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Dietary nutrients associated with short and long sleep duration. Data from a nationally representative sample☆

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Abstract

Short sleep duration is associated with weight gain and obesity, diabetes, cardiovascular disease, psychiatric illness, and performance deficits. Likewise, long sleep duration is also associated with poor physical and mental health. The role of a healthy diet in habitual sleep duration represents a largely unexplored pathway linking sleep and health. This study evaluated associations between habitual sleep parameters and dietary/nutritional variables obtained via the National Health and Nutrition Examination Survey (NHANES), 2007–2008. We hypothesized that habitual very short (<5 h) short (5–6 h) and long (9+ h) sleep durations are associated with intake of a number of dietary nutrient variables. Overall, energy intake varied across very short (2036 kcal), short (2201 kcal), and long (1926 kcal) sleep duration, relative to normal (2151 kcal) sleep duration ($p = 0.001$). Normal sleep duration was associated with the greatest food variety (17.8), compared to very short (14.0), short (16.5) and long (16.3) sleep duration ($p < 0.001$). Associations between sleep duration were found across nutrient categories, with significant associations between habitual sleep duration and proteins, carbohydrates, vitamins and minerals. In stepwise analyses, significant contributors of unique variance included theobromine (long sleep RR = 0.910, $p < 0.05$), vitamin C (short sleep RR = 0.890, $p < 0.05$), tap water (short sleep RR = 0.952, $p < 0.001$; very short (<5 h) sleep RR = 0.941, $p < 0.05$), lutein + zeaxanthin (short sleep RR = 1.123, $p < 0.05$), dodecanoic acid (long sleep RR = 0.812, $p < 0.05$), choline (long sleep RR = 0.450, $p = 0.001$), lycopene (very short (<5 h) sleep RR = 0.950, $p < 0.05$), total carbohydrate (very short (<5 h) sleep RR = 0.494, $p < 0.05$; long sleep RR = 0.509, $p < 0.05$), selenium (short sleep RR = 0.670, $p < 0.01$) and alcohol (long sleep RR = 1.172, $p < 0.01$). Overall, many nutrient variables were associated with short and/or long sleep duration, which may be explained by differences in food variety. Future studies should assess whether these associations are due to appetite dysregulation, due to short/long sleep and/or whether these nutrients have physiologic effects on sleep regulation. In addition, these data may help us better understand the complex relationship between diet and sleep and the potential role of diet in the relationship between sleep and obesity and other cardiometabolic risks.

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Keywords

Sleep; Sleep duration; Diet; Nutrition; Epidemiology

Introduction

Given the increasing prevalence of obesity and its consequences, a better understanding of factors that predispose individuals to weight gain and ultimately obesity is necessary to improve public health. One potential risk factor for increased food intake is insufficient or excessive sleep duration.

Laboratory studies of sleep restriction have provided some evidence for a link between short sleep durations and increased risk of weight gain. Levels of leptin, a satiety signal, were reduced after sleep restriction, while levels of ghrelin, an appetite stimulant, were increased (Spiegel, Leproult, et al., 2004; Spiegel, Tasali, Penev, & Van Cauter, 2004). In addition, subjective hunger and appetite increased, particularly for high fat, high carbohydrate foods, after sleep restriction (Spiegel, Tasali, et al., 2004). These studies controlled the subjects' food intake, but one study that allowed *ad libitum* eating in overweight sedentary adults, found that 2 weeks of 5.5 h in bed per night was associated with increased energy intake from snacks compared to 2 weeks of 8.5 h in bed per night, despite similar weight gain in both conditions (Nedeltcheva et al., 2009). Thus, these experimental studies of sleep restriction suggest short sleep may be associated with increased food intake. However, there is some conflicting evidence regarding the association between dietary fat intake and short sleep (Al-Disi et al., 2010; Diethelm, Remer, Jilani, Kunz, & Buyken, 2011; Rontoyanni, Baic, & Cooper, 2007).

Although laboratory studies can collect detailed measures in a controlled setting, they are by necessity short-term. To understand risk of chronic conditions, including obesity, we must examine habitual behavior outside the laboratory. Several studies have observed cross-sectional associations between higher mean Body Mass Index (BMI) and both short sleep durations and long sleep durations (Grandner & Drummond, 2007; Grandner, Patel, Gehrman, Perlis, & Pack, 2010; Knutson, 2010). To date, only a few studies have examined the association between habitual sleep duration and dietary behavior. Among a subset of Women's Health Initiative (WHI) participants, shorter average nocturnal sleep duration (assessed with wrist actigraphy) was associated with greater fat and calories consumed even after adjusting for BMI and physical activity (Grandner, Kripke, Naidoo, & Langer, 2010). Among a sample of adolescents, short sleep durations (<8 h) based on wrist actigraphy were also associated with an increase in the percentage of calories consumed from fats and a decrease in the percentage of calories from carbohydrates in girls but not boys (Weiss et al., 2010). In a study of adolescents across several European countries, those who slept <8 h were more sedentary and also demonstrated more unhealthy eating habits (e.g., less than adequate amounts of fruits, vegetables, and fish) (Garaulet et al., 2011). Finally, studies from Japan have found that shorter sleep durations are associated with less healthy dietary habits, including a preference for fatty foods, skipping breakfast, snacking and eating outside the home (Imaki, Hatanaka, Ogawa, Yoshida, & Tanada, 2002; Nishiura & Hashimoto, 2010).

In addition to sleep duration, sleep timing has been associated with dietary intake as well. For example, People who sleep later in the day (i.e. midpoint is at 5:30 am or later) obtained less sleep than those who sleep at more traditional times and also consumed significantly more calories after 8:00 pm and fewer servings of vegetables, even after controlling for sleep duration (Baron, Reid, Kern, & Zee, 2011). In terms of macronutrients, late sleepers

consumed a higher percentage of carbohydrates, fat and protein after 8:00 pm than average sleepers (Baron, Reid, Horn, & Zee, 2013). A Japanese study of over 3000 female students reported that later sleep times were associated with a greater percentage of fat intake and a lower percentage of protein and carbohydrate intake (Sato-Mito et al., 2011). A German study of adolescents observed a significant association between later bed and rise times and increased consumption of caffeinated drinks and fast food but reduced consumption of dairy products (Fleig & Randler, 2009).

These studies have all made important contributions to our understanding of the associations between habitual diet and habitual sleep. However, it should be noted that none of these studies drew on a nationally-representative sample of US adults. Either the samples were non-US adults or they consisted of special populations, such as postmenopausal women, which limit their generalizability to the general US population. For these reasons, a study that leverages a nationally-representative sample would constitute an important advance in this domain.

Accordingly, the goal of the present study was to determine whether an association between self-reported habitual sleep duration and dietary patterns was present in a large, nationally representative study in the US.

Methods

Data source

The subjects used in this study were participants in the 2007– 2008 National Health and Nutrition Examination Survey (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 concerning their demographic, socioeconomic, nutritional, and related statuses during in-person interviews conducted in the home. Additionally, physical examinations were performed in mobile medical facilities to collect medical and physiological data; additional laboratory tests were also performed from blood and urine samples collected on-site.(Centers for Disease Control & Prevention, 2008a, 2008b) In order to compensate for under-representation, African Americans, Hispanics, and adults over 60 were over-sampled.

Sampling in this survey was performed to ensure generalizability to the US population. 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(Centers for Disease Control & Prevention, 2006). For the present study, analyses included adults aged 18+ with complete data on all independent and dependent variables (n = 5587).

