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Sleep symptoms associated with intake of specific dietary nutrients

MICHAEL A. GRANDNER[1,2], NICHOLAS JACKSON[1,2], JASON R. GERSTNER[1,2] and KRISTEN L. KNUTSON[3]

[1]Center for Sleep and Circadian Neurobiology, University of Pennsylvania, Philadelphia, PA, USA, [2]Division of Sleep Medicine, Department of Medicine, University of Pennsylvania, Philadelphia, PA, USA and [3]Section of Pulmonary and Critical Care, Department of Medicine, University of Chicago, Chicago, IL, USA

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Correspondence
Michael A. Grandner, PhD, Center for Sleep and Circadian Neurobiology, 3624 Market Street, Suite 205, Philadelphia, PA 19104, USA.
Tel.: 215 615-1756;
fax: 215 701-1831;
e-mail:grandner@gmail.com

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SUMMARY

Sleep symptoms are associated with weight gain and cardiometabolic disease. The potential role of diet has been largely unexplored. Data from the 2007–2008 National Health and Nutrition Examination Survey (NHANES) were used (n = 4552) to determine which nutrients were associated with sleep symptoms in a nationally representative sample. Survey items assessed difficulty falling asleep, sleep maintenance difficulties, non-restorative sleep and daytime sleepiness. Analyses were adjusted for energy intake, other dietary factors, exercise, body mass index (BMI) and sociodemographics. Population-weighted, logistic regression, with backwards-stepwise selection, examined which nutrients were associated with sleep symptoms. Odds ratios (ORs) reflect the difference in odds of sleep symptoms associated with a doubling in nutrient. Nutrients that were associated independently with difficulty falling asleep included (in order): alpha-carotene (OR = 0.96), selenium (OR = 0.80), dodecanoic acid (OR = 0.91), calcium (OR = 0.83) and hexadecanoic acid (OR = 1.10). Nutrients that were associated independently with sleep maintenance difficulties included: salt (OR = 1.19), butanoic acid (0.81), carbohydrate (OR = 0.71), dodecanoic acid (OR = 0.90), vitamin D (OR = 0.84), lycopene (OR = 0.98), hexanoic acid (OR = 1.25) and moisture (OR = 1.27). Nutrients that were associated independently with non-restorative sleep included butanoic acid (OR = 1.09), calcium (OR = 0.81), vitamin C (OR = 0.92), water (OR = 0.98), moisture (OR = 1.41) and cholesterol (OR = 1.10). Nutrients that were associated independently with sleepiness included: moisture (OR = 1.20), theobromine (OR = 1.04), potassium (OR = 0.70) and water (OR = 0.97). These results suggest novel associations between sleep symptoms and diet/metabolism, potentially explaining associations between sleep and cardiometabolic diseases.

INTRODUCTION

Sleep disorders, including insomnia and obstructive sleep apnea, are major public health issues that affect millions of Americans. Because sleep disorders can impair quality of life, increase risk of other diseases and result in an economic burden estimated to be tens of billions of dollars annually for both sleep apnea (Potts *et al.*, 2013) and insomnia (Kessler *et al.*, 2011), the consequences and causes of reduced sleep quality are important to identify.

Experimental studies that restricted time available for sleep found changes in appetite regulating hormones, specifically lower levels of leptin (a satiety signal) and higher levels of ghrelin (an appetite stimulant) compared to extended time in bed. This suggests that sleep loss may be associated with alterations in diet. For that reason, other experimental studies examined whether sleep restriction impacted dietary behaviour. For example, 6 nights of time in bed restricted to 4 h in men and women aged 30–45 years was associated with a significant increase in caloric intake, particularly from fat,

without a compensatory change in energy expenditure (St-Onge *et al*., 2011). Another study restricted time in bed to 5 h for 5 days and observed increased food intake compared to 9 h in bed (Markwald *et al*., 2013). This study also observed a slight increase in energy expenditure after sleep restriction; however, it was not equivalent to the increase in energy intake, and therefore there was significant weight gain as well. A third study examined the effect of sleep restriction that was two-thirds of their habitual time in bed, thereby accounting for individual differences in habitual sleep times (Calvin *et al*., 2013). This study also observed an increase in caloric intake after sleep restriction without any change in energy expenditure. The effects of all three studies were observed with just a few nights of sleep restriction, but if these effects became chronic it would lead to weight gain. Experimental studies that impaired sleep quality and assessed food intake have not yet been published; however, sleep disturbances are associated with sleep loss. Thus, effects of sleep restriction may also be observed when sleep quality is impaired as well. Because alterations in dietary composition have been shown to increase obesity risk, this possibility has important implications for the millions who suffer from sleep disorders such as insomnia and obstructive sleep apnea (Mozaffarian *et al*., 2011).

Experimental studies are conducted in controlled, artificial environments for only a short period of time, and therefore it is important to determine whether the associations between sleep and diet persist outside the laboratory. Only a few observational studies have examined whether there is an association between habitual sleep patterns and diet, but most of these focused on sleep duration (Grandner *et al*., 2010; Nishiura *et al*., 2010). A study of adults in India found that participants with symptoms of insomnia had a lower total caloric intake, lower protein intake and lower carbohydrate intake compared to normal sleepers (Zadeh and Begum, 2011). However, when examining the dietary proportions of macronutrients, the proportion of carbohydrate intake was slightly higher and the proportion of fat was slightly lower in the presence of insomnia (Zadeh and Begum, 2011). Among young female students in Japan, women with healthier sleep habits (including better sleep quality) were significantly more likely to eat breakfast regularly (Nakade *et al*., 2009), a dietary behaviour associated with better cardiometabolic health (Alexander *et al*., 2009; Mekary *et al*., 2012; Smith *et al*., 2010). In a study of women, shorter sleep duration measured using actigraphy (and, to a lesser extent, sleep diary) was associated with a higher consumption of fat and nutrients whose primary sources are high-fat foods, even after adjustment for demographics, socioeconomics, total energy intake, body mass index (BMI) and exercise (Grandner *et al*., 2010). Results from these few observational studies suggest that a relationship between sleep patterns and feeding behaviour may exist, but additional studies are necessary to determine the nature of these associations at the population level.

