High glycemic index and glycemic load diets as risk factors for insomnia: analyses from the Women's Health Initiative

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ABSTRACT

Background: Previous studies have shown mixed results on the association between carbohydrate intake and insomnia. However, any influence that refined carbohydrates have on risk of insomnia is likely commensurate with their relative contribution to the overall diet, so studies are needed that measure overall dietary glycemic index (GI), glycemic load, and intakes of specific types of carbohydrates.

Objective: We hypothesized that higher GI and glycemic load would be associated with greater odds of insomnia prevalence and incidence.

Methods: This was a prospective cohort study with postmenopausal women who participated in the Women's Health Initiative Observational Study, investigating the relations of GI, glycemic load, other carbohydrate measures (added sugars, starch, total carbohydrate), dietary fiber, and specific carbohydrate-containing foods (whole grains, nonwhole/refined grains, nonjuice fruits, vegetables, dairy products) with odds of insomnia at baseline (between 1994 and 1998; $n = 77{,}860$) and after 3 y of follow-up (between 1997 and 2001; $n = 53{,}069$).

Results: In cross-sectional and longitudinal analyses, higher dietary GI was associated with increasing odds of prevalent (fifth compared with first quintile OR: 1.11; CI: 1.05, 1.16; P-trend $= 0.0014$) and incident (fifth compared with first quintile OR: 1.16; CI: 1.08, 1.25; P-trend < 0.0001) insomnia in fully adjusted models. Higher intakes of dietary added sugars, starch, and nonwhole/refined grains were each associated with higher odds of incident insomnia. By contrast, higher nonjuice fruit and vegetable intakes were significantly associated with lower odds of incident insomnia. Also, higher intakes of dietary fiber, whole grains, nonjuice fruit, and vegetables were significantly associated with lower odds of prevalent insomnia.

Conclusions: The results suggest that high-GI diets could be a risk factor for insomnia in postmenopausal women. Substitution of high-GI foods with minimally processed, whole, fiber-rich carbohydrates should be evaluated as potential treatments of, and primary preventive measures for, insomnia in postmenopausal women. *Am J Clin Nutr* 2020;111:429–439.

Keywords: insomnia, glycemic index, glycemic load, epidemiology, postmenopausal women

Introduction

Insomnia has high personal, societal, and financial costs and disproportionately affects women. It is associated with automobile accidents, problems with work performance, decreased quality of life, and increased medical and psychiatric comorbidities (1). The annual expenses from insomnia due to direct medical costs, lost productivity, accidents, and

Supported by NIH National Heart, Lung, and Blood Institute (NHLBI) grant R01HL128226 (to M-PS-O). The WHI program is funded by the NHLBI, NIH, US Department of Health and Human Services through contracts HHSN268201600018C, HHSN268201600001C, HHSN268201600002C, HHSN268201600003C, and HHSN268201600004C.

Supplemental Figure 1 is available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

Data described in the article, code book, and analytic code will be made available upon request pending application and approval.

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Abbreviations used: GI, glycemic index; MET, metabolic equivalent; WHI, Women's Health Initiative; WHIIRS, Women's Health Initiative Insomnia Rating Scale.

Received July 16, 2019. Accepted for publication October 10, 2019.

First published online December 11, 2019; doi: https://doi.org/10.1093/ajcn/nqz275.

insomnia-related depression and alcohol abuse have been estimated to be $150–175 billion in 2016 dollars (2).

Cognitive behavioral therapy and pharmacotherapy are widely accepted treatments of insomnia, yet psychotherapy can be time-consuming and expensive and pharmacotherapy with sedative hypnotics can increase the risk of adverse cognitive and psychomotor events and daytime fatigue (3). It is therefore beneficial to identify novel risk factors for insomnia that could suggest straightforward and low-cost interventions with fewer potential iatrogenic effects.

The relation between diet and sleep is an emerging area of inquiry, with macronutrients and carbohydrate intake having recently been explored (4); however, previous studies have yielded inconsistent findings. Two cross-sectional studies found low carbohydrate intakes in subjects with insomnia symptoms (5, 6), whereas another cross-sectional study of middle-aged female Japanese workers found increased consumption of confectionary to be significantly associated with poor sleep quality (7). There was a significant trend toward worse sleep quality with increasing carbohydrate intake. Further, participants with poor sleep quality had the highest carbohydrate intake and consumed more confectionary and less rice. The authors therefore hypothesized that both the total amount of carbohydrate and the glycemic index (GI) of the carbohydrates consumed could affect sleep quality. However, because these studies were cross-sectional, and given that the relation between carbohydrate consumption and insomnia could be bidirectional, prospective studies are needed to further examine this association.

Any influence that refined carbohydrates have on insomnia is likely commensurate with the proportion of the overall diet they constitute, so dietary GI and glycemic load are good measures to evaluate the quality and quantity of carbohydrate intake. An experimental study in young 18- to 35-y-old men with random assignment to a high-GI carbohydrate meal 4 h before bedtime showed a significantly shortened sleep onset latency compared with a low-GI meal (8). A limitation of this experimental study was its small sample size and short duration. Longitudinal epidemiologic studies can enhance causal inference by establishing the temporal order of variables, incorporating longer durations, and including larger sample sizes that allow for the control of more factors. To our knowledge, there are no current prospective epidemiologic studies examining the relation between GI and glycemic load and subsequent insomnia.

The Women's Health Initiative (WHI) Observational Study of postmenopausal women provides a unique opportunity to explore the association between dietary GI and glycemic load and insomnia. We hypothesized that higher GI and glycemic load were associated with greater odds of prevalent and incident insomnia in a large, well-characterized sample of postmenopausal women who were followed longitudinally.

Methods

The WHI Observational Study includes a socioeconomically and racially/ethnically diverse cohort of 93,676 postmenopausal women between the ages of 50 and 79 y from 40 clinical centers in 24 states and the District of Columbia recruited between 1 September, 1994 and 31 December, 1998 (9). Women were excluded if they did not plan on residing in the area for $\geq$3 y, had a life expectancy of <3 y, or suffered from substance abuse, mental illness, or dementia. We conducted cross-sectional analyses so our results could be compared with other cross-sectional studies (5–7). Because the relation between diet and insomnia could be bidirectional, we also conducted longitudinal analyses, excluding baseline insomnia, to better explore a potential cause–effect relation. The cross-sectional analyses for this study included women who completed the food questionnaire and Women's Health Initiative Insomnia Rating Scale (WHIIRS) at baseline (n = 77,860). Persons with insomnia at baseline were excluded from the longitudinal analyses, which included women who completed the food questionnaire at baseline and the WHIIRS after 3 y of follow-up (n = 53,069). **Supplemental Figure 1** shows a flow diagram of the study participants. All participants provided informed consent with documents approved by institutional review boards at all 40 study sites across the United States. This study was approved by the institutional review board of Columbia University/New York State Psychiatric Institute.

