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Relationships among dietary nutrients and subjective sleep, objective sleep, and napping in women

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Abstract

Objective—To describe which dietary nutrient variables are related to subjective and objective habitual sleep and subjective and objective napping.

Methods—Participants were 459 postmenopausal women enrolled in the Women's Health Initiative. Objective sleep was estimated using one week of actigraphy. Subjective sleep was prospectively estimated with a daily sleep diary. Dietary nutrients were calculated from food frequency questionnaires.

Results—The most significant correlations were with subjective napping, including (from strongest to weakest): total fat, calories, saturated fat, monounsaturated fat, trans fat, water, proline, serine, tyrosine, phenylalanine, valine, cholesterol, leucine, glutamic acid, ash, isoleucine, histidine, sodium, tryptophan, protein, threonine, cystine, methionine, phosphorous, polyunsaturated fat, animal protein, aspartic acid, arginine, lysine, alanine, caffeine, riboflavin, gamma-tocopherol, glycine, retinol, delta-tocopherol, vitamin D, and selenium. Actigraphic nocturnal sleep duration was negatively associated with total fat, monounsaturated fat, trans fat, saturated fat, polyunsaturated fat, calories, gamma-tocopherol, cholesterol, and alpha-tocopherol-eq.

Conclusions—Actigraphic total sleep time was negatively associated with intake of fats. Subjective napping, which may be a proxy for subjective sleepiness, was significantly related to fat intake as well as intake of meat.

Keywords

Sleep; Diet; Nutrition; Obesity; Napping; Sleep Duration; Women

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INTRODUCTION

Epidemiological and laboratory studies have indicated that self-reported short sleep duration is associated with increased risks for metabolic disruption, including impaired glucose tolerance, impaired insulin resistance, increased ghrelin, decreased leptin, and increased body mass index (BMI)(1-12). These findings may partially explain the increased mortality associated with short sleep duration, which has been replicated by many studies (13-14). But the role of diet in these sleep-related metabolic phenomena is currently unknown.

Although epidemiological studies have benefited from large numbers of participants, they have not measured sleep using prospective or objective methods. Thus, it is not known whether these associations are caused by sleep or by other factors. Additionally, while laboratory studies carefully measured sleep, the controlled setting of the laboratory offered little ecological validity, and the small number of participants provided limited generalizability (13). Thus, it is unknown whether these carefully-recorded observations will translate to considerations of population health.

The present study helps to address these issues by using sleep recorded prospectively with sleep diaries and objectively using actigraphy, both well-validated estimates of habitual sleep (15-19). Additionally, this study examined dietary variables using validated nutritional assessments(20). Finally, by employing a large sample of women from the Women's Health Initiative(21-22), we were able to demonstrate sufficient power to detect subtle relationships, at least in this group of older women. Thus, the present study aims to describe the relationships among dietary nutrient variables and subjective and objective sleep as well as subjective and objective estimates of napping. Using this approach, we explored which dietary nutrients were associated with which sleep variables.

METHODS

Subjects

Subjects were 423 women recruited as part of an ancillary study of the Women's Health Initiative (WHI), a large, multi-site, longitudinal study of health in postmenopausal women (a description of methods and rationale has been published previously [21-22]). All women were post-menopausal (mean age 68, SD 7.76, range 50 to 81). Baseline characteristics for education, income and BMI are included in Table 1.

Recruitment emphasized ethnic diversity. Clinical measurements included weight and height (to compute BMI) obtained by personnel during clinic visits(21). Additional questionnaires measured numerous demographic variables, including age, education, income, and estimated minutes of daily moderate/strenuous physical activity (computed with questions addressing estimates of time spent doing various activities in general) (21). Several previous reports of data from these subjects have appeared (23-30). In addition, each participant completed a Structured Clinical Interview for the DSM-IV (SCID; [31]), and a composite variable denoting whether participants reported probable Major Depressive Disorder, Bipolar Disorder, Dysthymia or Mild Depression was computed to assess presence of affective disorders.

Sleep Assessment

Subjective sleep data were obtained from averaging one week of sleep diaries. During this time, one week of actigraphy was also collected. Subjective sleep variables included estimated total sleep time (S-TST), wake time after sleep onset (S-WASO), and number of naps(S-NAPS).