The goal of the present analyses was to determine whether an association between self-reported sleep quality and dietary factors was present in a large, nationally representative study in the United States. The National Health and Nutrition Examination Survey (NHANES) provided a unique opportunity to examine these cross-sectional associations in a large sample of adults aged 18 years and older. In addition to data on macronutrient composition, NHANES has detailed information on micronutrients and other dietary behaviours, allowing for the assessment of associations between sleep, diet and nutrition in a large population. Given the sparse literature on the relationships between sleep and both macro- and micro-nutrients, cross-sectional associations will provide novel information about intake of different nutrients that are associated with sleep disturbances, which may help to generate specific hypotheses for future studies.

METHODS

Data source

The subjects used in this study were participants in the 2007–2008 NHANES, a national survey conducted by the Centers for Disease Control and Prevention, reporting the health and nutritional characteristics of children and adults. Participants were administered questionnaires assessing their demographic, socioeconomic, nutritional and related statuses during in-person interviews conducted in the home. Also, physical examinations were performed in mobile medical facilities to collect medical and physiological data; additional laboratory tests were performed from blood and urine samples collected onsite. In order to compensate for underrepresentation, African Americans, Hispanics and adults over aged 60 years were oversampled.

Sampling in this survey was performed to ensure generalizability to the entire population across all ages. Because of the complexity of the survey design coupled with variable probabilities of selection, the data used in the following analyses were also weighted to control for representativeness by following the procedures outlined in the current NHANES Analytic and Reporting Guidelines (2006). For the present study, analyses included adults aged 18 years and older with complete data on all independent and dependent variables (n = 4548).

Measures

Sleep symptoms

Sleep symptoms included difficulty falling asleep, difficulty maintaining sleep, non-restorative sleep and daytime sleepiness. These represent hallmark symptoms of a number of sleep disorders, including the most prevalent (e.g. insomnia and obstructive sleep apnea). Difficulty falling asleep was assessed with the question: 'In the past month, how often did you have trouble falling asleep?'. Difficulty maintaining sleep was assessed with the question: 'In the past month, how often did you wake up during the night and had trouble

getting back to sleep?'. Non-restorative sleep was assessed with the question:, 'In the past month, how often did you feel unrested during the day, no matter how many hours of sleep you had?'. Daytime sleepiness was assessed using the question: 'In the past month, how often did you feel excessively or overly sleepy during the day?'. Responses were categorized as none, once a month, two to four times a month, five to 15 times a month and 16–30 times a month.

Diet and nutrition

Diet and nutrition data were collected as part of standard NHANES procedures (Centers for Disease Control and Prevention, 2008). This consisted of 24-hour recall, guided by a structured interview (day 1 data). Bean bags, measuring cups, rulers and other guides were used to aid in determining amounts and assisting subject recall. Dietary nutrient information was based on established values and parameters (Moshfegh *et al*., 2008; Raper *et al*., 2004;, Rumpler *et al*., 2008). A validated 24-hour recall is generally considered sufficient to generalize to overall eating patterns at the population level (Dary and Imhoff-Kunsch, 2012). The dietary interview component of NHANES is conducted as a partnership between the US Department of Agriculture (USDA) and the US Department of Health and Human Services (DHHS). Under this partnership, the DHHS National Center for Health Statistics (NCHS) is responsible for the sample design and data collection and USDA's Food Surveys Research Group is responsible for the dietary data collection methodology, maintenance of the databases used to code and process the data and data review and processing. The 24-hour recall method has been validated rigorously (Moshfegh *et al*., 2008; Raper *et al*., 2004; Rumpler *et al*., 2008). Variables included in the present analysis included assessments of overall diet, macronutrients and micronutrients, including fats, proteins, vitamins, minerals, salt, water and other substances. For a complete list, see Supplementary materials ('Dietary variables assessed').

Sociodemographic, socioeconomic and health covariates

A number of potential confounders were assessed. These included age, sex, race/ethnicity (non-Hispanic white, Hispanic/Latino, black/African American and Asian/other), education (less than high school, high school graduate, some college and college graduate), household income (<$20 000, $20–25 000, $25–35 000, $35–45 000, $45–55 000, $55–65 000, $65–75 000 and >$75 000), minutes of exercise per day and objectively measured BMI. Depression was measured with: 'Over the last 2 weeks, how often have you been bothered by… feeling down, depressed, or hopeless?'. Responses were recorded as: 'not at all', 'several days', 'more than half the days' and 'nearly every day'. These variables were specifically chosen a priori because of their potential associations with both sleep symptoms and dietary behaviour, and they were used in the one previous study of dietary nutrients and sleep duration (Grandner *et al*., 2010).

Statistical analyses

Differences in dietary and demographic variables between sleep groups were assessed using independent *t*-tests for continuous variables and Pearson's χ^2 for categorical variables.

We used ordinal logistic regression models with each sleep symptom as the dependent variable. Although it may be argued that sleep symptoms may cause changes in certain dietary behaviours, the nature of cross-sectional data does not allow for determination of causation. Thus, we can only test for associations and having the sleep symptoms as the dependent variables substantially reduces the number of regression models providing the most parsimonious analysis. Therefore, the effects of diet on the presence of sleep symptoms were assessed using ordinal logistic regression. Separate regression models were estimated for each dietary factor and nutrient. Finally, to examine the most parsimonious model explaining each sleep symptom, a backward stepwise selection procedure was implemented with demographic, depression, nutrient intake and special diet variables including alcohol intake forced into each model. Additional variables were then selected based upon an inclusion significance criterion of 0.05 and exclusion criterion of 0.10. These variables are considered to contribute unique variance to the model and will be presented in order of the amount of variance they explain. To avoid model selection bias due to collinearity, dietary variables that were correlated above rho = 0.75 were excluded from the variable list in the model selection procedure (when variables were collinear, the variable with the highest correlation with the sleep item was retained).

All continuous dietary variables were log-transformed for analysis. Values represent odds associated with a 100% increase in intake for continuous variables, with the exception of fatty acids, which were expressed in standardized units, such that their effects are reported in terms of their standard deviations. Analyses were weighted appropriately for representativeness in accordance with NHANES 2007–2008 weighting guidelines. Because of the number of hypotheses being tested, *P*-values were Benjamini–Hochberg-corrected for false discovery rate (Benjamini and Hochberg, 1995). This allows us to maintain an alpha level of 0.05 for analyses.