Ascertainment of dietary variables

At baseline, participants completed a 145-item FFQ designed for the WHI. The dietary variables were computed from mean daily intake of foods and beverages reported on the WHI FFQ. Data from 113 women screened for participation in the WHI were used to test the reliability and validity of the WHI FFQ (10). The mean energy-adjusted correlation coefficient between 30 nutrient estimates from the FFQ and the means from four 24-h dietary recalls and a 4-d food record was 0.50. The energy-adjusted de-attenuated correlation coefficient between carbohydrate intake estimated by the WHI FFQ and 8 d of dietary intake was 0.63 and for fiber 0.65. Test–retest reliability for the nutrient intake estimates between the first and second administrations of the WHI FFQ was high, with mean intraclass correlation coefficients of 0.76.

GI was defined as an index of the postprandial glucose response of a food, compared with an equal amount of carbohydrate (50 g) from a reference food, typically glucose or white bread (11, 12). The GI variable in the WHI was applied to available carbohydrate (total carbohydrate less dietary fiber) with glucose being used as the reference food. The GI of a specific food is equal to the blood glucose incremental AUC of the test food for a given time postconsumption divided by the blood glucose incremental AUC of the reference food multiplied by 100. Dietary GI is considered a measure of the quality of carbohydrate-based foods in the overall diet and is estimated as the weighted mean (with weights based on the total carbohydrate content per serving consumed) of the GI values of all carbohydrate foods consumed during the dietary period. The glycemic load of a food is equal to its GI multiplied by the total grams of carbohydrate per serving divided by 100. Dietary glycemic load is estimated as the sum of the glycemic loads of all carbohydrate foods consumed during the dietary period unadjusted for energy intake. The methodology used to construct the GI and glycemic load database for the WHI was detailed previously (11).

Although the exposures of interest were GI and glycemic load, we also examined other measures of carbohydrate consumption computed from mean daily intake of foods and beverages reported on the WHI FFQ, including dietary added sugar, total

sugars, starch, and total carbohydrate. The USDA's MyPyramid Equivalents Database 2.0 (13) was used to assess added sugars used as ingredients in processed and prepared foods such as cakes, breads, sodas, jellies, chocolates, and ice cream, and sugars eaten separately or added to foods at the table. Examples of added sugars include white sugar, brown sugar, raw sugar, corn syrup, corn syrup solids, high-fructose corn syrup, malt syrup, maple syrup, pancake syrup, fructose sweetener, honey, molasses, anhydrous dextrose, and dextrin. Added sugars do not include naturally occurring sugars such as fructose in fruit or lactose in milk, unless the sugar is added to the food item. The percentage total sugar content of foods is used to estimate gram equivalents of added sugars in caloric sweeteners. The number of added sugars equivalents for each sweetener ingredient in a multi-ingredient food is calculated using the recipe retention factor method (14) and then totaled: total sugars in the sweetener ingredient in 100 g of a multi-ingredient food (grams) = [weight of sweetener ingredient in 100 grams of food × (total sugars in 100 g ingredient/100) × (% retention)]/100% + (%moisture change) + (%fat change).

Dietary fiber and specific carbohydrate-containing foods (whole grains, nonwhole/refined grains, nonjuice fruits, vegetables, and dairy products) were also considered. Dietary fiber and specific types and sources of carbohydrates were categorized into quintiles for analyses.

Ascertainment of insomnia

The presence of insomnia was measured at baseline and at 3-y follow-up using participant responses to the WHIIRS, a 5-item instrument that has been found to be a reliable and valid measure of perceived insomnia symptoms. The construct validity of the WHIIRS was supported by successfully detecting self-reported sleep disturbance differences in women taking hormone therapy compared with those taking a placebo as well as in groups known to differ in severity of their vasomotor symptoms (15). The WHIIRS was found to have a highly stable factor structure with no major differences across age, race, and ethnicity groups (16). A score of ≥9 indicates a high risk of insomnia and the need for further clinical evaluation (17). We refer to a score of ≥9 on the WHIIRS as insomnia throughout the article.

Covariates

We chose as covariates for our multivariable models variables theorized to vary by diet and by insomnia and which therefore could act as confounders or mediators of the relation between the dietary variables and insomnia. Covariates in the analyses included age (5-y interval); race/ethnicity (American Indian/Alaskan Native, Asian/Pacific Islander, black, Hispanic, white not of Hispanic origin, missing); education (less than high school graduate, high school graduate, some college, college graduate, postgraduate, missing); annual income (<$10,000, $10K–19,999, $20K–34,999, $35K–49,999, $50K–74,999, $75K–99,999, $100K–149,999, ≥$150,000, don't know, missing); live alone (no, yes, missing); live with husband or partner (no, yes, missing); live with children (no, yes, missing); smoking status (never smoked, past smoker, current smoker, missing); alcohol intake (nondrinking, past drinker, <1 drink/mo, <1 drink/wk, 1 to <7 drinks/wk, ≥7 drinks/wk, missing); caffeine intake (quintiles); stressful life events (quintiles, missing); social support (quintiles, missing); depression (no, yes, missing); physical activity measured in metabolic equivalent (MET)-hours per week [<3, 3 to <9, 9 to <18, 18 to <27, ≥27 MET-h/wk (1 MET = 58.2 W/m^2), missing]; BMI (in kg/m^2) (underweight: <18.5; normal: 18.5–24.9; overweight: 25.0–29.9; obesity I: 30.0–34.9; obesity II: 35.0–39.9; obesity III: ≥40; missing); diabetes (no, yes, missing); hypertension (no, yes, missing); myocardial infarction (no, yes, missing); cardiovascular disease (no, yes, missing); asthma (no, yes, missing); overactive thyroid (no, yes, missing); bodily pain (none, very mild, mild, moderate, severe, missing); hot flashes (none, mild, moderate, severe, missing); hormone replacement therapy (no, yes, missing); and snoring (not in past 4 wk, less than once a week, 1 or 2 times/wk, 3 or 4 times/wk, ≥5 times/wk, don't know, missing).

Statistical analyses

Chi-square tests for categorical variables and *t* tests for continuous variables were used to evaluate differences by insomnia and by GI quintiles. Multivariable logistic regression was used to calculate ORs to examine the cross-sectional relation between the dietary variables and insomnia prevalence. Persons with insomnia at baseline were excluded from the longitudinal analyses. The longitudinal relation between dietary variables and incident insomnia after 3 y was examined using multivariable logistic regression to calculate energy-adjusted ORs. We adjusted for total energy intake because it can be associated with disease risk owing to differences in physical activity, body size, and metabolic efficiency. In addition, specific nutrients contribute toward total energy intake and individuals who consume more total energy also tend to eat more specific nutrients. The energy partition model (18) was used to adjust for energy consumption (Model 1) in analyses of dietary GI, glycemic load, added sugars, total sugars, starch, and total carbohydrate. Glycemic

TABLE 1 Baseline characteristics by dietary GI quintile and incidence of insomnia 3 y later, continuous variables[1]

	Dietary GI quintiles						Incident insomnia 3 y later		
Baseline characteristics	1 (Low)	2	3	4	5 (High)	P^2	Yes	No	P^2
Mean insomnia WHIIRS	5.064 ± 3.66	5.263 ± 3.70	5.296 ± 3.63	5.413 ± 3.73	5.501 ± 3.80	<0.0001	11.278 ± 2.36	3.957 ± 2.39	<0.0001
Age, y	63.77 ± 7.3	63.56 ± 7.3	63.48 ± 7.3	63.32 ± 7.3	62.63 ± 7.2	<0.0001	63.39 ± 7.3	63.35 ± 7.3	0.5837
BMI, kg/m^2	26.41 ± 5.3	26.46 ± 5.4	26.78 ± 5.5	27.13 ± 5.7	27.77 ± 6.1	<0.0001	27.36 ± 5.9	26.81 ± 5.6	<0.0001
Physical activity, MET-h/wk	17.72 ± 16.0	16.06 ± 14.8	14.71 ± 14.3	13.27 ± 13.7	11.10 ± 13.0	<0.0001	13.57 ± 14.1	14.80 ± 14.7	<0.0001

[1] Values are means ± SDs unless stated otherwise. GI, glycemic index; MET, metabolic equivalent; WHIIRS, Women's Health Initiative Insomnia Rating Scale.
[2] Differences by insomnia and GI quintiles were tested with *t* tests for continuous variables.