Measures

Sleep duration—Sleep duration was assessed with the survey item, “How much sleep do you usually get at night on weekdays or workdays?” Responses were coded in whole numbers and categorized as “very short” (<5 h per night), “Short” (5–6 h per night), “Normal” (7–8 h per night), and “Long” (≥9 h per night) sleep duration. These categories were chosen based on the existing laboratory and epidemiologic literature regarding sleep duration (Grandner & Drummond, 2007; Grandner, Patel, Gehrman, Perlis, et al., 2010).

Diet and nutrients—Diet and nutrient data were collected as part of standard NHANES procedures (Centers for Disease Control & Prevention, 2008a, 2008b). This consisted of 24-

h recall, guided by a structured interview (day 1 data). For example, 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, Perloff, Ingwerson, Steinfeldt, & Anand, 2004; Rumpler, Kramer, Rhodes, Moshfegh, & Paul, 2008). The dietary interview component of NHANES was conducted as a partnership between the U.S. Department of Agriculture and the U.S. Department of Health and Human Services. Under this partnership, the National Center for Health Statistics was responsible for the sample design and data collection and the Food Surveys Research Group is responsible for the dietary data collection methodology, maintenance of the databases used to code and process the data, data review, and processing.

Variables included in the present analyses include measures that describe overall diet, whether the respondent was adhering to a special diet, how the dietary intake that was included for analysis compared to typical intake, and specific levels of nutrients. All nutrients were evaluated in absolute intake (e.g., mg/day) except for individual fatty acids. Due to restricted range of values, fatty acids are reported as ratio relative to total intake of that type of fatty acid (i.e., saturated, monounsaturated or polyunsaturated). Also, since the data consisted of nutrient values only (and not dietary constituents), no data were available on specific foods consumed and the timing of meals.

Overall diet was represented as total energy intake and food variety. Total energy intake was operationalized as total kcal. Food variety was operationalized as total number of foods consumed. Respondents indicated whether they were adhering to any special diet or a number of specific diets, including weight loss, low fat or low cholesterol, low salt or sodium, or diabetic diet.

Participants were asked whether the day's intake that they described was typical for them. Comparison to typical diet was coded as the evaluation diet being "less than usual," "same as usual" or "more than usual." This control variable helps us operationalize the degree of caution with which to interpret results. For example, if one sleep duration category was more likely to have been reporting "less than usual" consumption, this would confound observed differences. Therefore, we evaluated whether groups differed on this variable and included it as a covariate in adjusted models.

Salt use in food preparation was assessed categorically (yes/no), and table salt use was assessed as "never," "rarely," "occasionally," and "often." Overall nutrient categories (measured in grams) include total protein, total carbohydrates, total sugars, total dietary fiber, and total fat. Fat categories (measured in grams) included saturated fat, polyunsaturated fat, monounsaturated fat, and cholesterol. Saturated fatty acids included butanoic, hexanoic, octanoic, decanoic, dodecanoic, tetradecanoic, hexadecanoic, and octadecanoic, assessed as ratio relative to total saturated fat intake. Monounsaturated fatty acids included hexadedenoic, octadecenoic, eicosenoic, and docosenoic acid, assessed as ratio relative to total monounsaturated fat intake. Polyunsaturated fatty acids included octadecadienoic, octadecatrienoic, octadecatetraenoic, eicosatetraenoic, eicosapentaenoic acid, docosapentaenoic, and docosahexaenoic acid, assessed relative to total polyunsaturated fat.

Vitamins and minerals were also assessed. Vitamins included alpha-tocopherol (mg), added alpha-tocopherol (mg), retinol (mcg) vitamin A as retinol activity equivalents (vitamin A RAE [retinol activity equivalents]; mcg), alpha-carotene (mcg), beta-carotene (mcg), beta-cryptoxanthin (mcg), lycopene (mcg), lutein and zeaxanthin (mcg), thiamin (mg), riboflavin (mg), niacin (mcg), vitamin B6 (mg), total folate (mcg), folic acid (mcg), food-based folate (mcg), folate as dietary folate equivalents (folate DFE; mcg), choline (mcg), vitamin B12

(mcg), added vitamin B12 (mcg), vitamin C (mg), vitamin D2 and D3 (mcg), and vitamin K (mcg). Minerals included calcium (mg), phosphorus (mg), magnesium (mg), iron (mg), zinc (mg), copper (mg), sodium (mg), potassium (mg), and selenium (mcg).

Other substances measured included water, caffeine, alcohol, and theobromine. Water was assessed (in grams) several ways. These included total moisture (total from food and drink), tap water, bottled water, and plain water (includes tap water, water from a drinking fountain or water cooler, bottled water, and spring water). Caffeine and alcohol were measured in mg. Theobromine – an alkaloid found in chocolate – was measured in mg.

Physical activity—Physical activity was assessed using standard NHANES procedures. The NHANES physical activity assessment includes 20 items designed to assess sedentary activity, as well as moderate and vigorous work and recreational activity. Average minutes per week of both moderate and vigorous activity, for both work and recreational settings, are computed as part of NHANES. Work and recreational activity were combined for global measures of minutes per week of moderate and vigorous activity.

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), and objectively-measured BMI. These variables were specifically chosen because not only are they all likely confounders (related to both sleep and diet), but they were also used in the one previous study of dietary nutrients and sleep duration (Grandner, Patel, Gehrman, Xie, et al., 2010).

Statistical analyses

Differences in dietary and demographic variables between sleep duration groups were assessed using ANOVA for continuous variables and Pearson's Chi-square for categorical variables.

The effects of diet on sleep duration were assessed using multinomial logistic regression, with sleep duration categories referenced to 7–8 h of sleep. Three models were evaluated: First, unadjusted associations were examined. Then, these associations were adjusted for overall dietary pattern, so that only explained variance in sleep duration that is not already accounted for by these factors (total energy intake, variety of foods, comparison to usual diet and special diet) is described. This will allow for an assessment of effects over and above overall diet. Finally, demographic, socioeconomic and health factors (age, gender, income, education, BMI and exercise) were added as covariates, so that the effects of these covariates on associations can be examined separately and remaining effects reflect adjustment for all covariates.

In order to examine the most parsimonious model explaining sleep duration, a backward stepwise selection procedure was implemented with demographic, nutrient intake, and special diet variables retained. Variables were selected based upon an inclusion significance criterion of 0.05 and exclusionary criterion of 0.10. This means that variables with $p > 0.10$ were not evaluated for inclusion in the stepwise analysis (thus minimizing unnecessary colinearity) and those with $p < 0.05$ were included in the models. Variables with $p > 0.05$ but <0.10 were evaluated but not included. To avoid model selection bias due to colinearity, dietary variables that were correlated above rho = 0.75 were excluded from the variable list in the model selection procedure.

All continuous dietary variables were log-transformed for analysis. Fatty Acids were expressed in standardized units, such that their effects are reported in terms of their standard deviations. Analyses were appropriately weighted 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, Drai, Elmer, Kafkafi, & Golani, 2001; Benjamini & Hochberg, 1995; Keselman, Cribbie, & Holland, 2002). This correction is less conservative than the traditional Bonferroni correction procedure, but it is considered to be more appropriate for identifying true discoveries in these types of analyses. All statistical analyses were performed using STATA version 12 (STATA Corp., College Station, TX).