RESULTS

Sample characteristics

Characteristics of the sample are reported in Table 1. All cases were weighted, resulting in a sample that was matched closely to the general population. Sleep symptoms were, however, distributed differentially across sociodemographic, socioeconomic and health variables, justifying their inclusion

Table 1 Subject characteristics by sleep symptoms

			Difficulty falling asleep						*Difficulty maintaining sleep*					
Variable	*Category*	*Total sample*	*Almost always*	*Often*	*Sometimes*	*Rarely*	*Never*	P	*Almost always*	*Often*	*Sometimes*	*Rarely*	*Never*	P
n (%)		4548	363 (8%)	463 (10%)	966 (21%)	888 (20%)	1868 (41%)		362 (8%)	565 (12%)	1095 (24%)	848 (19%)	1678 (37%)	
Age	Mean (SD)	46.3 (16.5)	46.7 (14.9)	44.6 (14.8)	46.8 (16.6)	47.4 (15.6)	45.8 (17.8)	0.09	48.5 (14.6)	46.7 (15.4)	47.8 (16.2)	46.5 (16.0)	44.5 (17.7)	<0.01
Sex	Female	53.1%	67.90%	63.90%	55.17%	49.47%	47.28%	<0.01	66.55%	62.05%	58.89%	46.48%	46.09%	<0.01
	Male	46.9%	32.10%	36.10%	44.83%	50.53%	52.72%		33.45%	37.95%	41.11%	53.52%	53.91%	
Race/ethnicity	Non-Hispanic white	71.6%	72.80%	79.87%	72.19%	76.55%	65.36%	<0.01	76.10%	78.25%	71.68%	74.31%	66.28%	<0.01
	Hispanic/Latino	13.0%	11.02%	8.84%	12.09%	10.74%	16.74%		10.26%	8.57%	12.04%	12.80%	16.27%	
	Black/African American	10.9%	11.31%	8.30%	10.10%	7.45%	14.06%		9.71%	10.25%	9.77%	9.17%	13.17%	
	Asian/other	4.5%	4.87%	2.99%	5.62%	5.27%	3.83%		3.93%	2.93%	6.51%	3.72%	4.29%	
Education	Less than high school	25.5%	25.24%	17.52%	15.94%	15.20%	22.25%	<0.01	22.39%	18.80%	18.50%	13.59%	21.84%	<0.01
	High school graduate	19.0%	30.02%	24.68%	23.60%	24.05%	26.43%		33.80%	23.84%	25.77%	23.44%	24.81%	
	Some college	25.4%	30.80%	34.76%	34.50%	28.79%	26.45%		27.49%	34.32%	28.53%	32.14%	28.97%	
	College graduate	30.1%	13.93%	23.04%	25.96%	31.96%	24.87%		16.33%	23.04%	27.19%	30.83%	24.38%	
Income	<20 k	33.0%	30.57%	17.35%	16.58%	11.52%	14.70%	<0.01	25.40%	19.15%	15.22%	11.85%	15.70%	0.02
	20–25 k	16.1%	7.37%	5.51%	7.28%	7.34%	7.49%		6.05%	6.91%	7.33%	5.48%	8.41%	
	25–35 k	7.2%	13.51%	11.44%	12.59%	9.75%	12.39%		12.41%	13.68%	12.69%	9.84%	11.56%	
	35–45 k	11.9%	6.46%	6.66%	9.09%	10.46%	9.07%		8.43%	7.10%	8.20%	10.61%	9.19%	
	45–55 k	8.9%	7.04%	10.93%	8.53%	9.16%	7.23%		7.23%	8.58%	9.33%	7.60%	8.20%	
	55–65 k	8.3%	5.10%	9.64%	4.87%	7.15%	7.97%		6.55%	5.14%	7.39%	6.82%	7.77%	
	65–75 k	7.1%	8.19%	7.36%	7.36%	8.02%	7.43%		7.39%	8.31%	7.88%	6.30%	7.91%	
	>75 k	7.6%	21.75%	31.12%	33.69%	36.60%	33.70%		26.54%	31.13%	31.96%	41.50%	31.25%	
Minutes of exercise	Mean (SD)	166 (223)	161 (207)	167 (215)	163 (211)	169 (204)	168 (248)	0.99	165 (216)	186 (244)	155 (203)	162 (204)	170 (241)	0.41
Body mass index	Mean (SD)	28.7 (6.8)	29.5 (7.7)	29.0 (6.4)	28.2 (6.3)	28.4 (5.8)	29.0 (7.5)	0.06	29.6 (7.4)	28.7 (6.9)	28.6 (6.2)	28.3 (6.3)	28.8 (7.3)	0.36
Depression	Not at all	75.9%	48.57%	59.29%	72.40%	81.69%	86.16%	<0.01	52.58%	63.46%	71.99%	84.06%	84.49%	<0.01
	Several days	17.5%	32.82%	30.07%	20.75%	13.94%	10.21%		30.53%	26.53%	20.85%	12.73%	11.26%	
	Nearly half the days	3.5%	6.57%	4.80%	4.61%	3.29%	1.91%		6.39%	4.89%	4.13%	2.35%	2.57%	
	All the time	3.0%	12.03%	5.84%	2.24%	1.08%	1.71%		10.50%	5.12%	3.04%	0.86%	1.67%	