TABLE 2 Baseline characteristics by dietary GI quintile and incidence of insomnia 3 y later, categorical variables[1]

		Dietary GI quintiles						Incident insomnia 3 y later		
Baseline characteristics	*n*	1 (Low)	2	3	4	5 (High)	P^2	Yes	No	P^2
Total *n*	53,069	10,613	10,614	10,614	10,614	10,614		9783	43,286	
Insomnia *n*	9783	1728	1924	1943	2065	2123	<0.0001	9783	43,286	
Median GI		47.0	49.8	51.7	53.5	56.3				
Race/ethnicity, %							<0.0001			0.0079
American Indian/Alaskan Native	730	1.4	1.4	1.2	1.3	1.6		1.4	1.4	
Asian/Pacific Islander	1653	2.3	3.1	3.8	3.7	2.6		2.5	3.3	
Black	3474	4.7	4.3	5.4	6.8	11.6		6.3	6.6	
Hispanic	1543	3.5	2.9	2.7	2.9	2.5		3.0	3.0	
White not of Hispanic origin	45,528	87.7	87.9	86.8	85.1	81.4		86.5	85.6	
Missing race/ethnicity	141	0.3	0.3	0.2	0.3	0.3		0.3	0.3	
Education ≥college grad, %	24,350	52.8	50.4	47.9	43.2	35.2	<0.0001	42.4	46.7	<0.0001
Annual income ≥$50,000, %	21,941	48.0	45.7	43.8	41.1	36.7	<0.0001	40.5	43.7	<0.0001
Live alone, %	14,040	28.7	27.5	26.2	25.2	24.7	<0.0001	25.8	26.6	0.1680
Live with husband or partner, %	33,934	62.8	64.1	64.7	64.8	63.4	0.0003	65.3	63.6	0.0060
Live with children, %	5403	8.3	8.9	9.6	11.5	12.7	<0.0001	10.3	10.2	0.9117
Smoking status, %							<0.0001			<0.0001
Never smoked	27,042	48.5	51.6	52.4	52.2	50.5		48.6	51.5	
Past smoker	22,429	45.6	43.0	41.7	40.6	40.5		44.3	41.8	
Current smoker	2993	4.6	4.4	5.1	6.2	7.8		5.8	5.6	
Missing smoking	605	1.4	1.0	1.2	1.0	1.2		1.3	1.1	
Alcohol intake, %							<0.0001			<0.0001
Nondrinker	5428	7.9	8.2	9.7	11.1	14.1		9.7	10.3	
Past drinker	9010	15.6	14.8	16.0	17.7	20.8		18.5	16.6	
<1 drink/mo	6108	9.5	10.0	11.5	11.8	14.7		12.0	11.4	
<1 drink/wk	10,820	19.3	20.8	20.4	21.1	20.3		20.4	20.4	
1 to <7/wk	14,393	28.7	30.7	29.0	26.6	20.7		26.1	27.4	
≥7/wk	7061	18.3	15.0	13.1	11.3	8.8		12.8	13.4	
Missing alcohol	249	0.6	0.5	0.4	0.5	0.5		0.5	0.5	
Caffeine, %							<0.0001			0.2737
Quintile 1	10,613	21.5	19.8	19.6	19.5	19.5		20.0	20.0	
Quintile 2	10,614	20.5	20.6	20.2	20.0	18.7		20.1	20.0	
Quintile 3	10,615	23.8	21.0	18.9	18.2	18.2		19.7	20.1	
Quintile 4	10,613	13.5	19.3	21.7	22.4	23.0		20.7	19.8	
Quintile 5	10,614	20.7	19.3	19.5	20.0	20.5		19.5	20.1	
Stressful life events, %							<0.0001			<0.0001
Quintile 1	15,361	29.8	29.6	29.4	28.5	27.5		23.6	30.2	
Quintile 2	6792	12.8	13.2	13.1	12.9	12.0		10.2	13.4	
Quintile 3	8902	16.2	17.0	17.0	16.9	16.7		15.9	17.0	
Quintile 4	11,684	21.8	22.2	21.4	22.3	22.3		23.6	21.7	
Quintile 5	9396	17.4	16.5	17.1	17.5	20.0		25.1	16.0	
Missing stressful life events	934	1.9	1.6	2.0	1.9	1.4		1.7	1.8	
Social support, %							<0.0001			<0.0001
Quintile 1	10,969	20.0	19.6	20.8	20.6	22.3		25.3	19.6	
Quintile 2	10,924	20.4	20.9	20.6	20.8	20.2		21.7	20.3	
Quintile 3	10,362	19.0	20.2	19.6	19.5	19.3		18.0	20.0	
Quintile 4	10,552	20.4	20.2	19.4	20.2	19.2		18.5	20.2	
Quintile 5	9169	18.2	16.9	17.7	16.8	16.7		14.5	17.9	
Missing social support	1093	2.0	2.1	1.9	2.0	2.4		2.0	2.1	
Depression, %	3285	5.3	5.6	6.3	6.4	7.5	<0.0001	9.5	5.4	<0.0001
Diabetes, %	2375	4.4	4.4	4.3	4.6	4.7	0.9285	4.9	4.4	0.0296
Hypertension, %	16,104	28.1	28.8	30.6	31.3	32.9	<0.0001	32.9	30.0	<0.0001
Myocardial infarction, %	1051	1.9	1.6	1.8	2.2	2.4	0.0001	2.5	1.9	0.0004
Cardiovascular disease, %	8951	16.5	16.7	17.0	17.0	17.3	0.2214	19.6	16.3	<0.0001
Asthma, %	3829	7.4	7.0	7.2	7.0	7.6	0.4081	8.8	6.9	<0.0001
Overactive thyroid, %	1447	2.4	2.6	2.7	2.8	3.2	<0.0001	3.0	2.7	<0.0001
Bodily pain, %							<0.0001			<0.0001
None	11,894	25.1	23.0	22.3	21.2	20.4		13.7	24.4	
Very mild	20,967	39.8	40.4	39.8	39.5	38.0		33.7	40.8	
Mild	10,321	18.0	19.3	19.4	20.3	20.3		23.0	18.7	
Moderate	8254	14.3	14.3	15.4	15.9	18.0		23.4	13.8	
Severe	1534	2.7	2.8	2.9	2.9	3.2		6.2	2.2	
Missing bodily pain	99	0.2	0.2	0.1	0.2	0.2		0.1	0.2	
Hot flashes, %							<0.0001			<0.0001
None	42,764	82.7	83.0	80.8	79.7	76.9		77.4	81.3	
Mild	7889	13.5	13.7	14.7	15.3	17.1		16.5	14.5	
Moderate	1892	2.9	2.7	3.5	3.9	4.8		4.6	3.3	
Severe	381	0.6	0.5	0.7	0.7	1.0		1.2	0.6	
Missing hot flashes	143	0.3	0.2	0.3	0.4	0.2		0.3	0.3	