Results

Sample characteristics

Characteristics of the sample are reported in Table 1. All cases were weighted, resulting in a sample that was nationally-representative. Sleep duration categories were, however, differentially distributed across sociodemographic, socioeconomic, and health variables, justifying their inclusion as covariates. Women were more likely to be very short (<5 h) or long (9+ h) sleepers and less likely to be Short compared to men. Non-Hispanic Whites were most likely to be normal (7–8 h) or long (9+ h) sleepers, Hispanic/Latino respondents were more likely to be normal (7–8 h) or Short sleepers, Blacks/African–Americans were more likely to be very short (<5 h) or short (5–6 h) sleepers, as were Asian/Other respondents. Less educational attainment was associated with generally shorter sleep duration. Regarding income, lower income groups tended to be more likely to exhibit very short (<5 h) or long (9+ h) sleep. Regarding minutes of exercise, the shortest sleepers exercised the most; however, the shortest sleepers also had the highest BMIs, with very short (<5 h) sleepers having a mean BMI that was 1.9 points higher than the long (9+ h) sleepers.

Difference in overall diet

Omnibus comparisons of overall diet factors across sleep duration groups are found in Table 2. Total energy intake, number of foods in diet, reported diet vs. usual, and low salt/sodium diet differentiated groups. Overall, the lowest total energy intake was found among the very short (<5 h) and long (9+ h) sleep groups, with the highest in the short (5–6 h) sleep group. The normal (7– 8 h) sleep group reported the greatest food variety, with the least food variety reported among very short (<5 h) and long (9+ h) sleepers. The very short (<5 h) group was most likely to be reporting a dietary pattern that consists of either more or less food than usual. They were also most likely to report being on a low salt/sodium diet.

In multinomial regression analyses (Table 3), total energy intake was lower in the long sleep group, relative to normal (7–8 h) sleep, but this was not significant after adjustment for covariates. Number of foods in diet was lower among all groups relative to normal (7–8 h) sleep, in both unadjusted and adjusted analyses. In unadjusted analyses, the very short (<5 h) and long sleep groups were more likely to report a dietary pattern that includes less food than usual, but this was not significant after adjustment. Very short (<5 h) sleepers were more likely to report a special diet. This was largely driven by the finding that very short (<5 h) and short (5–6 h) sleepers were more likely to report a low salt/sodium diet (in both unadjusted and adjusted analyses).

Differences in macronutrient intake

Table 2 describes overall differences in macronutrient intake. Significant differences among sleep duration groups were found for all macronutrients (protein, carbohydrates, sugars, dietary fiber, and fat). In all cases, the very short (<5 h) and long sleep groups reported the

lowest intake of all categories. Also, in all cases (except dietary fiber), the short (5–6 h) sleep group reported the highest intake across macronutrient categories.

In multinomial logistic regression analyses (Table 4), very short (<5 h) sleep was associated with decreased intake of protein, carbohydrates, sugars, dietary fiber, and fat, relative to normal (7–8 h) sleep. Short (5–6 h) sleep was associated with decreased dietary fiber. long sleep was associated with decreased intake of protein, carbohydrates, sugars, dietary fiber, and fat. In analyses adjusted for overall diet, the only association that remained was decreased protein and carbohydrates in the very short (<5 h) sleep group. These associations remained in fully-adjusted models (Table 5).

Water intake differentiated groups (Table 2). Moisture, plain water, and tap water were all differentially reported by sleep duration. For moisture and plain water, very short (<5 h) sleepers consumed the most, followed by Short sleepers, followed by normal (7–8 h) sleepers, followed by long (9+ h) sleepers. For tap water, normal sleepers consumed the most. In regression analyses (Table 4), very short (<5 h) sleep was associated with decreased tap water, short (5–6 h) sleep was associated with decreased plain and tap water, and long sleep was associated with decreased moisture. After adjustment for overall diet (Table 4) and other covariates (Table 5), only the association between short (5–6 h) sleep and less tap water remained.

Differences in micronutrient intake

Fats—Overall differences in intake of categories of fats (Table 2) were found for total saturated fat, monounsaturated fat, polyunsaturated fat, and cholesterol, with the greatest intake in the short (5–6 h) sleep group for all categories. In regression analyses (Table 4), very short (<5 h) sleep was associated with decreased cholesterol intake and long sleep was associated with decreased saturated and monounsaturated fat, as well as cholesterol. These associations were no longer significant after adjustment (Table 5).

Regarding specific fatty acids, no overall associations were found (Table 2). In regression analyses, decreased octadecenoic acid was seen among very short (<5 h) sleepers, but this was seen only in unadjusted analyses and not after adjustment (Tables 4 and 5).

Vitamins—Table 2 shows that intake of many vitamins was differentially reported across sleep duration categories. Table 4 shows that many of these resulted in lower intake associated with very short (<5 h) and long sleep in unadjusted analyses. After adjusting for overall diet, some of the effects for very short (<5 h) sleep remained, including decreased lycopene, thiamin, total folate, folic acid, and folate DFE (dietary folate equivalents). In fully-adjusted analyses (Table 5), the associations for thiamin, total folate, and folate DFE remained.

Minerals—Table 2 shows that all minerals that were examined were differentially reported across sleep duration categories. Regression analyses (Table 4) showed that very short (<5 h) sleep was associated with decreased intake of all assessed minerals, as was long sleep (with the exception of copper, which was a trend). After adjustment for overall diet, only decreased phosphorus, magnesium, iron, zinc and selenium in the context of very short (<5 h) sleep and decreased phosphorus in the context of long sleep remained significant. All of these remained in fully-adjusted models (Table 5), with the exception of lower magnesium in very short (<5 h) sleep.

Other—Overall, only intake of theobromine differentiated groups, with the highest intake reported in normal (7–8 h) sleepers (Table 2). In regression analyses, very short, short, and

long sleep were associated with less theobromine in unadjusted but not adjusted analyses (Tables 4 and 5). Alcohol intake was associated with long sleep in the fully-adjusted model, but not in other analyses.

Stepwise analysis—After forcing covariates into the model, all nutrient variables were entered in a backwards stepwise regression model (results displayed in Table 6). In accordance with this procedure, nutrient variables were retained in order contribution of unique variance to the sleep duration outcome, with the largest unique contributor first, followed by the smallest significant unique contributor to be retained in the model. The largest contributor of unique variance to sleep duration was theobromine (which was lower in short and long sleep). After the variance explained by theobromine was removed, the next largest contributor of unique variance was vitamin C, which was lower in short (5–6 h) sleepers. This was followed by tap water (lower in very short (<5 h) and short (5–6 h) sleep), then Lutein + zeaxanthin (higher in short (5–6 h) sleep), then dodecanoic acid (lower in long sleep), then choline (lower in long sleep), then lycopene (lower in very short (<5 h) and long sleep), then total carbohydrate (lower in very short (<5 h) and long sleep), then selenium (lower in very short (<5 h) and short (5–6 h) sleep), then finally alcohol (higher in long sleep).

Discussion

In these nationally-representative data, certain dietary characteristics did differ significantly between the normal sleepers (7–8 h) and the other sleep duration categories. For example, compared to the normal sleepers, all other groups ate a smaller number of food types, indicating reduced variety in their diets. Very short (<5 h) and short (5–6 h) sleepers were both more likely to be on a low salt diet. In stepwise analyses, slightly increased energy intake was associated with very short (<5 h) sleep compared to normal sleep.