Table 1 *Continued*

			Non-restorative sleep						*Daytime sleepiness*					
Variable	*Category*	*Total sample*	*Almost always*	*Often*	*Sometimes*	*Rarely*	*Never*	*P*	*Almost always*	*Often*	*Sometimes*	*Rarely*	*Never*	*P*
n (%)		4548	462 (10%)	687 (15%)	1201 (26%)	703 (16%)	1495 (33%)		272 (6%)	525 (12%)	1191 (26%)	908 (20%)	1652 (36%)	
Age	Mean (SD)	46.3 (16.5)	44.5 (14.9)	42.6 (14.0)	44.8 (14.9)	48.3 (16.2)	50.1 (19.9)	<0.01	44.2 (15.7)	43.3 (14.7)	45.2 (15.7)	46.6 (15.1)	48.8 (18.8)	<0.01
Sex	Female	53.1%	65.8%	58.3%	55.0%	45.4%	46.9%	<0.01	57.98%	64.9%	51.6%	53.6%	48.2%	<0.01
	Male	46.9%	34.2%	41.8%	45.0%	54.6%	53.1%		42.0%	35.1%	48.5%	46.4%	51.8%	
Race/ethnicity	Non-Hispanic white	71.6%	76.6%	78.1%	73.9%	72.0%	61.8%	<0.01	71.5%	79.5%	73.8%	75.6%	63.2%	<0.01
	Hispanic/Latino	13.0%	9.7%	11.0%	10.4%	12.2%	19.4%		12.8%	7.5%	10.9%	10.7%	19.2%	
	Black/African American	10.9%	9.1%	8.3%	9.8%	10.8%	14.7%		10.5%	9.6%	10.0%	9.4%	13.3%	
	Asian/other	4.5%	4.6%	2.6%	5.9%	5.0%	4.0%		5.2%	3.4%	5.4%	4.3%	4.3%	
Education	Less than high school	25.5%	16.5%	24.4%	28.6%	29.5%	24.1%	<0.01	14.0%	18.0%	28.0%	32.6%	23.5%	<0.01
	High school graduate	19.0%	21.8%	13.4%	17.5%	14.1%	26.7%		25.8%	17.7%	17.4%	12.8%	24.3%	
	Some college	25.4%	29.3%	24.2%	24.0%	26.2%	25.7%		26.4%	27.5%	23.6%	25.3%	26.1%	
	College graduate	30.1%	32.4%	38.1%	30.0%	30.2%	23.4%		33.9%	36.9%	30.9%	29.3%	26.1%	
Income	<20 k	33.0%	23.5%	35.6%	37.4%	38.2%	27.0%	<0.01	21.0%	30.3%	37.3%	38.2%	28.8%	<0.01
	20–25 k	16.1%	24.4%	15.2%	14.4%	9.8%	19.0%		30.5%	16.6%	14.5%	12.0%	17.5%	
	25–35 k	7.2%	7.2%	7.4%	6.1%	5.9%	9.1%		8.4%	6.7%	7.3%	4.5%	9.0%	
	35–45 k	11.9%	13.8%	10.5%	12.3%	10.1%	12.7%		10.6%	15.3%	10.5%	10.9%	12.6%	
	45–55 k	8.9%	7.4%	7.5%	7.6%	11.7%	10.2%		6.9%	6.5%	8.4%	10.3%	9.8%	
	55–65 k	8.3%	7.8%	9.2%	8.2%	8.6%	8.0%		9.3%	8.0%	7.7%	8.7%	8.6%	
	65–75 k	7.1%	8.2%	7.8%	5.3%	6.9%	8.2%		5.1%	9.2%	6.6%	6.4%	7.3%	
	>75 k	7.6%	7.8%	6.8%	8.8%	8.9%	5.9%		8.2%	7.5%	7.7%	9.0%	6.4%	
Minutes of exercise	Mean (SD)	166 (223)	150 (198)	173 (216)	172 (216)	183 (223)	152 (239)	0.13	175 (227)	157 (192)	167 (215)	179 (210)	159 (252)	0.55
Body mass index	Mean (SD)	28.7 (6.8)	29.2 (7.0)	28.8 (6.3)	28.9 (6.6)	28.4 (6.4)	28.5 (7.5)	0.55	30.2 (8.0)	29.2 (7.7)	28.8 (6.6)	28.2 (5.5)	28.5 (7.0)	0.03
Depression	Not at all	75.9%	48.6%	59.3%	72.4%	81.7%	86.2%	<0.01	52.6%	63.5%	72.0%	84.1%	84.5%	<0.01
	Several days	17.5%	32.8%	30.1%	20.8%	13.9%	10.2%		30.5%	26.5%	20.9%	12.7%	11.3%	
	Nearly half the days	3.5%	6.6%	4.8%	4.6%	3.3%	1.9%		6.4%	4.9%	4.1%	2.4%	2.6%	
	All the time	3.0%	12.0%	5.8%	2.2%	1.1%	1.7%		10.5%	5.1%	3.0%	0.9%	1.7%	

as covariates. Those with difficulty falling asleep or difficulty maintaining sleep were more likely to be female, non-Hispanic white, have less education, earn less income and report greater depressive symptoms. Those with non-restorative sleep and daytime sleepiness were more likely to be younger, female, non-Hispanic white, have lower income and greater depressive symptoms. Non-restorative sleep varied significantly by educational level, but not in a linear fashion. In addition, daytime sleepiness was associated with higher BMI.

Overview of reported results

The results presented below are categorized based on the complexity of the analysis. First, results of unadjusted, simple comparisons using analysis of variance (ANOVA) are reported (Table S1a–d). Secondly, unadjusted and adjusted ordinal logistic regression results for overall diet are reported (Table S2). Thirdly, unadjusted and adjusted ordinal logistic regression results for specific macronutrients and micronutrients are presented (Table S3a–d). Fourthly, the stepwise regression results are presented in Tables 2–5. While the ordinal regression results presented in Table S3 consider each nutrient in a separate model (ignoring intercorrelations among nutrients), the stepwise results report on ordinal regression analyses that account for the overlap among nutrients. Therefore, although the other analyses are relevant, the stepwise results are considered the principal findings.

Group differences in dietary variables

Results of bivariate analyses (*F*-tests for continuous and χ^2 for categorical variables) are reported in Table S1, which describes differences according to difficulty falling asleep (1a), differences according to difficulty maintaining sleep (1a), differences according to non-restorative sleep (1c) and differences according to daytime sleepiness (1d). See Supplementary materials for written interpretations of these data. Overall, dietary pattern differences were seen more for difficulty falling asleep and difficulty maintaining sleep than the other two sleep symptoms.