(*Continued*)

TABLE 2 (*Continued*)

Baseline characteristics	*n*	Dietary GI quintiles						Incident insomnia 3 y later		
		1 (Low)	2	3	4	5 (High)	P^2	Yes	No	P^2
Hormone replacement therapy, %	26,509	51.1	52.3	50.5	49.2	46.7	<0.0001	50.9	49.8	<0.0001
Snoring, %							<0.0001			<0.0001
Not in past 4 wk	12,712	26.8	24.7	24.4	23.0	20.8		22.5	24.3	
Less than once a week	2722	5.6	5.1	4.9	5.0	5.0		5.2	5.1	
1 or 2 times/wk	3282	6.0	5.9	6.6	6.4	6.1		5.9	6.3	
3 or 4 times/wk	2574	4.3	4.9	4.8	5.2	5.1		5.1	4.8	
≥5 times/wk	4792	7.6	7.8	8.5	9.9	11.4		10.3	8.7	
Don't know	26,806	49.3	51.4	50.6	50.2	51.1		50.6	50.5	
Missing snoring	181	0.4	0.3	0.3	0.3	0.4		0.4	0.3	

[1]GI, glycemic index.
[2]Differences by depression and GI quintiles were tested with chi-square (χ^2) tests for categorical variables.

load, added sugars, total sugars, starch, and total carbohydrate are macronutrients that are highly collinear with total calories. The energy partition model allows the examination of the separate effects of calories and macronutrients by subtracting the macronutrient calories from the total calories, therefore creating a variable that is less highly correlated with the macronutrient. In the energy partition model, the primary nutrient coefficient is included as 1 term and energy from other nutrients is included as a second term in the multivariate models. It was not possible to precisely measure the number of calories in each increment of fiber, whole grains, nonwhole/refined grains, nonjuice fruit, vegetables, and dairy products, which would have been required to use the energy partition model. Also, these foods make up a smaller proportion of the overall diet and therefore are not highly collinear with total calories. The nutrient density model (19) was therefore used to adjust for energy consumption (Model 1) in analyses of fiber, whole grains, nonwhole/refined grains, nonjuice fruit, vegetables, and dairy products. In the nutrient density model, nutrient densities are computed by dividing nutrient values by total caloric intake and then included with total caloric intake in the multivariable models. To explore potential attenuation in the ORs from controlling for different types of covariates, we included variables in Model 2 that could act as confounders and included variables in Model 3 that could act as mediators. Covariates in the first multivariable-adjusted model (Model 2) included age, race/ethnicity, education, income, smoking, alcohol, caffeine, stressful life events, social support, overactive thyroid, bodily pain, hormone replacement therapy, and snoring. The final adjusted model (Model 3) included the variables in Model 2, plus depression, physical activity, BMI, diabetes, hypertension, myocardial infarction, cardiovascular disease, asthma, and hot flashes. Stratified analyses were conducted to explore interaction by physical activity. Tests for linear trend were performed by modeling a numeric value (−2, −1, 0, 1, 2) for each dietary quintile category.

Results are reported as ORs and 95% CIs. P values < 0.05 were considered statistically significant. Statistical analyses were conducted using SAS statistical software version 9.4 (SAS Institute).

Results

The baseline characteristics for women in the WHI Observational Study population according to their GI quintile, based on available carbohydrate, and incidence of insomnia after 3 y of follow-up are shown in **Tables 1** and **2**. Higher GI was associated with younger age, higher BMI, and less physical activity. Higher GI was also associated with African ancestry, lower education, lower income, not living alone, living with husband or partner, living with children, smoking, abstinence from alcohol, caffeine consumption, more stressful life events, less social support, depression, hypertension, myocardial infarction, overactive thyroid, bodily pain, hot flashes, not receiving hormone replacement therapy, and snoring. Insomnia was associated with higher GI quintiles, higher BMI, and less physical activity. Insomnia was also associated with white race/ethnicity, lower education, lower income, living with husband or partner, past and current smoking, more stressful life events, less social support, depression, diabetes, hypertension, myocardial infarction, cardiovascular disease, asthma, overactive thyroid, bodily pain, hot flashes, hormone replacement therapy, and snoring.

Table 3 shows the results from the cross-sectional multivariable analyses at the baseline visit (n = 77,860). In energy-adjusted results (Model 1), participants whose dietary GIs were in the third, fourth, and fifth quintiles reported significantly more insomnia than the participants in the first quintile. The inclusion of variables in Models 2 and 3 progressively attenuated the associations, resulting in only the fifth quintile for GI being significantly associated with insomnia. The test for trend was statistically significant for all 3 models. As the consumption of dietary added sugars and nonwhole/refined grains increased, the likelihood of experiencing co-occurring insomnia was greater with the trends being statistically significant. The odds of insomnia prevalence were lower with higher consumption of dietary fiber, whole grains, nonjuice fruit, and vegetables and the trends were statistically significant. There were no associations of glycemic load, dietary total sugars, starch, total carbohydrate, or dairy products with insomnia prevalence. Physical activity was not found to act as an effect modifier in stratified analyses.

The results from the 3-y longitudinal multivariable analyses (n = 53,069) are shown in **Table 4**. Subjects with higher dietary GI and glycemic load and higher consumption of added sugars, starch, and nonwhole/refined grains were more likely to have insomnia after 3 y in energy-adjusted analyses (Model 1). Although the results were slightly attenuated by the variables in Models 2 and 3, women in the higher dietary GI, added sugars, and starch quintiles remained significantly more likely to have insomnia after 3 y with significant tests for linear trend

TABLE 3 Adjusted ORs and 95% CIs from logistic regression analyses of insomnia prevalence according to quintiles of energy-adjusted GI, glycemic load, carbohydrate consumption, fiber, whole grains, nonwhole/refined grains, nonjuice fruit, vegetables, and dairy products[1]