Our results demonstrated an inverse U-shaped distribution of energy intake across sleep duration categories, which is inconsistent with previous findings of sleep deprivation being associated with increased energy intake (St-Onge et al., 2011). It should be noted, though, that many of these differences in energy intake across nutrient categories were not statistically significant. One potential explanation for this finding may be reduced food variety among the shortest and longest sleepers, which was found in the present study. This is consistent with a previous study in adolescents, which found decreased consumption of healthy foods (Garaulet et al., 2011). The results present other conflicting findings as well. For example, shorter sleep was associated with higher BMI (which is consistent with many previous studies), but our findings also showed that very short (<5 h) sleep was associated with decreased energy intake. This is in conflict with previous laboratory studies that show a U-shaped distribution of BMI across sleep duration categories (Kripke, Garfinkel, Wingard, Klauber, & Marler, 2002) and that acute sleep deprivation leads to increased energy intake (St-Onge et al., 2011). This may be related to our finding that very short (<5 h) sleepers reported the most exercise. If this is the case (increased BMI despite decreased energy intake and increased exercise), there may be fundamental changes in energy balance and energy utilization occurring relative to sleep duration. Another possible explanation for this paradox (higher BMI despite decreased energy consumption and increased exercise) could be differences in dietary habits. Although the available data can only suggest these differences (e.g., different patterns of special diets, macronutrients, and food variety), these may have played a role in the present findings. Future research needs to explore, in general population samples (vs. laboratory samples that present acute sleep disruption), associations between energy balance and sleep. One potential factor that may play a role in this association is eating behavior. For example, one previous study (Chaput et al., 2005), found that psychological aspects of dietary behavior play a role in the association of sleep and BMI.

This study assessed sleep, mood, overall mental and physical health, and eating behaviors during a weight loss program. They found that initial weight loss of ~5 kg was associated with improved sleep and perceived mental and physical health, accompanied by less rigid dietary patterns. Later, at ~10 kg of weight loss, mood, sleep, and perceived mental/physical health worsened. This was accompanied by changes in dietary behavior, including a more rigid control of food intake. These findings suggest that rigid eating behavior may facilitate weight loss but may worsen sleep and mood.

Although not the focus of the present study, sleep duration categories were associated with sociodemographic variables, in accordance with a number of prior studies. In the present sample, the very short (<5 h) and short (5–6 h) sleepers tended to be less educated, lower income, Black/African American adults with higher BMI but more physical activity. It is beyond the scope of the current paper to speculate regarding these associations, but it should be noted that these differences may play a role in how diet is associated with sleep. For this reason, future studies should also at least include these covariates in any analysis.

The results of these analyses are not consistent with the findings from the WHI study, which found a significant negative association between average nocturnal sleep duration and average amount of fat and calories consumed (Grandner, Kripke, et al., 2010). The discrepancy in results may be due to how sleep was assessed, which was based on self-report in NHANES while WHI used wrist actigraphy. Notably, when the WHI study evaluated subjective sleep duration, the only association that was significant was with protein (increased sleep duration was associated with increased protein). In the present study, this was partially replicated, as increased protein was associated with decreased likelihood of very short (<5 h) sleep in multinomial regression. In addition to the possibility that the discrepancy is explained by the method used to record sleep, age and gender may have also played a role, since the WHI included only postmenopausal women. A prior study among adolescents supports the possibility of an interaction by gender because they found an association between short (5– 6 h) sleep and increased calories consumed from fats in girls only (Weiss et al., 2010). Because of the potential health implications, particularly with respect to obesity risk, identification of potential modifiers of the association between sleep duration and diet, including age and gender, warrants further research.

Whether or not the differences in the consumption of specific micronutrients have consequences for health is an important question. Lycopene, whose consumption was reduced in very short (<5 h) sleepers, is an antioxidant and may protect against cancer through its effects on cell differentiation and growth (Palozza, Parrone, Simone, & Catalano, 2011).

The nutrients consumed less by Short sleepers included vitamin C, Lutein and zeaxanthin and selenium. Vitamin C is another antioxidant (Hermsdorff et al., 2011), which could protect against cardiovascular disease and cancer. Lutein and zeaxanthin may help reduce the risk of developing age-related macular degeneration, particularly later in life (Ma et al., 2012). Selenium is an essential micronutrient that plays an important role in regulating inflammation and immunity(Huang, Rose, & Hoffmann, 2012). In animal models, it has been shown to significantly increase wakefulness through inhibition of the enzyme prostaglandin D synthase(Hayaishi, 1999). This is counterintuitive, as the short (5–6 h) sleepers consumed less, not more, selenium. Perhaps another pathway is implicated, in which less selenium is associated with more sleep difficulty; this idea is supported by one case study showing reduced OSA symptoms with selenium supplementation (Dekok, 2005).

Self-reported long sleepers were more likely to have reported increased alcohol intake, which may have important health consequences, particularly if alcohol consumption is

excessive. Furthermore, if increased alcohol consumption leads to more time spent in bed, then this could reduce physical activity and increase the risk of morbidity and mortality associated with self-reported long sleep. Long sleep (9+ h) was also associated with reduced consumption of theobromine, a methylxanthine found in tea and chocolate and a metabolite of caffeine thought to have some stimulant effects but likely has no psychotropic effects in humans (Benton, 2004). It was also associated with choline, which is an essential micronutrient that is particularly important for fetal development (Caudill, 2010).

Dodecanoic acid, also known as "Lauric acid," is a 12-carbon chain saturated fatty acid that is enriched in coconut oil. Regarding physiologic effects, it has been shown to increase serum high-density lipoprotein (HDL) cholesterol when added to the diet, without affecting low-density lipoprotein (LDL) levels, compared to *trans*-fatty acids derived from partially hydrogenated soybean oil (de Roos, Schouten, & Katan, 2001). Results from epidemiological studies have suggested that consumption of *trans*-fatty acids compared to saturated fatty acids increases the risk of cardiovascular disease (Ascherio, Katan, Zock, Stampfer, & Willett, 1999). Our results show that increasing dietary consumption of dodecanoic acid is associated with reduced chance of being a long sleeper, suggesting that diets enriched with this saturated fatty acid may not only reduce the ratio of LDL/HDL levels, which in turn is associated with healthy cardiovascular function, but may also be associated with 7–8 h sleep duration.

Thus, each implicated micronutrient has the potential to impact health, but whether the differences observed in this study would have significant clinical impact is unknown. Furthermore, the mechanisms that would explain the differences in micronutrient intake between sleep duration groups remain to be identified. Also, the reduced variety of food types among short sleepers likely contributed to the reduced intake of micronutrients.

There are some limitations to this analysis that need to be considered. First, sleep duration and dietary intake were self-reported. Objective measures of sleep duration, such as polysomnography and actigraphy, were not employed in the present study, although actigraphy has been used as a measure of sleep in prior epidemiologic studies (Knutson et al., 2009; Kripke, Langer, Elliott, Klauber, & Rex, 2011; Lauderdale et al., 2009). Although self-reported sleep duration is moderately correlated with actigraphic sleep duration ($r = 0.5$) (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008), numerous studies have observed significant associations between self-reported sleep duration and measures of health, including BMI and obesity (Cappuccio et al., 2008; Grandner, Patel, Gehrman, Perlis, et al., 2010; Knutson, 2010). Because of this, we argue that subjective, retrospective ratings of habitual sleep duration bear some resemblance to values obtained using objective methods and show important associations to health variables. Even if these are just survey measures, they likely reflect habitual sleep duration. Another important limitation is that even though aspects of overall dietary pattern were included as covariates, since these variables differed by sleep duration category, it is possible that the assessment of differences in macronutrients and micronutrients may have been somewhat unreliable.