Actigraphic sleep recordings were made using an Actilume™ wrist actigraph worn for one week. All records were hand-scored for sleep, with the assistance of a validated algorithm (26). The Actilume measured physical activity each second which was then averaged across one-minute epochs. Computations of total sleep time (A-TST), sleep efficiency (A-SEFF), sleep acrophase (A-ACRO, the peak of a fitted 24-hour cosine), and minutes asleep out of bed (A-NAPS) were computed using ACTION 3 software (Ambulatory Monitoring Inc., Ardsley, NY).

Diet Assessment

Dietary nutrient variables were computed based on values from a semi-quantitative Food Frequency Questionnaire (FFQ), which asked about the portion size and frequency of consumption over the last three months of 122 foods or food groups, including vitamins and supplements (20). This questionnaire also addressed other issues, such as added fats and food preparation. Nutrients were calculated using an automated script that referenced a database derived from the University of Minnesota Nutrition Coding Center (32). The WHI FFQ was based on measures previously used in a number of clinical trials(33–35), has been validated previously(20) and has been reported in a number of studies from the WHI(36, 37–39). This measure yielded 88 distinct dietary variables.

Data Analysis

To determine whether affective disorder should be included as a covariate, all subjective and objective sleep variables were evaluated with independent samples t-tests, comparing those with diagnosis to those without. A total of 29 participants were identified as having a present affective illness. When sleep variables were compared, no significant differences were found (p values ranging from 0.165 for actigraphic naps to 0.917 for sleep acrophase), except for subjective estimates of WASO ($t(423) = -2.9, p < .05$), though r^2 for this relationship, after adjusting for the other covariates (described below), was 0.016, indicating that presence of affective disorder explained 1.6% of the variance of subjective wake after sleep onset and no significant proportion of variance of any other variable. As subjective WASO was not significantly correlated with any variable, affective disorder was rejected as a covariate, suggesting that relationships between sleep and dietary variables are not explained by depression or other affective illness.

To evaluate sleep and nutrient variables, partial correlations (controlling for age, education, income, BMI, minutes of daily moderate/strenuous physical activity and daily grams food consumption) evaluated the relationships between subjective and objective sleep variables and 88 nutrient variables derived from the FFQ. Due to the large number of correlations, plots of p-values aided in establishing significance criterion, based on methods developed by Schweder and Spjøtvoll(40). The plot of ranked p-values was analyzed to determine the inflection point at which values deviate from the primary line. This deviation point is thought to represent the p-value at which significant findings are first observed. An alternative method, developed by Benjamini and Hochberg(41–43), was also used to derive a significance criterion. This method uses ranked p-values to determine the cutoff, at which point the Type-I error rate is below .05.

RESULTS

Significance Criterion

Examination of p-values established a $p = .004$ significance criterion among 602 correlations based on the Schweder and Spjøtvoll criteria(40); this identical criterion was established with the Benjamini and Hochberg method(41–43). Thus, all correlations of $p < .004$ were considered statistically significant.

Significant partial correlations (controlling for age, education, income, exercise, BMI and total dietary grams) are reported in Table 2. Forty-nine of 63 reported correlations met the $p=.004$ significance cutoff, while 14 met a $p<.01$ cutoff. This latter threshold identified correlations that tended towards significance and may be of interest for further study, but did not achieve the significance level established for this study.

Sleep Variables

Partial correlations are displayed in Table 2 (actigraphy) and Table 3 (subjective sleep). A-ACRO was significantly correlated with Vitamin D: the greater the Vitamin D intake, the later the activity acrophase (fitted peak). A-TST was significantly negatively correlated with increased fat intake of several kinds, as well as forms of Vitamin E, which is usually found in fat. A-SEFF was significantly correlated with cholesterol and a trend was evidenced for Vitamin B12. Sleep diary variables were not significantly related to any dietary nutrient variables.

Napping Variables

Partial correlations with napping variables are also displayed in Table 2 and 3. A-NAPS was not significantly correlated with any dietary variable, but trends were found for some fat variables. S-NAPS, however, was significantly correlated with a number of variables, including many fat variables, a number of amino acids, water, cholesterol, and others.

