,40], ours is the first study investigating the association between AL and sleep disturbances based on national survey data. The NHANES 1999 to 2004 data showed that greater AL was associated with elevated prevalence of pain in US adults [14]. The NHANES 1999 to 2004 data also indicated that US adults with high AL were more likely to have periodontitis than their counterparts with low AL [40]. In our study, we found that US adults with greater biological "wear and tear" as measured by AL were more likely to have insufficient sleep as measured by short sleep duration and diagnosed sleep apnea or sleep apnea symptoms, or other sleep disorders. Furthermore, these relationships were independent of sociodemographic and lifestyle factors. Our findings indicate that greater biological "wear and tear" is independently associated with insufficient sleep and sleep disturbances, thereby suggesting their importance in enhancing physiological functioning among US adults. Contrary to our hypothesis, we did not find that the association between AL and sleep was stronger among African Americans or Hispanic Americans. This might be because of self-reported sleep information used in our study. African Americans and Hispanic Americans might have underestimated their sleep problems. One recent study, for example, revealed that African and Hispanic respondents were relatively optimistic in their ratings than whites [41]. Studies that deploy objective measures of sleep behavior and sleep quality may overcome limitations associated with reliance on self-reported sleep measures.

Our study has several strengths. First, it is based on nationally representative and recent NHANES data collected between 2005 and 2008, with balanced gender representation and geographic diversity, and likely to be free of the referral biases that may occur from studies of sleep clinic-based samples [29]. This allows greater generalizability than previous studies. Second, it has a large sample size, which uses highly structured protocols and allows us to conduct stratified analyses to examine whether the associations between AL and sleep parameters differ by sociodemographic characteristics. Third, we conducted a robust set of statistical analyses by applying multivariable logistic regression and stratified analyses to examine the associations between AL and sleep disturbances.

This study has limitations. A major limitation is its cross-sectional study design; thus, we are unable to detect whether AL leads to sleep disturbances or vice versa, or neither may be true. Our findings could be explained by an underlying mechanism that

Table 4
Multivariable logistic regression models: associations of AL with sleep disturbances among 3330 US adults in the National Health and Nutrition Examination Survey 2005 to 2008*

Outcome variable	Unadjusted	*P* value	Adjusted†	*P* value
	OR (95% CI)		OR (95% CI)	
Sleep apnea	2.23 (1.64–3.01)	<.001	1.92 (1.40–2.63)	<.001
Sleep apnea symptoms				
Snoring	2.37 (1.94–2.89)	<.001	2.20 (1.79–2.69)	<.001
Snorting/stop breathing	2.62 (1.78–3.84)	<.001	2.16 (1.46–3.21)	<.001
Insomnia‡	1.71 (1.21–2.41)	.002	1.70 (1.16–2.47)	.006
Insomnia component				
Prolonged sleep latency	1.57 (1.26–1.94)	<.001	1.42 (1.08–1.88)	.013
Frequent nocturnal awakenings	1.13 (0.91–1.41)	.269	0.99 (0.77–1.27)	.944
Early morning awakening	1.23 (1.01–1.49)	.041	1.03 (0.83–1.28)	.793
Unrefreshed sleep	1.12 (0.91–1.38)	.281	1.13 (0.88–1.45)	.347
Short sleep duration (<6 h)	1.56 (1.19–2.06)	.002	1.35 (1.00–1.82)	.048
Diagnosed sleep disorder	2.54 (1.95–3.32)	<.001	2.26 (1.66–3.08)	<.001

* AL was measured using the following nine components and their corresponding cutoffs: (1) systolic blood pressure 140 mm Hg or more, (2) diastolic blood pressure 90 mm Hg or more, (3) heart rate 90 beats/minute or more, (4) total cholesterol level 240 mg/dL or more, (5) high-density lipoprotein cholesterol less than 40 mg/dL (6) body mass index 30 kg/m^2 or more, (7) glycosylated hemoglobin 6.4% or more, (8) C-reactive protein 0.3 mg/dL or more, and (9) albumin less than 3.8 g/dL. Each cutoff was coded as a dichotomous variable, and the AL score was defined as the sum of the indicators for the nine components. High AL was defined as a total of AL score 3 or more, whereas low AL was defined as the AL score less than 3.
† The following variables were adjusted for in the models: age, sex, marital status, education, household income, race/ethnicity, country of birth, alcohol consumption, cigarette smoking, and regular physical activity participation.
‡ Insomnia (yes/no) was defined by using the National Heart, Lung, and Blood Institute Working Group definition as one of the four insomnia symptoms plus at least one self-reported daytime functional impairment due to lack of sleep.