Results from multivariable regression analyses of overall diet

Results from unadjusted and adjusted analyses are reported in Table S2. In unadjusted analyses, difficulty maintaining sleep was associated with lower food variety, higher likelihood of less food reported versus usual intake and being on a special diet. After adjustment for covariates, these were not significant. Non-restorative sleep was associated with lower likelihood of being on a low fat/cholesterol diet in both unadjusted and adjusted analyses. Daytime sleepiness was associated with increased caloric intake in adjusted analyses. It was also associated with higher likelihood of less food reported compared to usual diet in unadjusted analyses only, and being on a low fat/cholesterol diet in both unadjusted and adjusted analyses.

Results from multivariable regression analyses of specific nutrient variables

Results from multivariable regression analyses are reported in Table S3 for difficulty falling asleep (3a), difficulty maintaining sleep (3b), non-restorative sleep (3c) and daytime sleepiness (3d). See Supplementary information for interpretations of these results.

Results from stepwise regression analyses

Results from the stepwise regression for difficulty falling asleep are reported in Table 2. After all sociodemographic, socioeconomic, health and dietary covariates were forced into the model, the nutrient variables that were significantly associated with greater difficulty falling asleep were, in order, less alpha carotene, less selenium, less dodecanoic acid, less calcium, and more hexadecanoic acid. The nutrients that were associated significantly with greater difficulty maintaining asleep (Table 3), in order, were more salt use, less butanoic acid, less carbohydrate, less dodecanoic acid, less vitamin D, less lycopene, more hexanoic acid and more moisture. For non-restorative sleep (Table 4), the nutrients that explained the most unique variance were, in order, more butanoic acid, less calcium, less vitamin C, less plain water, more moisture and more cholesterol. Finally, the nutrients that were associated significantly with greater daytime sleepiness (Table 5) were, in order, more moisture, more theobromine, less potassium and less plain water.

DISCUSSION

Results from these nationally representative data indicate that sleep symptoms are associated with some dietary components. Overall diet was associated significantly with sleep symptoms. Difficulty maintaining sleep was associated with fewer foods in the diet and, along with daytime sleepiness, was associated with being on a special diet. Being on a low fat/cholesterol diet was associated with less non-restorative sleep and daytime sleepiness.

Several of the specific nutrients were associated with sleep symptoms as well. Many of these nutrients are associated with health, as will be described, and therefore may have implications for associations between sleep disturbances and disease risk. Reduced selenium intake was associated with difficulty falling asleep. Selenium is found in meats, seafood, dairy products, grains and nuts and is an essential micronutrient that plays an important role in initiating and enhancing immunity as well as in immunoregulation, which is crucial for preventing excessive responses that could lead to chronic inflammation (Huang *et al.*, 2011). Less vitamin C intake was associated with non-restorative sleep. Vitamin C, which is

Table 2 Stepwise ordinal logistic regression model reflecting odds ratios (OR) and 95% confidence intervals (95% CI) of associations between 100% increase in dietary variables and difficulty falling asleep

Variable	*Category*	*OR (95% CI)*	P
Covariates forced into the model			
Number of foods		1.01 (1.00, 1.03)	0.18
Energy (kcal) per 100		1.02 (1.01, 1.03)	0.003
Income	<$20 000	1.45 (1.14, 1.85)	0.002
	$20–25 000	1.09 (0.81, 1.45)	0.57
	$25–35 000	1.05 (0.81, 1.37)	0.69
	$35–45 000	1.03 (0.78, 1.35)	0.84
	$45–55 000	1.32 (0.99, 1.76)	0.06
	$55–65 000	0.90 (0.63, 1.29)	0.57
	$65–75 000	1.12 (0.80, 1.57)	0.50
	>$75 000	Reference	
Education	Less than high school	0.76 (0.60, 0.97)	0.03
	High school	0.90 (0.72, 1.13)	0.38
	Some college	1.13 (0.91, 1.39)	0.27
	College graduate	Reference	
Diet versus usual	More	1.31 (0.96, 1.81)	0.09
	Less	0.92 (0.74, 1.15)	0.47
Race/ethnicity	White	Reference	
	Hispanic	0.60 (0.50, 0.73)	<0.001
	Black	0.59 (0.48, 0.72)	<0.001
	Other	0.96 (0.68, 1.37)	0.84
Male gender		0.64 (0.54, 0.76)	<0.001
Body mass index		1.00 (0.99, 1.01)	0.96
Exercise		1.00 (1.00, 1.00)	0.25
Age		1.00 (1.00, 1.01)	0.79
Special diet		1.22 (0.82, 1.82)	0.32
Weight loss diet		0.79 (0.49, 1.27)	0.32
Low fat/low cholesterol diet		0.96 (0.58, 1.59)	0.87
Low salt/sodium diet		1.40 (0.78, 2.51)	0.27
Diabetic diet		0.67 (0.43, 1.06)	0.09
Alcohol (log)		0.99 (0.94, 1.05)	0.82
Depression	Several days	0.18 (0.10, 0.29)	<0.001
	Nearly half the days	0.50 (0.29, 0.84)	0.01
	All the time	0.47 (0.27, 0.84)	0.01
	Not at all	Reference	
Contributors of unique variance			
Alpha-carotene (log)		0.96 (0.93, 1.00)	0.04
Selenium (log)		0.80 (0.65, 0.99)	0.04
Dodecanoic (log ratio)		0.91 (0.84, 0.98)	0.01
Calcium (log)		0.83 (0.70, 0.98)	0.03
Hexadecanoic acid (log ratio)		1.10 (1.02, 1.20)	0.02

found in high concentrations in fruit and vegetables, is an antioxidant (Hermsdorff *et al*., 2012), which could protect against the development of cardiovascular disease and cancer.