DISCUSSION

The present study explored relationships among 88 dietary nutrient variables and measures of subjective sleep (sleep time, WASO), actigraphic sleep (sleep time, WASO, sleep efficiency, acrophase), and napping (subjective and actigraphic). Employing Type-I error control, the study yielded 49 significant correlations of 602. Most of the significant correlations were with subjective napping and actigraphic sleep time.

Sleep Acrophase is Positively Associated with Vitamin D

This study found a significant relationship between circadian phase of sleep and dietary Vitamin D intake. Later sleep acrophase, an indicator of sleep timing, was associated with more dietary Vitamin D. For most people, most Vitamin D is obtained through sunlight(44), though dietary Vitamin D is usually obtained through supplementation, usually in pills or in dairy products(44). It is currently unknown why those who consumed more Vitamin D would demonstrate a sleep phase delay, especially since in this same subject group, those exposed to more light had earlier circadian acrophases(45). Possibly, computed dietary Vitamin D intake may be correlated with dairy products intake, which in turn would be correlated with fat intake. Also, there may be other confounding variables unaccounted for which may explain this relationship, including the season of the year that data were collected.

Less Sleep was Associated with More Fat Intake

A number of previous studies have associated short sleep with obesity(1, 46), but these studies did not examine habitual diet. The present analyses approached this issue from a different direction - they demonstrated that those who slept less, as verified by actigraphy, consumed more fat. It was not the case that these individuals were simply more obese (analyses controlled for BMI), ate more (analyses controlled for total grams consumed), or were less likely to engage in physical activity (analyses controlled for moderate-strenuous physical activity). Additionally, it should be noted that many fat-related variables were significant, suggesting a pattern for overall fat intake, rather than fat related to specific foods. This relationship was not found in the subjective sleep data, suggesting that objective estimates of sleep continuity may

be required for future studies of sleep and diet and metabolism. Conceivably, short sleep causes high fat intake which then causes increased BMI, but it is also conceivable that high fat intake causes both short sleep and high BMI. It is also possible that short sleep affects leptin and ghrelin, which alters appetite and satiety. Further study of the causality is needed.

Recent evidence suggests that sleep is associated with synthesis of macromolecules (proteins, lipids, cholesterol and heme)(47). One way in which this may explain increased fat intake associated with reduced sleep is that it is conceivable that high intake of exogenous fats does not require synthesis of lipid and cholesterol macromolecules, which would decrease a signal for sleep. Both lipid and cholesterol are synthesized in the endoplasmic reticulum (ER). In addition, proteins are folded and post-translationally modified in the ER. High levels of synthetic activity lead to ER stress and protein misfolding. One of the ways the cell relieves ER stress is to decrease protein translation(48) through phosphorylation of eIF2 α by phosphorylated pancreatic ER kinase (P-PERK). It has been hypothesized that P-eIF2 α is a signal for sleep(49). Thus it is plausible that the increased fat intake through reduced lipid synthesis delays the phosphorylation of eIF2 α and hence the signal for sleep. On the other hand, obesity, which is often associated with increased fat intake (especially in the American population studied) may be associated with increased ER stress(50–52).

Another way in which increased fat intake could be associated with decreased sleep is through the mechanism of energy conservation. One of the hypotheses for the function of sleep is that it is time when energy stores are replenished(53). Increasing evidence suggests higher energy expenditure following protein ingestion as compared to carbohydrates or fat(54–58). If the energy expenditure following fat consumption is less than that for proteins, then it is possible that the need for sleep is reduced.

The relationship between short sleep duration and fat intake may explain the relationship between cholesterol and actigraphic sleep efficiency - perhaps cholesterol is preferentially associated with sleep disturbance in addition to sleep duration. While there is no present hypothesis for this relationship, it should be noted that genes regulating cholesterol metabolism have been previously shown to be activated during sleep relative to sleep deprivation(47), and sleep disruption may alter cholesterol metabolism, resulting in differences in cholesterol intake.

It should also be noted that a trend was evidenced for a negative association between sleep time and water intake, possibly because water intake is associated with sleep disruption due to its diuretic effects(59). Other possibilities would be that those with higher water intake include those with high intake of sweet liquids, leading to obesity. Caffeine, interestingly, was not associated with sleep duration (by shortening sleep) or timing (by delaying it).