	Median	Prevalent insomnia at baseline, *n*	Prevalent insomnia at baseline, OR (95% CI)		
			Model 1	Model 2	Model 3
Dietary GI					
Quintile 1	47.1	4478	1.00	1.00	1.00
Quintile 2	49.9	4667	1.05 (1.00, 1.10)	1.04 (0.99, 1.09)	1.03 (0.98, 1.09)
Quintile 3	51.7	4785	1.08 (1.03, 1.13)	1.06 (1.01, 1.11)	1.04 (0.99, 1.10)
Quintile 4	53.6	4835	1.09 (1.04, 1.14)	1.05 (0.99, 1.10)	1.02 (0.97, 1.08)
Quintile 5	56.4	5257	1.23 (1.17, 1.29)	1.14 (1.08, 1.20)	1.11 (1.05, 1.16)
P-trend			$P < 0.0001$	$P < 0.0001$	$P = 0.0014$
Dietary glycemic load, g/d					
Quintile 1	53.8	4647	1.00	1.00	1.00
Quintile 2	74.9	4611	0.94 (0.90, 0.99)	0.98 (0.93, 1.03)	0.99 (0.94, 1.04)
Quintile 3	92.3	4817	0.96 (0.91, 1.01)	1.02 (0.97, 1.08)	1.03 (0.98, 1.09)
Quintile 4	112.0	4848	0.93 (0.88, 0.98)	0.99 (0.94, 1.05)	1.01 (0.95, 1.06)
Quintile 5	147.5	5099	0.94 (0.89, 0.99)	1.00 (0.95, 1.07)	1.01 (0.95, 1.07)
P-trend			$P = 0.0272$	$P = 0.7506$	$P = 0.5603$
Dietary added sugar, g					
Quintile 1	17.9	4436	1.00	1.00	1.00
Quintile 2	29.0	4709	1.06 (1.01, 1.12)	1.07 (1.01, 1.12)	1.07 (1.02, 1.13)
Quintile 3	39.6	4815	1.07 (1.02, 1.13)	1.08 (1.03, 1.14)	1.09 (1.03, 1.15)
Quintile 4	53.1	4882	1.07 (1.01, 1.13)	1.07 (1.01, 1.13)	1.07 (1.01, 1.13)
Quintile 5	80.5	5180	1.13 (1.07, 1.20)	1.10 (1.04, 1.17)	1.09 (1.03, 1.16)
P-trend			$P < 0.0001$	$P = 0.0051$	$P = 0.0182$
Dietary total sugars, g					
Quintile 1	50.4	4795	1.00	1.00	1.00
Quintile 2	73.8	4784	0.96 (0.91, 1.01)	0.99 (0.94, 1.04)	1.00 (0.95, 1.05)
Quintile 3	93.4	4735	0.91 (0.87, 0.96)	0.96 (0.91, 1.01)	0.97 (0.92, 1.02)
Quintile 4	116.0	4749	0.88 (0.84, 0.93)	0.94 (0.89, 0.99)	0.95 (0.90, 1.01)
Quintile 5	156.1	4959	0.89 (0.84, 0.94)	0.94 (0.89, 0.99)	0.95 (0.90, 1.01)
P-trend			$P < 0.0001$	$P = 0.0075$	$P = 0.0277$
Dietary starch, g					
Quintile 1	38.4	4586	1.00	1.00	1.00
Quintile 2	56.1	4627	0.97 (0.92, 1.02)	1.00 (0.95, 1.05)	1.01 (0.95, 1.06)
Quintile 3	70.8	4775	0.98 (0.93, 1.03)	1.02 (0.97, 1.08)	1.03 (0.97, 1.09)
Quintile 4	88.5	4950	0.99 (0.93, 1.04)	1.05 (0.99, 1.11)	1.06 (1.00, 1.12)
Quintile 5	120.3	5084	0.97 (0.91, 1.03)	1.04 (0.97, 1.11)	1.04 (0.98, 1.11)
P-trend			$P = 0.5039$	$P = 0.1206$	$P = 0.0831$
Dietary total carbohydrate, g					
Quintile 1	115.0	4677	1.00	1.00	1.00
Quintile 2	158.5	4734	0.96 (0.92, 1.01)	1.00 (0.95, 1.06)	1.01 (0.96, 1.06)
Quintile 3	193.7	4736	0.92 (0.88, 0.97)	0.99 (0.94, 1.05)	1.00 (0.95, 1.06)
Quintile 4	233.6	4882	0.92 (0.88, 0.97)	1.00 (0.95, 1.06)	1.02 (0.96, 1.08)
Quintile 5	303.6	4993	0.89 (0.84, 0.94)	0.97 (0.92, 1.03)	0.99 (0.93, 1.05)
P-trend			$P < 0.0001$	$P = 0.4432$	$P = 0.8248$
Fiber, g					
Quintile 1	10.6	5404	1.00	1.00	1.00
Quintile 2	13.7	5045	0.91 (0.87, 0.96)	0.96 (0.92, 1.01)	0.97 (0.92, 1.02)
Quintile 3	15.9	4754	0.85 (0.81, 0.89)	0.92 (0.88, 0.97)	0.93 (0.88, 0.98)
Quintile 4	18.2	4575	0.81 (0.77, 0.85)	0.90 (0.86, 0.95)	0.92 (0.87, 0.97)
Quintile 5	21.1	4244	0.74 (0.71, 0.78)	0.84 (0.80, 0.89)	0.87 (0.82, 0.92)
P-trend			$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
Whole grains, oz					
Quintile 1	0.24	5095	1.00	1.00	1.00
Quintile 2	0.68	4945	0.95 (0.90, 0.99)	0.98 (0.93, 1.03)	0.99 (0.94, 1.04)
Quintile 3	1.06	4811	0.91 (0.87, 0.96)	0.96 (0.92, 1.01)	0.98 (0.93, 1.03)
Quintile 4	1.47	4633	0.87 (0.83, 0.92)	0.93 (0.88, 0.98)	0.95 (0.90, 1.00)
Quintile 5	2.29	4538	0.85 (0.81, 0.89)	0.91 (0.86, 0.95)	0.93 (0.88, 0.98)
P-trend			$P < 0.0001$	$P < 0.0001$	$P = 0.0010$
Nonwhole/refined grains, oz					
Quintile 1	1.73	4572	1.00	1.00	1.00
Quintile 2	2.64	4762	1.04 (0.99, 1.10)	1.06 (1.00, 1.11)	1.06 (1.01, 1.12)
Quintile 3	3.29	4831	1.06 (1.01, 1.11)	1.08 (1.03, 1.14)	1.08 (1.03, 1.13)

(*Continued*)

TABLE 3 (*Continued*)