Calcium intake was associated with decreased difficulty falling asleep and non-restorative sleep. Although published evidence linking dietary calcium (or calcium supplementation) with insomnia symptoms is scarce, fewer sleep difficulties associated with increased calcium may have been a result of the effects of calcium on lowering blood pressure (Liebman *et al*., 1986). Theobromine was found to be associated with daytime sleepiness. This is somewhat in conflict with a previous report from this sample associating theobromine with lower likelihood of long sleep duration (Grandner *et al*., 2013), which is associated with increased daytime sleepiness (Grandner and Kripke, 2004). As theobromine may have stimulant qualities (Benton, 2004) and is frequently found in products containing caffeine, this may reflect increased consumption of foods or drinks that may function as stimulants by those with daytime sleepiness (although it should be noted that there were no significant findings for caffeine in this sample). Vitamin D was associated with less difficulty maintaining sleep. Although research on sleep effects of vitamin D is scarce, previous research has shown that dietary vitamin D was associated with later sleep timing and increased subjective napping in postmenopausal women (Grandner *et al*., 2010). Lycopene, an antioxidant with effects on cell differentiation and growth (Palozza *et al*., 2011), was also associated with less difficulty falling asleep. In a previous study in this

Table 3 Stepwise ordinal logistic regression model reflecting odds ratios (OR) and 95% confidence intervals (95% CI) of associations between 100% increase in dietary variables and difficulty maintaining sleep

Variable	*Category*	*OR (95% CI)*	P
Covariates forced into the model			
Number of foods		1.00 (0.99, 1.02)	0.77
Energy (kcal) per 100		1.02 (1.01, 1.04)	0.002
Income	<$20 000	1.22 (0.96, 1.55)	0.10
	$20–25 000	0.90 (0.66, 1.23)	0.51
	$25–35 000	1.06 (0.82, 1.37)	0.64
	$35–45 000	0.95 (0.72, 1.24)	0.70
	$45–55 000	1.09 (0.83, 1.43)	0.55
	$55–65 000	0.85 (0.59, 1.22)	0.38
	$65–75 000	1.03 (0.73, 1.44)	0.87
	>$75 000	Reference	
Education	Less than high school	0.84 (0.65, 1.09)	0.19
	High school	1.03 (0.82, 1.29)	0.83
	Some college	0.98 (0.79, 1.20)	0.83
	College graduate	Reference	
Diet versus usual	More	1.15 (0.87, 1.52)	0.33
	Less	1.16 (0.94, 1.43)	0.17
Race/ethnicity	White	Reference	
	Hispanic	0.69 (0.57, 0.84)	<0.001
	Black	0.72 (0.59, 0.87)	0.001
	Other	0.89 (0.64, 1.25)	0.51
Male gender		0.57 (0.48, 0.68)	<0.001
Body mass index		1.00 (0.99, 1.01)	0.89
Exercise		1.00 (1.00, 1.00)	0.03
Age		1.01 (1.01, 1.02)	0.00
Special diet		1.36 (0.92, 2.00)	0.13
Weight loss diet		1.02 (0.66, 1.58)	0.93
Low fat/low cholesterol diet		0.96 (0.57, 1.62)	0.87
Low salt/sodium diet		1.28 (0.73, 2.24)	0.39
Diabetic diet		0.73 (0.45, 1.18)	0.19
Alcohol (log)		1.01 (0.96, 1.07)	0.73
Depression	Several days	0.23 (0.15, 0.35)	<0.001
	Nearly half the days	0.55 (0.36, 0.86)	0.01
	All the time	0.50 (0.29, 0.85)	0.01
	Not at all	Reference	
Contributors of unique variance			
Salt use		1.19 (1.01, 1.41)	0.04
Butanoic (log ratio)		0.81 (0.69, 0.97)	0.02
Carbohydrate (log)		0.71 (0.55, 0.92)	0.01
Dodecanoic (log ratio)		0.90 (0.84, 0.98)	0.01
Vitamin D (log)		0.84 (0.75, 0.95)	0.01
Lycopene (log)		0.98 (0.96, 1.00)	0.05
Hexanoic (log ratio)		1.25 (1.05, 1.50)	0.01
Moisture (log)		1.27 (1.05, 1.53)	0.01

sample, very short sleepers were found to have consumed less lycopene than 7–8-hour sleepers (Grandner *et al.*, 2013). Potassium was associated with less daytime sleepiness. One previous study found that potassium was associated with earlier sleep timing (Sato-Mito *et al.*, 2011) although, if there is a common mechanism, it is unknown. The finding that salt use was associated with impaired sleep is the opposite of what was reported in a previous study, which found that restricted sodium intake caused sleep disruption (Vitiello *et al.*, 1983).

The present study found that more total moisture was associated with difficulty maintaining sleep, non-restorative sleep and daytime sleepiness, but that more total plain water consumed was associated with less non-restorative sleep and daytime sleepiness. In this context, data from the same sample showed that greater water intake was associated with less likelihood of very short or short sleep duration (Grandner *et al.*, 2013), and a previous study found that water was associated with greater actigraphic sleep time and fewer subjective naps (Grandner *et al.*, 2010). The difference between these variables is that water intake was specific to water itself, and total moisture refers to the total moisture content of all foods and beverages (e.g. watermelon, lettuce, coffee). These results suggest that drinking more water, which is a behaviour associated with a number of health benefits (Muckelbauer *et al.*, 2009), may also be associated

Table 4 Stepwise ordinal logistic regression model reflecting odds ratios (OR) and 95% confidence intervals (95% CI) of associations between 100% increase in dietary variables and non-restorative sleep

Variable	*Category*	*OR (95% CI)*	P
Covariates forced into the model			
Number of foods		1.01 (1.00, 1.03)	0.12
Energy (kcal) per 100		1.00 (0.99, 1.01)	0.93
Income	<$20 000	1.01 (0.80, 1.28)	0.90
	$20–25 000	0.92 (0.68, 1.24)	0.59
	$25–35 000	0.96 (0.75, 1.24)	0.77
	$35–45 000	0.84 (0.64, 1.09)	0.19
	$45–55 000	0.98 (0.74, 1.28)	0.86
	$55–65 000	0.87 (0.59, 1.28)	0.48
	$65–75 000	0.96 (0.72, 1.27)	0.77
	>$75 000	Reference	
Education	Less than high school	0.77 (0.60, 0.97)	0.03
	High school	1.02 (0.82, 1.27)	0.87
	Some college	1.23 (1.01, 1.50)	0.04
	College graduate	Reference	
Diet versus usual	More	1.06 (0.77, 1.47)	0.72
	Less	1.07 (0.88, 1.30)	0.52
Race/ethnicity	White	Reference	
	Hispanic	0.51 (0.42, 0.62)	<0.001
	Black	0.57 (0.47, 0.69)	<.001
	Other	0.77 (0.57, 1.04)	0.09
Male gender		0.66 (0.56, 0.78)	<0.001
Body mass index		1.01 (1.00, 1.02)	0.15
Exercise		1.00 (1.00, 1.00)	0.96
Age		0.98 (0.97, 0.98)	<0.001
Special diet		1.40 (0.94, 2.06)	0.09
Weight loss diet		0.73 (0.47, 1.13)	0.16
Low fat/low cholesterol diet		0.58 (0.35, 0.95)	0.03
Low salt/sodium diet		1.36 (0.82, 2.25)	0.23
Diabetic diet		0.75 (0.44, 1.27)	0.29
Alcohol (log)		0.95 (0.90, 1.00)	0.06
Depression	Several days	0.15 (0.09, 0.23)	<0.001
	Nearly half the days	0.35 (0.22, 0.56)	<0.001
	All the time	0.44 (0.26, 0.76)	0.003
	Not at all	Reference	
Contributors of unique variance			
Butanoic (log ratio)		1.09 (1.00, 1.19)	0.04
Calcium (log)		0.81 (0.67, 0.98)	0.03
Vitamin C (log)		0.92 (0.86, 0.99)	0.02
Total plain water drank yesterday (log)		0.98 (0.95, 1.00)	0.09
Moisture (log)		1.41 (1.15, 1.71)	0.001
Cholesterol (log)		1.10 (1.00, 1.21)	0.05