Although the dietary patterns were based on self-report, the method employed by NHANES to assess dietary intake has been validated (Centers for Disease Control & Prevention, 2008a, 2008b). In addition, others have used the NHANES dietary data and found significant associations between certain nutrients and health outcomes, including fracture risk (Zhong, Okoro, & Balluz, 2009) and anthropometric measures (Bradlee, Singer, Qureshi, & Moore, 2010). Finally, due to the cross-sectional nature of this analysis, direction of effect cannot be determined. Indeed, it is possible that certain nutrients could impact sleep (e.g. alcohol) while sleep may also impact food intake, as proposed by the laboratory studies discussed previously. Also, respondents were only asked about weekday/

workday sleep. These results may be different in the context of average (all days) or weekend/day off sleep.

Another important limitation of these data is that dietary nutrient information does not include specific foods consumed, nor does it include timing of meals. Therefore, we could not, for example, examine the incidence of skipping breakfast across sleep duration categories, whether short (5–6 h) sleepers consumed more calories at night, or whether certain foods characterized groups. These are certainly relevant factors that should be incorporated into future studies.

The results of these analyses demonstrated differences in dietary behavior and nutrient intake between those who reported sleeping 7–8 h and the three other sleep duration groups: very short (<5 h), Short (5–6 h) and Long (≥9 h) sleepers. Minor differences in nutrient intake, particularly micronutrients, could have important health implications. Future research should incorporate objective measures of sleep in a prospective design to determine whether certain sleep durations impact food choices and nutrient intake.

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Table 1

Subject characteristics by sleep duration category.

Variable	Category	Total sample	Very short sleep (<5 h)	Short sleep (5–6 h)	Normal sleep (7–8 h)	Long sleep (9+ h)	*P*-value[a]
N (%)		4548 (100)	270 (5.9)	1545(34.0)	2424(53.3)	309(6.8)	
Age	Mean (SD)	46.3 ± 16.5	45.8 ± 15.4	45.8 ± 16.6	46.6 ± 16.0	47.0 ± 20.1	0.6393
Sex	Female (%)	53.12	55.52	49.96	53.13	65.66	0.0027
	Male (%)	46.88	44.48	50.04	46.87	34.34	
Race/ethnicity	Non-Hispanic White (%)	71.56	61.51	66.84	74.49	77.02	<0.0001
	Hispanic/Latino	13.04	10.73	12.88	13.61	10.90	
	Black/African American (%)	10.87	22.94	14.44	7.85	9.80	
	Asian/other (%)	4.53	4.82	5.83	4.05	2.29	
Education	Less than high school (%)	19.04	27.93	18.74	17.75	23.88	<0.0001
	High school graduate (%)	25.39	33.03	26.24	24.44	23.16	
	Some college (%)	30.06	32.71	33.55	28.28	26.59	
	College graduate (%)	25.52	6.33	21.48	29.53	26.36	
Income	<$20,000 (%)	16.06	29.69	16.30	14.33	18.37	<0.0001
	$20–$25,000 (%)	7.18	8.44	7.22	6.37	12.67	
	$25–$35,000 (%)	11.85	17.85	12.18	10.91	13.36	
	$35–$45,000 (%)	8.89	6.65	9.43	9.13	6.15	
	$45–$55,000 (%)	8.34	7.79	7.53	8.41	11.95	
	$55–$65,000 (%)	7.05	7.11	7.80	6.51	8.05	
	$65–$75,000 (%)	7.60	11.66	6.72	8.14	3.90	
	>$75,000 (%)	33.03	10.80	32.83	36.22	25.54	
Minutes of exercise	Mean (SD)	166 ± 223	222 ± 304	189 ±259	152 ±193	130± 206	0.0002
Body Mass Index	Mean (SD)	28.7 ± 6.8	29.7 ± 7.0	29.5 ± 7.4	28.3 ± 6.4	27.8 ± 6.8	0.0001

[a]One-way ANOVA for continuous variables and X^2 for categorical variables.

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Table 2

Dietary variables by sleep duration category. Only variables that differed across sleep duration groups are shown.*

Variable	Units	Very short sleep (<5 h)	Short sleep (5–6 h)	Normal sleep (7–8 h)	Long sleep (9+ h)	*P*-value[a]
Overall diet						
Total energy intake	kcal (M ±SD)	2036 ±1367	2201 ± 1074	2151± 950	1926 ± 978	0.001
Number of foods in diet	number (M ± SD)	14.0 ± 6.8	16.5 ±6.4	17.8 ± 6.0	16.3 ± 6.5	<0.001
Reported vs. usual	% More	9.68	8.61	6.54	3.12	0.007
	% Less	24.32	16.72	14.24	15.66	
Special diet						
Low salt/sodium diet	% Yes	4.60	2.70	1.08	2.59	0.003
Nutrient categories						
Total protein	g (M ±SD)	74.4 ± 54.9	83.4 ±45.8	83.3 ± 39.6	72.8 ± 44.6	0.001
Total carbohydrates	g (M ±SD)	236 ± 157	267 ± 136	260±123	225 ±120	<0.001
Total sugars	g (M ±SD)	115 ±105	124 ± 85	119 ± 79	101 ± 69	0.003
Total dietary fiber	g (M ±SD)	13.2 ± 10.1	15.9 ± 10.9	16.6 ± 9.6	14.2 ± 8.7	<0.001
Total fat	g (M ±SD)	79.4 ± 67.6	84.1 ±49.9	82.3 ± 45.0	74.7 ± 48.0	0.012
Fats						
Total saturated fat	g (M ±SD)	27.4 ±27.7	27.8 ± 17.9	27.3 ± 16.2	24.6 ± 18.1	0.018
Total monounsaturated fat	g (M ±SD)	29.3 ±25.1	31.0 ± 19.7	30.4 ± 17.7	27.3 ± 18.0	0.023
Total polyunsaturated fat	g (m± sd)	16.0 ± 14.2	17.9 ± 11.8	17.4 ± 10.8	16.4 ± 12.0	0.011
Total cholesterol	g (M ±SD)	290 ± 305	307 ± 263	296 ± 248	247 ± 230	0.006
Vitamins						
Alpha-tocopherol	mg (M ± SD)	6.55 ± 6.07	7.57 ±6.22	7.83 ± 5.43	6.96 ± 5.00	0.002
Added alpha-tocopherol	mg (M ± SD)	0.206 ± 1.823	0.505 ± 2.745	0.589 ± 2.622	0.471 ±2.023	0.017
Retinol	mcg (M ± SD)	445 ± 658	424 ±477	446 ± 409	359 ± 327	<0.001
Vitamin A RAE	mcg (M ± SD)	603 ± 724	607 ± 588	639 ± 523	545 ± 435	0.001
Alpha-carotene	mcg (M ± SD)	290 ± 804	370± 955	375 ±1003	365 ± 786	0.025
Beta-carotene	mcg (M ± SD)	1715 ± 3163	1976 ± 3434	2083 ± 3389	2015 ± 3087	0.002
Beta-cryptoxanthin	mcg (M ± SD)	67.8 ±215.4	74.0 ± 177.5	76.4 ± 163.7	73.2 ± 126.5	0.004
Lycopene	mcg (M ± SD)	4448 ±9905	5623 ± 10,422	6152 ± 10,658	4899 ± 7889	0.001
Lutein + zeaxanthin	mcg (M ± SD)	1460 ±4137	1495 ± 3283	1413 ± 2625	1352 ± 2629	0.011