Subjective Napping is Associated with intake of Fats (and Meat)

Objective estimates of napping were not significantly associated with any nutrient variables, but subjective perception of napping was associated with many. It should be noted that the largest number of relationships were seen with this variable, and these relationships represented those of the greatest magnitude. Nearly every fat-related variable was represented among the strongest correlations. Additionally, a number of other nutrients were related to subjective napping: amino acids, vitamins, minerals and others. Taken together, these nutrients (in addition to many of the fats) may reflect intake of meat. It is unclear whether ingestion of meat is itself associated with subjective napping or whether most fat content in the diet comes from meat or is at least associated with more intake of meat(60) and that these other nutrients are present because of their relationship to fats. If this were the case, however, they should have been present in the list of significant relationships with sleep duration, where many of the fat variables were prominently featured.

As actigraphic napping was unrelated to any variable and subjective napping was associated with most of the relationships and those of the highest magnitude, the data suggest that this difference reflects more than the well-known discrepancy between subjective and objective estimates of sleep(61). Rather, these two assessments may be measuring different constructs, with actigraphy measuring actual naps taken and subjective recollections serving as a proxy for subjective daytime sleepiness or fatigue, which was not measured directly in this group. Thus, future studies should examine subjective sleepiness in this context.

Limitations of the Study

This study suffers from some important limitations. First, the sample used for this study may be limited in its generalizability. While the sample was quite large, representing one of the largest samples ever collected that measured objectively-verified habitual sleep duration, it contained only women enrolled in the WHI, a study of postmenopausal women. This group had a restricted age range and did not include men.

A second limitation of this study is the Type-I error control employed. Although this study employed two separately-validated procedures(40–43) that arrived at the exact same study-wise α criterion, it is possible that the large number of comparisons requires stricter Type-I error control. Assuming the most conservative estimate using Bonferroni criteria ($\alpha=0.000083$), only the strongest correlations for subjective napping would still achieve significance. This, however, lends strength to these observations.

A third limitation of this study was that the FFQ may be a flawed measure of food intake (62), and even if it did measure intake, it did not address hunger and cravings, which have been previously associated with sleep loss(7). Future studies should measure actual food intake and these dimensions to obtain a clearer picture of the relationship between sleep and diet.

Finally, there are a number of other factors that may explain these relationships. For example, mental illness not addressed by affective diagnosis may impact both sleep and diet as well as attempts at weight loss and unexpected weight gain or loss, which were not measured in this study.

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Table 1

Baseline subject characteristics

Category	Variable	% of respondents
<i>Education</i>		
	Didn't go to school	0.2%
	Grade school (1–4 yrs)	0.9%
	Grade school (5–8 yrs)	0.9%
	Some high school	4.1%
	High school graduate	11.3%
	Vocational school	10.2%
	Some college or Associate Degree	35.7%
	College graduate or Baccalaureate Degree	12.4%
	Some college or professional school after	
	College graduation	12.0%
	Master's Degree	11.7%
	Doctoral Degree	0.7%
<i>Family Income</i>		
	< \$10,000	5.7%
	\$10,000–\$19,999	13.1%
	\$20,000–\$34,999	25.5%
	\$35,000–\$49,999	20.5%
	\$50,000–\$74,999	19.5%
	\$75,000–\$99,999	6.9%
	\$100,000–\$149,999	5.7%
	\$150,000 +	3.1%
<i>BMI</i>		
	Underweight(≤ 18.4)	2.9%
	Normal (18.5–26.9)	40.3%
	Overweight (27.0–29.9)	34.0%
	Obese (30.0–39.9)	19.6%
	Morbidly Obese (≥ 40.0)	3.2%

Table 2

Partial correlations between dietary nutrient variables and subjective and objective sleep and napping variable estimates.