	Median	Prevalent insomnia at baseline, *n*	Prevalent insomnia at baseline, OR (95% CI)		
			Model 1	Model 2	Model 3
Quintile 4	3.97	4801	1.04 (1.00, 1.10)	1.07 (1.02, 1.13)	1.07 (1.01, 1.12)
Quintile 5	5.34	5056	1.12 (1.07, 1.18)	1.17 (1.11, 1.23)	1.16 (1.11, 1.23)
P-trend			$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
Nonjuice fruit, cups					
Quintile 1	0.54	5470	1.00	1.00	1.00
Quintile 2	1.06	4968	0.88 (0.84, 0.92)	0.92 (0.88, 0.97)	0.93 (0.89, 0.98)
Quintile 3	1.59	4747	0.83 (0.79, 0.87)	0.91 (0.86, 0.95)	0.92 (0.87, 0.97)
Quintile 4	2.07	4521	0.79 (0.75, 0.83)	0.87 (0.83, 0.92)	0.89 (0.84, 0.93)
Quintile 5	2.74	4316	0.74 (0.70, 0.78)	0.83 (0.79, 0.87)	0.85 (0.80, 0.89)
P-trend			$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
Vegetables, cups					
Quintile 1	0.81	5370	1.00	1.00	1.00
Quintile 2	1.20	4911	0.88 (0.84, 0.92)	0.93 (0.88, 0.97)	0.94 (0.90, 0.99)
Quintile 3	1.48	4803	0.82 (0.78, 0.86)	0.89 (0.85, 0.94)	0.91 (0.86, 0.95)
Quintile 4	1.76	4516	0.79 (0.76, 0.83)	0.88 (0.84, 0.93)	0.90 (0.86, 0.95)
Quintile 5	2.22	4422	0.76 (0.72, 0.80)	0.85 (0.81, 0.90)	0.88 (0.83, 0.93)
P-trend			$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
Dairy products, cups					
Quintile 1	0.49	4901	1.00	1.00	1.00
Quintile 2	1.03	4845	0.96 (0.92, 1.01)	0.96 (0.92, 1.01)	0.98 (0.93, 1.03)
Quintile 3	1.46	4804	0.95 (0.90, 1.00)	0.97 (0.92, 1.01)	0.99 (0.94, 1.04)
Quintile 4	1.97	4812	0.95 (0.91, 1.00)	0.97 (0.92, 1.02)	0.99 (0.94, 1.04)
Quintile 5	3.17	4660	0.91 (0.86, 0.95)	0.94 (0.89, 0.99)	0.96 (0.92, 1.02)
P-trend			$P = 0.0001$	$P = 0.0432$	$P = 0.3147$

[1]Model 1 adjusted for energy. Glycemic load was based on available carbohydrate. Model 2 adjusted for the variables in Model 1 plus age, race/ethnicity, education, income, smoking, alcohol, caffeine, stressful life events, social support, overactive thyroid, bodily pain, hormone replacement therapy, and snoring. Model 3 adjusted for the variables in Model 2 plus depression, physical activity, BMI, diabetes, hypertension, myocardial infarction, cardiovascular disease, asthma, and hot flashes. 1 oz = 28.3495 g; 1 cup = 236.588 mL. GI, glycemic index; oz, ounces.

across all models. There was a significant linear trend toward higher insomnia incidence for higher glycemic load. Higher consumption of fiber, whole grains, nonjuice fruit, and vegetables were significantly associated with decreased odds of insomnia incidence in Model 1, but these associations were attenuated with the inclusion of the covariates in Models 2 and 3, with only the fifth quintiles for nonfruit juice and vegetables remaining significant in fully adjusted models. There was a significant linear trend toward lower insomnia incidence for increasing nonjuice fruit consumption in all 3 models. There were no associations of dietary total sugar, total carbohydrate, whole grains, or dairy products with insomnia incidence in fully adjusted models. Effect modification by physical activity was not found in stratified analyses.

Discussion

This large prospective study among postmenopausal women demonstrated that progressively higher dietary GI was associated with increased insomnia incidence over 3 y after adjusting for demographic, behavioral, lifestyle, psychosocial, and medical factors. Added sugars, but not total sugars or total carbohydrates, were associated with insomnia incidence. This may be partly explained by the observation that added sugars, caloric sweeteners not naturally found in foods, typically have higher GIs, whereas total dietary sugars comprise an amalgam of various types of sugar and sugar from different food sources. The food source of a sugar influences the GI, with higher fiber content of a food slowing the metabolism of carbohydrates and lowering the GI (20). Increased consumption of nonjuice fruit was associated with a lower prevalence and incidence of insomnia. The GIs of fruits vary, but of the 7 most commonly consumed fruits in the United States, 4 have low GIs ($\leq$55 on the glucose reference scale) (apples, strawberries, oranges, peaches), 2 have intermediate GIs (56–69) (ripe bananas and grapes), and only 1 has a high GI ($\geq$70) (watermelon) (21, 22). A relatively low GI could be one of the characteristics of fruit that contribute to the association with a lower prevalence and incidence of insomnia.

Cross-sectional analyses did not demonstrate a relation between the consumption of starch and the prevalence of insomnia, but prospective analyses showed that individuals with higher starch consumption were progressively and significantly more likely to have developed insomnia incidence after 3 y. Although starches are complex carbohydrates, sources such as refined white bread and boiled potatoes have high GIs, whereas other fiber-rich sources including legumes, nuts/seeds, and yams generally have low GIs. When we examined different types of starches according to fiber content, we found that progressively higher consumption of whole grains was associated with lower insomnia prevalence, whereas the opposite was true for nonwhole/refined grains, with progressively higher consumption associated with higher insomnia prevalence and incidence. Increased vegetable consumption was also associated with decreased insomnia prevalence and incidence. The most commonly consumed vegetable by far in the United States

TABLE 4 Adjusted ORs and 95% CIs from logistic regression analyses of insomnia incidence according to quintiles of energy-adjusted GI, glycemic load, carbohydrate consumption, fiber, whole grains, nonwhole/refined grains, nonjuice fruit, vegetables, and dairy products[1]