Variable	Units	Very short sleep (<5 h)	Short sleep (5–6 h)	Normal sleep (7–8 h)	Long sleep (9+ h)	*P*-value[a]
Thiamin (vitamin B1)	mg (M ± SD)	1.36 ± 1.02	1.64 ±0.97	1.69 ± 1.13	1.50 ± 1.15	<0.001
Riboflavin (vitamin B2)	mg (M ± SD)	2.09 ± 1.67	2.25 ± 1.55	2.26 ± 1.24	1.96 ± 1.25	0.001
Niacin	mcg (M ± SD)	22.3 ± 16.1	26.1 ± 17.9	25.3 ± 14.0	21.6 ± 12.9	<0.001
Vitamin B6	mg (M ± SD)	1.69 ± 1.35	2.03 ± 1.56	2.04 ± 1.25	1.68 ± 0.98	<0.001
Total folate	mcg (M ± SD)	347 ± 265	403 ± 256	416 ± 247	373 ± 231	<0.001
Folic acid	mcg (M ± SD)	148 ±168	189 ±183	198 ±194	175 ±181	0.001
Food-based folate	mcg (M ± SD)	199 ±177	214±134	219 ±122	197 ±111	0.002
Folate DFE	mcg (M ± SD)	451± 362	535 ± 373	555 ± 372	495 ± 347	<0.001
Choline	mcg (M ± SD)	309 ± 251	333 ± 202	331±185	275 ±161	<0.001
Vitamin B12	mcg (M ± SD)	4.67 ±4.67	5.47 ± 6.70	5.49 ± 5.51	4.49 ± 4.74	0.001
Vitamin C	mg (M ± SD)	64.4 ± 84.0	82.4 ± 98.3	85.6 ± 89.0	82.2 ± 89.7	0.001
Vitamin D2 + D3	mcg (M ± SD)	4.01 ±4.81	4.32 ± 5.39	4.55 ± 4.75	3.49 ± 3.67	0.004
Vitamin K	mcg (M ± SD)	97.2 ± 190.1	99.3 ± 153.0	101.1 ± 133.4	91.6 ± 127.8	0.008
Minerals						
Calcium	mg (M ± SD)	894 ± 923	926± 571	959 ± 567	871± 640	0.002
Phosphorus	mg (M ± SD)	1227 ±1002	1345 ± 704	1369 ± 638	1170± 681	<0.001
Magnesium	mg (M ± SD)	259 ±180	295 ±169	303 ±137	266 ± 136	<0.001
Iron	mg (M ± SD)	12.7 ±9.5	15.6 ±9.5	15.5 ± 8.3	13.6 ± 8.3	<0.001
Zinc	mg (M ± SD)	10.4 ±8.5	12.2 ±8.6	12.6 ± 11.8	10.5 ±6.4	<0.001
Copper	mg (M ± SD)	1.17 ± 1.07	1.35 ± 1.02	1.38 ± 0.91	1.25 ± 0.73	0.001
Sodium	mg (M ± SD)	3286 ± 2523	3583 ± 2048	3494±1734	3001±1795	<0.001
Potassium	mg (M ± SD)	2368 ±1634	2660 ± 1409	2722 ±1173	2318 ±1059	<0.001
Selenium	mcg (M ± SD)	96.1 ± 70.2	112.2 ± 70.0	112.5 ±59.7	98.1 ± 64.4	<0.001
Water						
Moisture	g (M ±SD)	3123 ± 2032	3058 ±1587	3015 ± 1386	2714±1338	0.025
Plain water	g (M ±SD)	1023 ±1345	1014 ±1221	1015 ± 1046	906±1013	0.040
Tap water	g (M ±SD)	528 ±1073	534± 971	654 ± 930	555 ± 865	<0.001
Other						
Theobromine	mg (M ± SD)	39.6 ±89.7	40.0 ± 83.9	43.5 ± 75.8	28.6 ± 62.1	0.002

[*] Non-significant results were found for salt use, special diet, weight loss diet, low fat/cholesterol diet, diabetic diet, all specific monounsaturated, polyunsaturated and saturated fatty acids, added Vitamin B12, bottled water, caffeine, and alcohol.

[a] One-way ANOVA for continuous variables and X^2 tests for categorical variables.

Table 3

Dietary patterns associated with sleep duration (reference = 7–8 h); relative risk ratios and 95% confidence intervals in unadjusted and adjusted[a] using multinomial logistic regression (separate model for each variable below[a]).

Variable	Very short sleep (<5 h) RRR (95% CI)	Short sleep (5–6 h) RRR (95% CI)	Long sleep (9+ h) RRR (95% CI)
Unadjusted			
Total energy intake (kcal)	0.940 (0.826, 1.070)	1.024 (0.984, 1.065)	0.877 * (0.791, 0.972)
Number of foods in diet	0.581 *** (0.476, 0.710)	0.853 *** (0.795, 0.914)	0.830 * (0.705, 0.976)
Reported vs. usual diet			
More	1.776 (0.872, 3.617)	1.396 † (0.992, 1.964)	1.927 † (0.924, 4.018)
Less	2.050 *** (1.372, 3.064)	1.245 † (0.975, 1.591)	1.619 * (1.070, 2.448)
Any special diet (yes)	1.586 * (1.009, 2.492)	1.144 (0.883, 1.482)	1.095 (0.703, 1.704)
Low salt/sodium diet (yes)	4.424 ** (1.712, 11.436)	2.546 ** (1.410, 4.595)	2.438 † (0.994, 5.978)
Adjusted[b]			
Total energy intake (kcal)	0.968 (0.858, 1.093)	1.017 (0.972, 1.065)	0.920 (0.828, 1.023)
Number of foods in diet	0.671 *** (0.543, 0.830)	0.885 ** (0.820, 0.955)	0.855 * (0.735, 0.995)
Reported vs. usual diet			
More	1.359 † (0.966, 1.911)	0.494 (0.198, 1.234)	0.494 (0.198, 1.234)
Less	1.134 (0.873, 1.472)	1.025 (0.660, 1.592)	1.025 (0.660, 1.592)
Any special diet (yes)	1.752 * (1.093, 2.808)	1.164 (0.895, 1.514)	1.116 (0.699, 1.779)
Low salt/sodium diet (yes)	3.710 ** (1.619, 8.503)	2.481 ** (1.365, 4.511)	2.225 † (0.906, 5.463)

† $p < 0.10$.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

[a] Only variables with significant relationships to sleep are shown.

[b] Adjusted for age, sex, race/ethnicity, income, education, BMI, and exercise (minutes).

Table 4

Relative risk ratios for dietary nutrients associated with sleep duration (relative to 7–8 h) in unadjusted analyses and analyses adjusted for overall dietary pattern[a] (separate model for each variable below). Only variables where $p < 0.10$ are shown.