with healthy sleep, but that total moisture consumption may have some negative effects on sleep, due perhaps to fragmentation caused by more frequent sensations regarding urination (Ancoli-Israel *et al*., 2011).

Difficulty falling asleep was associated with greater intake of hexadecanoic acid, a saturated fat, whereas it was associated with less intake of dodecanoic acid, a monounsaturated fat. Difficulty maintaining sleep was also associated with less intake of both dodecanoic acid and butanoic acid and greater intake of hexanoic acid. Hexanoic acid (6 : 0), also known as caproic acid, is found in coconut oil and in goat's milk and cow's milk butter. Conversely, butanoic acid (4 : 0), also known as butyric acid, was found to be associated with a decreased likelihood of difficulty maintaining sleep. Butyric acid is found in cow's milk, and has been implicated in reducing risk of colon cancer (Parodi, 1997). Hexadecanoic acid (16 : 0), also known as palmitic acid, is found in butter, cheese, milk and meat. One study reported that rats that were fed high-fat diets enriched in palmitic acid showed an impairment of the ability of leptin and insulin to regulate food intake and body weight compared to animals fed a high-fat unsaturated-enriched diet or low-fat diet (Benoit *et al*., 2009). Interestingly, reduced intake of dodecanoic acid was associated with both difficulties falling asleep and maintaining sleep, perhaps suggesting that diets deficient in this fatty acid may contribute to the aetiology of insomnia symptoms. Dodecanoic acid, also known as lauric acid, is a 12-carbon chain saturated fatty acid that is enriched in coconut oil. Lauric acid has been shown to increase serum high-density lipoprotein cholesterol when added to the diet

Table 5 Stepwise ordinal logistic regression model reflecting odds ratios (OR) and 95% confidence intervals (95% CI) of associations between 100% increase in dietary variables and daytime sleepiness

Variable	*Category*	*OR (95% CI)*	P
Covariates forced into the model			
Number of foods		1.02 (1.01, 1.04)	0.004
Energy (kcal) per 100		1.01 (1.00, 1.02)	0.20
Income	<$20 000	1.04 (0.82, 1.33)	0.73
	$20–25 000	0.96 (0.71, 1.29)	0.77
	$25–35 000	0.96 (0.75, 1.24)	0.78
	$35–45 000	0.88 (0.68, 1.14)	0.32
	$45–55 000	0.92 (0.68, 1.24)	0.58
	$55–65 000	0.94 (0.66, 1.33)	0.73
	$65–75 000	1.00 (0.75, 1.33)	0.98
	>$75 000	Reference	
Education	Less than high school	0.96 (0.76, 1.22)	0.74
	High School	1.05 (0.85, 1.30)	0.63
	Some college	1.24 (1.02, 1.51)	0.04
	College graduate	Reference	
Diet versus usual	More	0.86 (0.63, 1.17)	0.33
	Less	1.16 (0.95, 1.43)	0.14
Race/ethnicity	White	Reference	
	Hispanic	0.46 (0.38, 0.56)	<0.001
	Black	0.64 (0.53, 0.78)	<0.001
	Other	0.89 (0.61, 1.29)	0.54
Male gender		0.85 (0.72, 1.01)	0.07
Body mass index		1.02 (1.00, 1.03)	0.01
Exercise		1.00 (1.00, 1.00)	0.98
Age		0.98 (0.98, 0.99)	<0.001
Special diet		1.59 (1.03, 2.46)	0.04
Weight loss diet		0.79 (0.50, 1.24)	0.31
Low fat/low cholesterol diet		0.56 (0.35, 0.91)	0.02
Low salt/sodium diet		0.94 (0.51, 1.75)	0.86
Diabetic diet		0.75 (0.40, 1.42)	0.38
Alcohol (log)		0.95 (0.90, 1.00)	0.06
Depression	Several days	0.17 (0.11, 0.27)	<0.001
	Nearly half the days	0.38 (0.24, 0.61)	<0.001
	All the time	0.43 (0.24, 0.77)	0.004
	Not at all	Reference	
Contributors of unique variance			
Moisture (log)		1.20 (0.97, 1.48)	0.09
Theobromine (log)		1.04 (1.00, 1.08)	0.08
Potassium (log)		0.70 (0.55, 0.89)	0.004
Total plain water drank yesterday (log)		0.97 (0.94, 1.00)	0.07

without affecting low-density lipoprotein (LDL) levels, compared to *trans*-fatty acids derived from partially hydrogenated soybean oil (De Roos *et al*., 2001). A previous study in this same sample found that dodecanoic acid was associated with decreased likelihood of long sleep duration (Grandner *et al*., 2013). Perhaps diets enriched with this saturated fatty acid may not only reduce the ratio of LDL/high-density lipoprotein (HDL) levels which, in turn, is associated with healthy cardiovascular function, but may also be associated with healthier sleep. Notably, cholesterol intake was associated with non-restorative sleep in this sample and was associated with shorter actigraphic sleep duration and sleep efficiency and subjective napping in a study of postmenopausal women (Grandner *et al*., 2010). Because dodecanoic acid has been shown to increase HDL ('good') cholesterol more than any other fatty acid (Mensink *et al*., 2003 PMID:12716665), future studies examining the role of diets containing this fatty-acid on 'good' versus 'bad' cholesterol levels will be needed to clarify further our observed associations and determine whether causality exists between dietary intake of these fatty acids and various health outcomes, including cardiovascular function and sleep quality.