	Median	Incident insomnia after 3 y, *n*	Incident insomnia 3 y later, OR (95% CI)		
			Model 1	Model 2	Model 3
Dietary GI					
Quintile 1	47.0	1728	1.00	1.00	1.00
Quintile 2	49.8	1924	1.13 (1.05, 1.21)	1.13 (1.05, 1.21)	1.13 (1.05, 1.21)
Quintile 3	51.7	1943	1.14 (1.06, 1.22)	1.12 (1.04, 1.20)	1.11 (1.03, 1.19)
Quintile 4	53.5	2065	1.22 (1.14, 1.31)	1.19 (1.11, 1.28)	1.18 (1.09, 1.27)
Quintile 5	56.3	2123	1.26 (1.18, 1.36)	1.18 (1.10, 1.28)	1.16 (1.08, 1.25)
P-trend			$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
Dietary glycemic load, g/d					
Quintile 1	53.6	1809	1.00	1.00	1.00
Quintile 2	74.5	1895	1.04 (0.97, 1.12)	1.07 (1.00, 1.16)	1.08 (1.00, 1.16)
Quintile 3	91.7	1950	1.06 (0.98, 1.14)	1.10 (1.02, 1.19)	1.10 (1.02, 1.19)
Quintile 4	111.3	2065	1.11 (1.03, 1.20)	1.14 (1.05, 1.24)	1.14 (1.05, 1.24)
Quintile 5	146.5	2064	1.07 (0.98, 1.16)	1.10 (1.01, 1.19)	1.09 (1.00, 1.19)
P-trend			$P = 0.0365$	$P = 0.0148$	$P = 0.0223$
Dietary added sugar, g					
Quintile 1	17.7	1765	1.00	1.00	1.00
Quintile 2	28.6	1837	1.04 (0.97, 1.12)	1.03 (0.95, 1.11)	1.03 (0.95, 1.11)
Quintile 3	39.1	1988	1.14 (1.05, 1.22)	1.13 (1.05, 1.22)	1.12 (1.04, 1.22)
Quintile 4	52.5	2050	1.17 (1.09, 1.27)	1.15 (1.06, 1.24)	1.13 (1.04, 1.22)
Quintile 5	79.2	2143	1.23 (1.14, 1.33)	1.16 (1.07, 1.26)	1.13 (1.04, 1.24)
P-trend			$P < 0.0001$	$P < 0.0001$	$P = 0.0007$
Dietary total sugars, g					
Quintile 1	50.5	1882	1.00	1.00	1.00
Quintile 2	73.6	1948	1.01 (0.94, 1.09)	1.04 (0.96, 1.12)	1.05 (0.97, 1.13)
Quintile 3	93.3	1959	0.99 (0.92, 1.07)	1.03 (0.96, 1.11)	1.03 (0.96, 1.12)
Quintile 4	115.6	1984	0.99 (0.92, 1.06)	1.03 (0.95, 1.11)	1.03 (0.95, 1.11)
Quintile 5	155.4	2010	0.97 (0.90, 1.05)	1.00 (0.92, 1.08)	0.99 (0.91, 1.08)
P-trend			$P = 0.3203$	$P = 0.8450$	$P = 0.7027$
Dietary starch, g					
Quintile 1	38.1	1807	1.00	1.00	1.00
Quintile 2	55.6	1896	1.04 (0.96, 1.12)	1.07 (0.99, 1.16)	1.08 (1.00, 1.17)
Quintile 3	70.3	1944	1.05 (0.97, 1.14)	1.09 (1.00, 1.18)	1.09 (1.01, 1.18)
Quintile 4	87.8	2039	1.09 (1.01, 1.18)	1.13 (1.03, 1.23)	1.13 (1.04, 1.23)
Quintile 5	119.3	2097	1.11 (1.01, 1.21)	1.14 (1.04, 1.25)	1.15 (1.05, 1.27)
P-trend			$P = 0.0167$	$P = 0.0064$	$P = 0.0043$
Dietary total carbohydrate, g					
Quintile 1	114.7	1839	1.00	1.00	1.00
Quintile 2	157.9	1946	1.05 (0.97, 1.12)	1.08 (1.00, 1.16)	1.08 (1.00, 1.16)
Quintile 3	192.9	1928	1.01 (0.94, 1.09)	1.06 (0.98, 1.14)	1.06 (0.98, 1.14)
Quintile 4	232.8	2036	1.06 (0.98, 1.14)	1.10 (1.02, 1.19)	1.10 (1.02, 1.19)
Quintile 5	302.7	2034	1.01 (0.93, 1.09)	1.05 (0.97, 1.15)	1.05 (0.96, 1.14)
P-trend			$P = 0.7533$	$P = 0.2319$	$P = 0.2724$
Fiber, g					
Quintile 1	10.6	2141	1.00	1.00	1.00
Quintile 2	13.7	2052	0.96 (0.90, 1.03)	1.00 (0.93, 1.07)	1.01 (0.94, 1.09)
Quintile 3	16.0	1921	0.89 (0.83, 0.96)	0.96 (0.90, 1.03)	0.98 (0.91, 1.05)
Quintile 4	18.2	1899	0.89 (0.83, 0.95)	0.98 (0.91, 1.05)	1.00 (0.92, 1.07)
Quintile 5	21.0	1770	0.83 (0.77, 0.89)	0.91 (0.85, 0.99)	0.94 (0.87, 1.01)
P-trend			$P < 0.0001$	$P = 0.0221$	$P = 0.1119$
Whole grains, oz					
Quintile 1	0.25	2020	1.00	1.00	1.00
Quintile 2	0.69	2049	1.01 (0.94, 1.08)	1.03 (0.96, 1.11)	1.05 (0.97, 1.12)
Quintile 3	1.07	1951	0.95 (0.89, 1.02)	0.98 (0.91, 1.05)	1.00 (0.93, 1.08)
Quintile 4	1.47	1868	0.91 (0.85, 0.97)	0.96 (0.89, 1.03)	0.97 (0.91, 1.05)
Quintile 5	2.30	1895	0.93 (0.87, 0.99)	0.97 (0.91, 1.05)	1.00 (0.93, 1.07)
P-trend			$P = 0.0014$	$P = 0.1146$	$P = 0.3442$
Nonwhole/refined grains, oz					
Quintile 1	1.70	1820	1.00	1.00	1.00
Quintile 2	2.62	1944	1.07 (1.00, 1.15)	1.08 (1.01, 1.16)	1.09 (1.01, 1.17)
Quintile 3	3.25	1960	1.07 (1.00, 1.15)	1.09 (1.01, 1.17)	1.09 (1.02, 1.18)

(*Continued*)

TABLE 4 (*Continued*)

	Median	Incident insomnia after 3 y, *n*	Incident insomnia 3 y later, OR (95% CI)		
			Model 1	Model 2	Model 3
Quintile 4	3.93	1976	1.08 (1.01, 1.16)	1.08 (1.00, 1.16)	1.08 (1.01, 1.17)
Quintile 5	5.26	2083	1.15 (1.08, 1.24)	1.17 (1.08, 1.25)	1.16 (1.08, 1.25)
P-trend			$P = 0.0002$	$P = 0.0003$	$P = 0.0007$
Nonjuice fruit, cups					
Quintile 1	0.56	2180	1.00	1.00	1.00
Quintile 2	1.09	2034	0.93 (0.87, 0.99)	0.97 (0.91, 1.04)	0.98 (0.92, 1.06)
Quintile 3	1.61	1905	0.86 (0.80, 0.92)	0.94 (0.87, 1.00)	0.95 (0.88, 1.02)
Quintile 4	2.09	1922	0.88 (0.82, 0.94)	0.97 (0.90, 1.04)	0.98 (0.91, 1.06)
Quintile 5	2.75	1742	0.80 (0.74, 0.86)	0.88 (0.82, 0.95)	0.90 (0.83, 0.97)
P-trend			$P < 0.0001$	$P = 0.0049$	$P = 0.0199$
Vegetables, cups					
Quintile 1	0.82	2111	1.00	1.00	1.00
Quintile 2	1.20	1983	0.93 (0.87, 1.00)	0.98 (0.91, 1.05)	0.99 (0.92, 1.06)
Quintile 3	1.48	2032	0.97 (0.91, 1.04)	1.03 (0.96, 1.11)	1.05 (0.98, 1.13)
Quintile 4	1.77	1911	0.91 (0.85, 0.98)	0.98 (0.91, 1.05)	0.99 (0.92, 1.07)
Quintile 5	2.21	1746	0.83 (0.78, 0.90)	0.90 (0.83, 0.97)	0.91 (0.84, 0.99)
P-trend			$P < 0.0001$	$P = 0.0127$	$P = 0.0556$
Dairy products, cups					
Quintile 1	0.48	1982	1.00	1.00	1.00
Quintile 2	1.02	2012	1.00 (0.94, 1.07)	1.01 (0.94, 1.09)	1.02 (0.95, 1.10)
Quintile 3	1.45	1951	0.96 (0.90, 1.03)	0.98 (0.91, 1.06)	1.00 (0.93, 1.08)
Quintile 4	1.97	1951	0.96 (0.89, 1.03)	0.97 (0.90, 1.04)	0.99 (0.92, 1.07)
Quintile 5	3.16	1887	0.92 (0.86, 0.99)	0.96 (0.89, 1.03)	0.98 (0.91, 1.06)
P-trend			$P = 0.0090$	$P = 0.1070$	$P = 0.3866$