Variable	Units	Model 1: Unadjusted			Model 2: Adjusted for overall diet		
		Very short sleep (<5 h)	Short sleep (5–6 h)	Long sleep (9+h)	Very short sleep (<5 h)	Short sleep (5–6 h)	Long sleep (9+ h)
Salt							
Table salt use (never)	%	Reference	Reference	Reference	Reference	Reference	Reference
Table salt use (rarely)	%	0.60 ± 0.22	1.04 ±0.18	0.96 ± 0.29	0.61 ± 0.22	1.04 ± 0.19	0.98 ± 0.30
Table salt use (occasionally)	%	0.44 ± 0.14 *	0.76 ±0.12	0.74 ± 0.21	0.45 ± 0.14 †	0.75 ± 0.12	0.76 ± 0.22
Table salt use (very often)	%	0.81 ± 0.25	0.91 ±0.14	0.75 ± 0.20	0.80 ± 0.24	0.89 ± 0.14	0.77 ± 0.21
Nutrient categories							
total protein	g	0.48 ± 0.08 ***	0.91 ± 0.08	0.54 ± 0.08 ***	0.42 ± 0.10 **	0.76 ± 0.11	0.51 ± 0.12 †
Total carbohydrates	g	0.54 ± 0.10 **	1.07 ±0.10	0.55 ± 0.08 ***	0.44 ± 0.12 *	1.02 ± 0.16	0.51 ± 0.14
Total sugars	g	0.77 ± 0.10	1.06 ±0.07	0.73 ± 0.07 **	0.89 ± 0.13	1.06 ± 0.08	0.83 ±0.12
Total dietary fiber	g	0.43 ± 0.07 ***	0.82 ± 0.07 *	0.64 ± 0.08 **	0.56 ± 0.11 †	0.84 ± 0.08	0.76 ± 0.13
Total fat	g	0.67 ± 0.10 *	1.02 ±0.08	0.72 ± 0.09 *	0.81 ± 0.16	1.02 ± 0.12	0.99 ± 0.25
Fats							
Total saturated fat	g	0.70 ± 0.11 †	1.00 ± 0.07	0.72 ± 0.09 *	0.81 ± 0.17	0.94 ± 0.11	0.93 ±0.18
Total monounsaturated fat	g	0.72 ± 0.11 †	1.03 ±0.07	0.72 ± 0.10 *	0.89 ± 0.18	1.01 ± 0.12	0.99 ± 0.23
Total polyunsaturated fat	g	0.63 ± 0.09 **	1.03 ±0.07	0.75 ± 0.11	0.76 ± 0.15	1.08 ± 0.11	1.04 ± 0.24
Total cholesterol	g	0.80 ± 0.08 †	1.01 ±0.05	0.76 ± 0.06 **	0.93 ± 0.10	1.02 ± 0.06	0.83 ± 0.08
Dodecanoic acid (SFA 12:0)	ratio	0.97 ± 0.10	0.92 ± 0.04	0.84 ± 0.06 †	1.00 ± 0.09	0.93 ± 0.04	0.85 ± 0.06
Hexadedenoic acid (MFA 16:1)	ratio	1.22 ±0.11 †	1.03 ±0.05	0.89 ± 0.08	1.14 ±0.10	1.01 ± 0.05	0.88 ± 0.08
Octadecenoic acid (MFA 18:1)	ratio	0.82 ± 0.06 *	0.94 ± 0.05	0.87 ± 0.11	0.87 ± 0.06	0.96 ± 0.05	0.90 ±0.10
Vitamins							
Alpha-tocopherol	mg	0.52 ± 0.10 **	0.89 ± 0.07	0.72 ± 0.11 †	0.68 ± 0.17	0.91 ± 0.09	0.96 ±0.19
Added alpha-tocopherol	mg	0.59 ± 0.14 †	0.91 ± 0.09	0.97 ± 0.15	0.67 ± 0.16	0.94 ± 0.09	1.00 ±0.16
Retinol	mcg	0.73 ± 0.05 ***	0.93 ± 0.04	0.78 ± 0.05 ***	0.83 ± 0.07	0.95 ± 0.04	0.83 ± 0.06

Variable	Units	Model 1: Unadjusted			Model 2: Adjusted for overall diet		
		Very short sleep (<5 h)	Short sleep (5–6 h)	Long sleep (9+h)	Very short sleep (<5 h)	Short sleep (5–6 h)	Long sleep (9+ h)
Vitamin A RAE	mcg	0.68 ± 0.06***	0.90 ± 0.04†	0.78 ± 0.06**	0.83 ± 0.09	0.94 ± 0.05	0.86 ± 0.08
Alpha-carotene	mcg	0.88 ± 0.04*	0.97 ± 0.02	0.95 ± 0.04	0.99 ± 0.04	1.01 ± 0.02	0.98 ± 0.04
Beta-carotene	mcg	0.77 ± 0.05**	0.95 ± 0.03	0.93 ± 0.05	0.90 ± 0.06	0.99 ± 0.03	1.00 ±0.06
Beta-cryptoxanthin	mcg	0.82 ± 0.04**	0.97 ± 0.03	0.93 ± 0.05	0.93 ± 0.05	1.00 ± 0.03	0.97 ± 0.06
Lycopene	mcg	0.91 ± 0.02***	0.98 ± 0.01	0.94 ± 0.02*	0.93 ± 0.02*	0.98 ± 0.01	0.96 ± 0.02
Lutein + zeaxanthin	mcg	0.76 ± 0.06**	0.98 ± 0.04	0.92 ± 0.07	0.94 ± 0.08	1.06 ± 0.04	1.00 ±0.06
Thiamin (vitamin B1)	mg	0.22 ± 0.08**	0.86 ±0.12	0.41 ± 0.13*	0.21 ± 0.09*	0.78 ± 0.15	0.53 ± 0.22
Riboflavin (vitamin B2)	mg	0.43 ±0.15*	0.89 ±0.11	0.39 ± 0.11**	0.61 ± 0.27	0.83 ± 0.14	0.44 ±0.17
Niacin	mcg	0.52 ± 0.09***	0.98 ± 0.09	0.54 ± 0.08***	0.52 ± 0.12†	0.92 ± 0.11	0.56 ± 0.12†
Vitamin B6	mg	0.32 ± 0.10**	0.89 ±0.11	0.40 ±0.10**	0.41 ± 0.16	0.88 ± 0.14	0.47 ±0.15
Total folate	mcg	0.51 ± 0.06***	0.88 ± 0.07	0.68 ± 0.09**	0.59 ± 0.09*	0.86 ± 0.08	0.79 ± 0.13
Folic acid	mcg	0.76 ± 0.05***	0.98 ± 0.04	0.84 ± 0.05*	0.80 ± 0.06*	0.97 ± 0.04	0.88 ± 0.06
Food-based folate	mcg	0.56 ± 0.08***	0.90 ± 0.07	0.74 ± 0.10†	0.76 ± 0.14	0.94 ± 0.09	0.96 ±0.16
Folate DFE	mcg	0.54 ± 0.06***	0.90 ± 0.06	0.69 ± 0.08**	0.61 ± 0.09*	0.88 ± 0.07	0.79 ± 0.12
Choline	mcg	0.58 ± 0.10**	0.97 ± 0.07	0.57 ± 0.08***	0.67 ± 0.14	0.95 ± 0.10	0.58 ± 0.11†
Vitamin B12	mcg	0.61 ± 0.10*	0.94 ± 0.07	0.66 ± 0.08**	0.70 ± 0.13	0.92 ± 0.07	0.76 ± 0.11
Vitamin C	mg	0.74 ± 0.05***	0.92 ± 0.03†	0.90 ± 0.07	0.89 ± 0.06	0.97 ± 0.04	0.98 ± 0.08
Vitamin D2 + D3	mcg	0.72 ± 0.11†	0.92 ± 0.06	0.70 ±0.08**	0.90 ± 0.12	0.95 ± 0.06	0.77 ± 0.09
Vitamin K	mcg	0.70 ± 0.08**	0.95 ± 0.05	0.81 ± 0.08†	0.92 ± 0.12	1.02 ± 0.06	0.92 ± 0.09
Minerals							
Calcium	mg	0.55 ± 0.09**	0.91 ± 0.06	0.69 ± 0.09*	0.66 ± 0.13	0.90 ± 0.08	0.81 ± 0.14
Phosphorus	mg	0.43 ± 0.08***	0.87 ± 0.08	0.50 ±0.08***	0.35 ± 0.10*	0.70 ± 0.10	0.40 ±0.10*
Magnesium	mg	0.40 ± 0.08***	0.81 ± 0.08†	0.55 ± 0.09**	0.44 ± 0.12*	0.73 ± 0.10	0.63 ±0.15
Iron	mg	0.38 ± 0.07***	0.95 ± 0.09	0.54 ± 0.09**	0.36 ± 0.09**	0.94 ± 0.11	0.59 ±0.14
Zinc	mg	0.44 ± 0.09***	0.90 ± 0.07	0.57 ± 0.09**	0.43 ± 0.11*	0.83 ± 0.09	0.64 ±0.16