Sleep Variable	Dietary Variable	r	P
<i>A-ACRO Sleep Acrophase (Actillum)</i>			
	Vitamin D (mcg)	0.161	0.0020
<i>A-TST Sleep Time (Actillum)</i>			
	Fat (g)	−0.185	0.0004
	Monounsaturated Fats (g)	−0.180	0.0005
	Trans Fatty Acid (g)	−0.174	0.0008
	Saturated Fatty Acids (g)	−0.171	0.0010
	Polyunsaturated Fats (g)	−0.168	0.0012
	Energy (Kcal)	−0.162	0.0019
	Gamma-Tocopherol (mg)	−0.157	0.0025
	Cholesterol (mg)	−0.157	0.0025
	Alpha-Toc Eq (mg)	−0.153	0.0032
	% Calories From Fat	−0.143	0.0060*
	Delta-Tocopherol (mg)	−0.140	0.0071*
	Water (g)	0.137	0.0084*
<i>A-SEFF Sleep Efficiency (Actillum)</i>			
	Cholesterol (mg)	−0.168	0.0012
	Vitamin B12 (mcg)	−0.147	0.0046*
<i>A-NAPS Napping (Actillum)</i>			
	Vitamin K (Nds Value) (mg)	0.141	0.0067*
	Trans Fatty Acid (g)	0.136	0.0088*
	Polyunsaturated Fatty Acids (g)	0.136	0.0092*
	% Calories Polyunsaturated Fat	0.134	0.0099*

All partial correlations adjusted for age, income, education, total dietary gram amount, BMI, and minutes of moderate-strenuous physical activity.

* These correlations are nominally significant at the $p < .01$ level but did not meet the study wise significance criterion of $p \leq .004$.

Table 3

Partial correlations between dietary nutrient variables and subjective sleep and napping.

Sleep Variable	Dietary Variable	r	P
<i>S-TST Hours Of Sleep (Subjective)</i>			
	% Calories From Protein	0.139	0.0076*
<i>S-WASO WASO (Subjective)</i>			
	Daily Vegetable Consumption	0.139	0.0075*
<i>S-NAPS Napping (Subjective)</i>			
	Fat (g)	0.241	0.000003
	Energy (Kcal)	0.238	0.000004
	Saturated Fatty Acids (g)	0.237	0.000004
	Monounsaturated Fats (g)	0.231	0.00001
	Trans Fatty Acid (g)	0.230	0.00001
	Water (g)	-0.226	0.00001
	Proline (g)	0.218	0.00003
	Serine (g)	0.217	0.00003
	Tyrosine (g)	0.215	0.00003
	Phenylalanine (g)	0.213	0.00004
	Valine (g)	0.209	0.00005
	Cholesterol (mg)	0.207	0.00006
	Leucine (g)	0.206	0.00007
	Glutamic Acid (g)	0.205	0.00007
	Ash (g)	0.205	0.00007
	Isoleucine (g)	0.204	0.00008
	Histidine (g)	0.203	0.00009
	Sodium (mg)	0.203	0.00009
	Tryptophan (g)	0.203	0.00009
	Protein (g)	0.200	0.0001
	Threonine (g)	0.200	0.0001
	Cystine (g)	0.200	0.0001
	Methionine (g)	0.196	0.0002
	Phosphorous (mg)	0.195	0.0002
	Polyunsaturated Fats (g)	0.194	0.0002
	Animal Protein (g)	0.191	0.0002
	Aspartic Acid (g)	0.190	0.0002
	Arginine (g)	0.190	0.0002
	Lysine (g)	0.190	0.0003
	Alanine (g)	0.184	0.0004
	Caffeine (mg)	-0.179	0.0006

Sleep Variable	Dietary Variable	r	P
	Riboflavin (mg)	0.179	0.0006
	Gamma-Tocopherol (mg)	0.170	0.0010
	Glycine (g)	0.169	0.0011
	Retinol (mcg)	0.169	0.0012
	Delta-Tocopherol (mg)	0.162	0.0019
	Vitamin D (mcg)	0.161	0.0020
	Selenium (mcg)	0.158	0.0024
	% Calories From Fat	0.148	0.0044 *
	Alpha-Toc Eq (mg)	0.146	0.0051 *
	Carbohydrate (g)	0.140	0.0070 *
	Sucrose (g)	0.137	0.0083 *

All partial correlations adjusted for age, income, education, total dietary gram amount, BMI, and minutes of moderate-strenuous physical activity.

* These correlations are nominally significant at the $p < .01$ level but did not meet the study wise significance criterion of $p \leq .004$.