Only a few other studies have examined associations between diet and indicators of sleep quality. Among young adults in India, symptoms of insomnia, which included difficulty falling asleep, difficulty maintaining sleep, early awakening and sleep duration $\leq$6 h and non-restorative sleep, were associated with a lower caloric intake (Zadeh and Begum, 2011). This is similar to our finding that those with difficulty falling asleep consumed fewer calories (Table S1a). However, this is dissimilar to our regression results that

showed a general positive relationship between caloric intake and sleep symptoms (Table S2). It should be noted that the study in India did not adjust for covariates. In a study of almost 10 000 older French adults (≥65 years), the Mediterranean diet (based on 11 dietary components) was associated with reduced odds of insomnia symptoms, including difficulty falling asleep and difficulty maintaining sleep in women (Jaussent *et al.*, 2011). These two studies were also cross-sectional, so it is not clear whether insomnia symptoms somehow determine dietary choices or if caloric intake or the dietary components of a Mediterranean diet affect insomnia symptoms.

The strengths of this paper include the large sample size, nationally representative data and detailed identification of dietary components. There are, however, some limitations to acknowledge. The self-reported sleep symptoms are nonspecific and could reflect a variety of underlying causes, including certain sleep disorders such as insomnia or sleep-disordered breathing. Furthermore, these are cross-sectional data so we cannot determine if the sleep disturbances can result in alterations in diet or if certain dietary components can impair sleep. With respect to sleep disturbances impacting diet, experimental studies of sleep restriction (discussed above) observed effects on appetite regulation, but similar experimental studies of sleep disturbances have not been published. In support of the latter casual direction, dietary supplements have actually been tested as a treatment for insomnia, including tart cherry juice (Pigeon *et al.*, 2010), melatonin, magnesium and zinc (Rondanelli *et al.*, 2011) and valerian (Taibi *et al.*, 2007), albeit with only limited to moderate success. Certainly, caffeine is probably part of a vicious cycle of poor sleep leading to increased caffeine consumption, which in turn promotes impaired sleep. Also, data on timing of meals is not available. Another limitation is related to the challenge of measuring dietary intake. Assessments of food intake over an arbitrary 24-hour period are prone to a number of biases. Some of these biases are partially addressed by including covariates (such as similarity to a typical day), but they cannot be accounted for completely. In this context, we recognize that all methods of assessing habitual diet are imperfect. Although the methods employed for the current study are well validated for population-level assessments, they are not well validated for individual assessments. Thus, the results should be interpreted with appropriate caution.

Finally, we did not adjust for supplement intakes in these analyses. Many Americans take various supplements; however, we did not include supplement data for several reasons. First, as supplements in the United States are not regulated, the listed ingredients are unreliable. The amount of specific ingredients may vary by supplement, brand and batch. Secondly, as supplements can provide substantial amounts of certain nutrients that are very difficult to obtain from dietary sources, associates between sleep and dietary data may be skewed. For example, if the amount of such nutrients contained in supplements exceeds the typical range of dietary intake by a wide margin, then nutrients from supplements would have a high degree of influence over the statistical results and would therefore render the results unreliable. Thirdly, recall of supplement intake was not performed in the same way as recall of diet. Adding this dimension would compound existing measurement error. Based on this reasoning, supplement data were not included.

The potential link between sleep quality and dietary nutrients has important implications for health. If increased consumption or deficiency of certain nutrients can impair sleep, this would increase the risk of developing insomnia, which is associated with reduced quality of life, increased work absenteeism and reduced productivity (Leger and Bayon, 2010). Alternatively, if disturbed sleep, as observed in insomnia and sleep apnea, can impact dietary choices then this association may partly explain cardiometabolic health problems associated with these sleep disorders. Indeed, sleep disturbances have been linked with impairments in glucose metabolism and increased diabetes risk (Knutson *et al.*, 2011). The results of these analyses warrant future research to examine the association between sleep disturbances and dietary choices in greater detail using a longitudinal design, and to conduct experimental studies to determine if these nutrients impair sleep.

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CONFLICT OF INTEREST

None to declare.

AUTHOR CONTRIBUTIONS

Study design (MAG, NJ, JRG, KLK), data acquisition (MAG, NJ), data analysis (MAG, NJ), interpretation of data (MAG, NJ, JRG, KLK), manuscript preparation (MAG, NJ, JRG, KLK).

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1. (a) Dietary variables by difficulty falling asleep (*n* and % for categorical variables and mean and standard deviation for continuous variables). (b) Dietary variables by

difficulty maintaining sleep (*n* and % for categorical variables and mean and standard deviation for continuous variables). (c) Dietary variables by non-restorative sleep (*n* and % for categorical variables and mean and standard deviation for continuous variables). (d) Dietary variables by daytime sleepiness (*n* and % for categorical variables and mean and standard deviation for continuous variables).

Table S2. Dietary factors associated with sleep symptoms; odds ratios and 95% confidence intervals in unadjusted analyses and analyses adjusted for covariates[a] using ordinal logistic regression.

Table S3. (a) Odds ratios (OR) for dietary nutrients associated with difficulty falling asleep in ordinal logistic regression analyses adjusted for overall diet (model 1) and fully adjusted analyses (model 2). (b) Odds ratios (OR) for dietary nutrients associated with difficulty maintaining sleep in ordinal logistic regression analyses adjusted for overall diet (model 1) and fully adjusted analyses (model 2). (c) Odds ratios (OR) for dietary nutrients associated with non-restorative sleep in ordinal logistic regression analyses adjusted for overall diet (model 1) and fully adjusted analyses (model 2). (d) Odds ratios (OR) for dietary nutrients associated with daytime sleepiness in ordinal logistic regression analyses adjusted for overall diet (model 1) and fully adjusted analyses (model 2).