Variable	Units	Model 1: Unadjusted			Model 2: Adjusted for overall diet		
		Very short sleep (<5 h)	Short sleep (5–6 h)	Long sleep (9+h)	Very short sleep (<5 h)	Short sleep (5–6 h)	Long sleep (9+ h)
Copper	mg	0.20 ± 0.10 **	0.81 ±0.13	0.47 ± 0.17 †	0.26 ± 0.17	0.77 ± 0.17	0.90 ± 0.42
Sodium	mg	0.61 ± 0.09 **	1.00 ± 0.08	0.56 ± 0.08 ***	0.71 ± 0.14	0.97 ± 0.12	0.56 ± 0.11 †
Potassium	mg	0.44 ± 0.08 ***	0.82 ± 0.08 †	0.54 ± 0.08 ***	0.54 ± 0.14	0.78 ± 0.10	0.57 ± 0.12 †
Selenium	mcg	0.51 ± 0.07 ***	0.89 ± 0.07	0.59 ± 0.08 ***	0.47 ± 0.08 **	0.74 ± 0.09 †	0.59 ±0.13
Water							
Moisture	g	0.80 ± 0.17	1.03 ±0.09	0.66 ± 0.09 *	1.07 ± 0.22	1.07 ± 0.10	0.81 ± 0.12
Plain water	g	0.93 ± 0.03 †	0.96 ±0.01 *	0.97 ± 0.03	0.97 ± 0.03	0.98 ± 0.02	0.98 ± 0.03
Tap water	g	0.92 ± 0.02 **	0.94 ±0.01 ***	0.97 ± 0.02	0.95 ± 0.03	0.96 ± 0.01 *	0.97 ± 0.02
Other							
Caffeine	mg	0.99 ± 0.05	1.00 ± 0.02	0.92 ± 0.03 †	1.05 ± 0.05	1.01 ± 0.02	0.94 ± 0.04
Theobromine	mg	0.89 ± 0.04 *	0.94 ± 0.02 *	0.89 ± 0.04 *	0.96 ± 0.05	0.96 ± 0.02	0.92 ± 0.04

† $p < 0.10$.

* $p < 0.05$.

** $p < 0.01$

*** $p < 0.001$.

[a] Covariates include total caloric intake (kcal), number of foods in diet, similarity to habitual diet, and special diets.

Table 5

Relative risk ratios for dietary nutrients associated with sleep duration (relative to 7–8 h) in analyses adjusted for overall dietary pattern, sociodemographics, socioeconomics, health, and special diets (separate model for each variable below).

Variable		Very short (<5 h)		Short (5–6 h)		Long (9+h)	
		RRR	95% CI	RRR	95% CI	RRR	95% CI
Total protein	g	0.46*	0.30–0.71	0.74	0.56–0.98	0.59	0.38–0.94
Total carbohydrates	g	0.46*	0.29–0.75	1.04	0.77–1.42	0.51	0.30–0.84
Lycopene	mcg	0.94†	0.90–0.98	0.99	0.97–1.02	0.96	0.92–1.01
Thiamin (vitamin B1)	mg	0.25*	0.11–0.56	0.79	0.54–1.15	0.57	0.26–1.26
Total folate	mcg	0.64*	0.48–0.85	0.89	0.73–1.07	0.83	0.61–1.15
Folic acid	mcg	0.82†	0.72–0.94	0.99	0.91–1.07	0.89	0.77–1.03
Folate DFE	mcg	0.65*	0.50–0.85	0.91	0.76–1.07	0.82	0.61–1.09
Phosphorus	mg	0.41*	0.25–0.69	0.75	0.55–1.01	0.45*	0.28–0.71
Magnesium	mg	0.51†	0.32–0.80	0.76	0.57–1.01	0.69	0.43–1.10
Iron	mg	0.38*	0.24–0.61	0.94	0.74–1.19	0.62	0.39–0.97
Zinc	mg	0.47*	0.29–0.77	0.85	0.68–1.07	0.66	0.42–1.06
Selenium	mcg	0.49*	0.36–0.68	0.72†	0.57–0.91	0.67	0.45–1.01
Tap water	g	0.95	0.90–1.00	0.95*	0.93–0.98	0.97	0.92–1.02
Alcohol	mg	1.06	0.93–1.20	1.00	0.94–1.07	1.19	1.07–1.33

Covariates included: Age, gender, income, education, race/ethnicity, body mass index, exercise, number of foods, energy (kcal), diet vs. usual, any special diets, weight loss diet, low fat/low cholesterol diet, low salt/sodium diet, and diabetic diet.

** $p < 0.01$.

*** $p < 0.001$.

† $p < 0.10$.

* $p < 0.05$.

Table 6

Stepwise multinomial regression model reflecting relative risk ratios (RR) and 95% confidence intervals (95% CI) of associations between 100% increase in dietary variables and sleep duration (relative to 7–8 h) (single model).

Variable	Very short (<5 h vs. 7–8 h)		Short (5–6 h vs. 7–8 h)		Long (9± h vs. 7–8 h)	
	RR (95% CI)	*P*	RR (95% CI)	*P*	RR (95% CI)	*P*
Theobromine (log)	0.971 (0.879, 1.073)	0.5688	0.957 (0.911, 1.004)	0.0729	0.910 (0.835, 0.991)	0.0307
Vitamin C (log)	0.895 (0.768, 1.044)	0.1574	0.890 (0.813, 0.975)	0.0123	1.052 (0.865, 1.279)	0.6113
Tap water (log)	0.941 (0.891, 0.994)	0.0295	0.952 (0.926, 0.980)	0.0008	0.962 (0.912, 1.014)	0.1512
Lutein + zeaxanthin (log)	1.112 (0.925, 1.336)	0.2573	1.123 (1.026, 1.230)	0.0117	1.119 (0.960, 1.303)	0.1496
Dodecanoic acid (ratio of log)	1.042 (0.880, 1.233)	0.6325	0.935 (0.858, 1.018)	0.1222	0.812 (0.684, 0.964)	0.0174
Choline (log)	0.739 (0.394, 1.386)	0.3451	1.043 (0.786, 1.383)	0.7713	0.450 (0.277, 0.731)	0.0013
Lycopene (log)	0.950 (0.905, 0.997)	0.0368	0.993 (0.968, 1.019)	0.5932	0.957 (0.914, 1.002)	0.0601
Total carbohydrate (log)	0.494 (0.287, 0.850)	0.0109	1.100 (0.787, 1.537)	0.5783	0.509 (0.264, 0.980)	0.0433
Selenium (log)	0.606 (0.353, 1.042)	0.0699	0.670 (0.504, 0.892)	0.0061	1.040 (0.605, 1.787)	0.8879
Alcohol (log)	1.019 (0.891, 1.166)	0.7844	0.988 (0.924, 1.056)	0.7226	1.172 (1.039, 1.321)	0.0097

The following covariates were forced into the model: age, gender, income, education, race/ethnicity, body mass index, exercise, number of foods, energy (kcal), diet vs. usual, any special diets, weight loss diet, low fat/low cholesterol diet, low salt/sodium diet, and diabetic diet.