[1]Model 1 adjusted for energy. Glycemic load was based on available carbohydrate. Model 2 adjusted for the variables in Model 1 plus age, race/ethnicity, education, income, smoking, alcohol, caffeine, stressful life events, social support, overactive thyroid, bodily pain, hormone replacement therapy, and snoring. Model 3 adjusted for the variables in Model 2 plus depression, physical activity, BMI, diabetes, hypertension, myocardial infarction, cardiovascular disease, asthma, and hot flashes. 1 oz = 28.3495 g; 1 cup = 236.588 mL. GI, glycemic index; oz, ounces.

is potatoes (21), with most varieties and methods of cooking resulting in high GIs (23), whereas the next 6 most commonly consumed vegetables (onions, tomatoes, head lettuce, romaine and leaf lettuce, bell peppers, and cucumbers) all have low GIs (21).

Our results could be viewed as surprising because carbohydrate intake has been shown to affect concentrations of tryptophan, a precursor for both serotonin and melatonin. Tryptophan competes with larger amino acids for the same transport system to cross the blood–brain barrier (24). Carbohydrate intake promotes insulin release, which stimulates the uptake of the competing larger amino acids into muscle tissue, increasing the ratio of tryptophan to the other amino acids in plasma, allowing tryptophan access to the transport system to cross the blood–brain barrier and contribute to serotonin synthesis (25). However, for this process to occur, the meal must contain only carbohydrate and be consumed without any protein remaining in the stomach. If the meal contains as little as 5% protein, then tryptophan concentrations will not increase; if the meal contains as little as 2.5% protein, the increase in tryptophan will be blunted (26). Sweet foods such as milk chocolate, sweetened yogurts, ice cream, and egg-based cakes and pastries contain enough protein to block any increase in tryptophan. Even foods such as potatoes, bread, and rice can have enough protein to blunt or prevent increases in tryptophan concentrations. Serotonin is a precursor for melatonin, but even if serotonin concentrations increase, any resultant effect upon melatonin is dependent upon the presence of darkness because sunlight and artificial light inhibit melatonin synthesis (27).

A plausible mechanism by which a high-GI diet may increase the risk of insomnia is through acute spikes and troughs in blood glucose. GI and glycemic load have been shown to provide physiologically valid estimates of postprandial glycemia and insulin demand in healthy individuals (28). Postprandial hyperglycemia from high dietary glycemic load and resultant compensatory hyperinsulinemia can lower plasma glucose to concentrations that compromise brain glucose, ~70 mg/dL (3.8 mmol/L) (29), triggering secretion of autonomic counter-regulatory hormones such as adrenaline, cortisol, glucagon, and growth hormone (30). Symptoms of counter-regulatory hormone responses can include heart palpitations, tremor, cold sweats, paresthesia, anxiety, irritability, and hunger (31). Hypoglycemia has been shown to produce arousal from sleep and substantially reduce sleep efficiency in nondiabetic adults (32, 33). High blood sugar from carbohydrate consumption can initially make one drowsy, helping one to fall asleep (4), but the compensatory hyperinsulinemia and counter-regulatory hormone responses can awaken one from sleep (32, 33). Higher-GI diets have also been shown to stimulate inflammatory immune responses (34), which could function to increase the risk of insomnia through anti-inflammatory cytokines that inhibit sleep (35). Added sugars could also negatively affect sleep quality by compromising the intestinal microbiome. Higher consumption of added sugars can contribute to intestinal dysbiosis, a maladaptive microbiota imbalance that can profoundly affect multiple aspects of sleep (36).

Possible limitations of our study include the measurement of dietary exposures from FFQs instead of dietary biomarkers or

food records and the assessment of our outcome of insomnia from self-reported symptoms as opposed to objective clinical diagnosis. The exact nutrient amounts for each food were not analytically measured, so some of the nutrient values were estimated or imputed rather than being exact analytic values from a laboratory assay. For example, 26–50% of the values for the variable "dietary added sugars" are estimated or imputed. Estimates were generally based on a similar food, another form of the same food, a known nutrient value associated with the missing value, or recipes or formulations from manufacturers. Although we would expect any misclassification of exposure or outcome to be random, resulting in nondifferential misclassification which typically leads to bias toward the null hypothesis (37), we cannot rule out the possibility that bias, particularly food recall bias, could be systematic and related to variables such as BMI, age, or ethnicity. Sleep deprivation from insomnia could also induce carbohydrate cravings, so reverse causation could have contributed to our results in the cross-sectional analyses (38). There is also a potential for residual confounding from unmeasured confounders and the possibility of false positives with multiple statistical tests. Because the variables included in Model 3 are theorized to be mediators of the relation between the dietary variables and insomnia, any resultant attenuation from their inclusion does not necessarily imply confounding, but could be consistent with some of these variables lying along the causal pathway. The participants' eating habits may not be representative of those common now, almost 20 y later. Finally, our study sample was confined to postmenopausal women, limiting the generalizability of our findings to other populations.

The results from this study suggest that a high-GI diet could be a risk factor for insomnia in postmenopausal women, whereas dietary fiber, nonjuice fruit, and vegetables reduce its risk. If high-GI diets increase the risk of insomnia, then dietary interventions that promote the consumption of whole unprocessed carbohydrates that are high in fiber and have low GIs could serve as potential treatments of, and primary preventive measures for, insomnia in postmenopausal women. Randomized controlled trials examining dietary patterns in relation to insomnia are needed to clarify these findings.

We acknowledge the following WHI investigators: Program Office (National Heart, Lung, and Blood Institute, Bethesda, MD): Jacques Rossouw, Shari Ludlam, Dale Burwen, Joan McGowan, Leslie Ford, and Nancy Geller; Clinical Coordinating Center (Fred Hutchinson Cancer Research Center, Seattle, WA): Garnet Anderson, Ross Prentice, Andrea LaCroix, and Charles Kooperberg; Investigators and Academic Centers: JoAnn E Manson (Brigham and Women's Hospital, Harvard Medical School, Boston, MA); Barbara V Howard (MedStar Health Research Institute/Howard University, Washington, DC); Marcia L Stefanick (Stanford Prevention Research Center, Stanford, CA); Rebecca Jackson (The Ohio State University, Columbus, OH); Cynthia A Thomson (University of Arizona, Tucson/Phoenix, AZ); Jean Wactawski-Wende (University at Buffalo, Buffalo, NY); Marian Limacher (University of Florida, Gainesville/Jacksonville, FL); Robert Wallace (University of Iowa, Iowa City/Davenport, IA); Lewis Kuller (University of Pittsburgh, Pittsburgh, PA); and Sally Shumaker (Wake Forest University School of Medicine, Winston-Salem, NC).

The authors' responsibilities were as follows—JEG and LH: designed the research; JEG: analyzed the data and had primary responsibility for the final content; and all authors: wrote the paper and read and approved the final manuscript. All authors report no conflicts of interest.

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