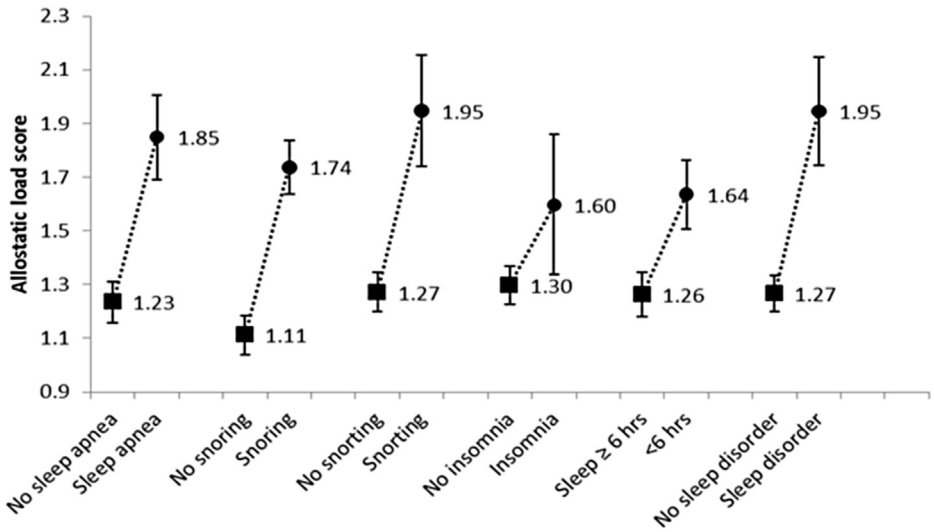

Fig. 2. Sleep disturbances and mean AL scores among 3330 US adults in the National Health and Nutrition Examination Survey 2005 to 2008: means and 95% CI limits of means.

affects both AL and sleep disturbances. Future research should seek an answer to this foundational question. Another limitation, as noted previously, is that sleep characteristics were assessed by self-reported questionnaire, which is subject to measurement error and/or report bias. In addition, there is considerable heterogeneity in the biomarkers selected to assess AL [17,20,21,36,40] and in the cut-points for defining high AL [14,16,20–22,42,43]. A recent review of 58 published articles on AL indicated that interpretations and comparisons across studies was challenging because of different AL biomarker measurement [17]. In our study, we applied nine biomarkers representing cardiovascular, inflammatory, and metabolic system functioning to evaluate the AL levels, as in prior research with the NHANES data set [32–34].

In summary, results from this cross-sectional study with a nationally representative sample suggest that high AL is associated with sleep apnea, sleep apnea symptoms, insomnia, short sleep duration, and diagnosed sleep disorder. These data support a potentially pervasive influence of sleep-related stresses on physiological functioning associated with cardio-metabolic disease and mortality. Individuals with sleep problems have a high burden of physical and psychological health conditions. Future research should focus on refining the definition of AL, or the development of a consensus opinion. Further prospective longitudinal studies, with objective measures of sleep duration and quality, are needed to examine the possible bidirectionality and causal associations between AL and sleep characteristics. Priorities for future research also include examining a broad range of antecedent allostatic challenges, and collecting reliable measures of multisystem dysregulation explicitly designed to assess AL at multiple time points in population-based prospective studies [17].

Table 5
Stratified analyses for the associations between high AL and sleep disturbances among 3330 US adults in the National Health and Nutrition Examination Survey 2005 to 2008, by sex and race/ethnicity*

	Sleep apnea	Snoring	Snorting/stop breathing	Insomnia†	Short sleep duration <6 h	Sleep disorder
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Sex						
Men	1.96 (1.35–2.84)***	2.00 (1.44–2.77)***	2.23 (1.44–3.45)***	1.43 (0.83–2.46)	1.30 (1.00–1.75)*	2.30 (1.54–3.53)***
Women	1.78 (1.09–2.89)*	2.24 (1.55–3.23)***	1.96 (0.98–3.90)	1.90 (1.10–3.44)*	1.31 (0.78–2.19)	2.30 (1.53–3.35)***
P for interaction	.931	.363	.890	.455	.832	.973
Race/ethnicity						
White	2.01 (1.39–2.91)***	1.97 (1.50–2.60)***	2.44 (1.50–3.98)***	1.90 (1.15–2.99)*	1.40 (1.01–2.05)*	2.60 (1.68–4.03)***
AA	1.80 (0.90–3.60)	2.44 (1.69–3.54)***	1.28 (0.52–3.15)	1.36 (0.71–2.62)	1.03 (0.69–1.53)	1.15 (0.57–2.33)
HA	1.43 (0.59–3.44)	3.29 (2.09–5.19)***	1.75 (0.57–5.35)	1.09 (0.49–2.44)	0.85 (0.47–1.57)	1.91 (0.59–6.16)
Other	1.43 (0.45–4.54)	2.85 (1.25–6.50)*	1.51 (0.30–7.20)	1.81 (0.56-5.83)	1.90 (0.78–4.67)	2.73 (0.73–10.2)
P for interaction	.498	.118	.413	.891	.181	.331

AA = African American; HA = Hispanic American.
The following variables were adjusted for in the models: age, sex, marital status, education, household income, country of birth, alcohol consumption, cigarette smoking, and regular physical activity participation.
*$P < .05$.
**$P < .01$.
***$P < .001$.

* AL was measured using the following nine components and their corresponding cutoffs: (1) systolic blood pressure 140 mm Hg or more, (2) diastolic blood pressure 90 mm Hg or more, (3) heart rate 90 beats/minute or more, (4) total cholesterol level 240 mg/dL or more, (5) high-density lipoprotein cholesterol less than 40 mg/dL (6) body mass index 30 kg/m^2 or more, (7) glycosylated hemoglobin 6.4% or more, (8) C-reactive protein 0.3 mg/dL or more, and (9) albumin less than 3.8 g/dL. Each cutoff was coded as a dichotomous variable, and the AL score was defined as the sum of the indicators for the nine components. High AL was defined as score 3 or more, whereas low AL was defined as AL score less than 3.

† Insomnia (yes/no) was defined by using the National Heart, Lung, and Blood Institute Working Group definition as one of the four insomnia symptoms plus at least one self-reported daytime functional impairment due to lack of sleep.

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