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Sleep apnoea symptoms and sleepiness associate with future diet quality: a prospective analysis in the Bogalusa Heart Study

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(Submitted 7 February 2024 – Final revision received 29 June 2024 – Accepted 25 July 2024)

Abstract

Sleep apnoea is a known risk factor for cardiometabolic diseases (CMD), but it is unknown whether sleep apnoea or its symptoms contribute to increased CMD through an association with diet quality. This study assessed the association between sleep apnoea symptoms on future diet quality in the Bogalusa Heart Study (BHS). This prospective study included 445 participants who completed a sleep apnoea questionnaire in 2007–2010 and a FFQ in 2013–2016 (mean follow-up: 5·8 years; age 43·5 years; 34 % male; 71 % White/29 % Black persons). Diet quality was measured with the Alternate Healthy Eating Index (AHEI) 2010, the Healthy Eating Index (HEI) 2015 and the alternate Mediterranean diet score. Adjusted mean differences in dietary patterns by sleep apnoea risk, excessive snoring and daytime sleepiness were estimated with multivariable linear regression. Models included multi-level socio-economic factors, lifestyle and health characteristics including BMI, physical activity and depressive symptoms. Those with high sleep apnoea risk, compared with low, had lower diet quality 5·8 years later (percentage difference in AHEI (95 % CI −2·1 % (−3·5 %, −0·7 %)). Daytime sleepiness was associated with lower diet quality. After adjusting for dietary pattern scores from 2001 to 2002, having high sleep apnoea risk and excessive sleepiness were associated with 1·5 % ($P < 0·05$) and 3·1 % ($P < 0·001$) lower future AHEI scores, respectively. These findings suggest that individuals with sleep apnea or excessive sleepiness should be monitored for diet quality and targeted for dietary interventions to improve CMD risk.

Keywords: **Diet quality: Dietary patterns: Sleep apnoea: Sleepiness: Snoring**

Both sleep apnoea and poor diet quality increase risk for cardiometabolic disease (CMD) and other chronic diseases[1,2]. The majority of Americans fall far short of diet quality recommendations for health[3]. Sleep apnoea syndrome impacts large proportions of the population, although prevalence estimates vary[4]. Sleep apnoea is when breathing partially (hypopnea) or completely (apnoea) stops during sleep. Objective classifications typically use the Apnoea–Hypopnea Index (AHI), measuring the number of apnoeas or hypopneas per hour. One multiethnic US cohort study with objective sleep measurements identified 34 % of adult participants to have moderate or severe sleep apnoea, defined as AHI ≥ 15[5], while other studies estimate 9–38 % of Americans may suffer from mild (AHI ≥ 5) or worse sleep apnoea. Sleep apnoea is highly associated with obesity and hypertension and increases risk for CVD, stroke, impaired glucose tolerance and diabetes[2,6].

Snoring and daytime sleepiness are common traits of sleep apnoea syndrome and can be associated with insufficient sleep quality or quantity. Insufficient sleep has shown associations with dietary intake in both short-term experimental trials and observational studies. For example, sleep deprivation in randomised crossover trials associates with higher total energy intake from increased consumption of added sugars and energy-dense snacks[7,8]. In one prospective observational study, participants of the Health Professionals Follow-up Study (HPFS) with insomnia symptoms had lower diet quality and vegetable intake and higher total energy intake after 2 years of follow-up compared with those without insomnia symptoms[9].

Abbreviations: AHEI, Alternate Healthy Eating Index; aMed, Alternate Mediterranean Diet; BHS, Bogalusa Heart Study; Berlin Q., Berlin Questionnaire; CES-D, Center for Epidemiologic Studies Depression Scale; CMD, cardiometabolic diseases; HEI, Healthy Eating Index; ICE, Index of Concentration at the Extremes.

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Multiple cross-sectional studies have also found associations between poor sleep and lower diet quality[10–16].

There is less evidence for associations between sleep apnoea and diet quality. A recent cross-sectional study found that individuals with higher diet quality based on the DASH diet had lower odds of sleep disordered breathing in a Chinese cohort[17]. Similar cross-sectional findings were observed among NHANES participants where those with higher diet quality and less inflammatory diets were less likely to also report sleep apnoea symptoms[18]. These studies assessed the association between diet with sleep apnoea risk as an outcome. A recent systematic review pointed to the gap in assessing potential associations in the other direction of this bidirectional or cyclical relationship[19,20]. This same review of studies exploring associations between Mediterranean diets and various sleep features did not report any that assessed sleep apnoea. Rather, the past literature has focused primarily on associations between diet quality with sleep duration or aspects of sleep quality. To our knowledge, there is no evidence for the impact of sleep apnoea or its symptoms on future diet quality in prospective analyses. If detected, an association between sleep apnoea symptoms and decreased diet quality may partially explain the influence of sleep apnoea on chronic disease risk, given the many known metabolic outcomes of poor diet. It could also signify sleep apnoea patients as an important group for targeting diet-related interventions to decrease disease risk. In addition, if sleep apnoea or its symptoms have an influence on diet quality, then diet-related interventions may need to address aspects of sleep health to be successful among those suffering from sleep disorders.

The objective of this study was to determine the effect of sleep apnoea risk and its primary symptoms, snoring and sleepiness, on future diet quality in the midlife Bogalusa Heart Study (BHS) cohort. The BHS represents an understudied population as a lower-income, bi-racial (Black/White), mostly rural southeastern US community that is highly impacted by CMD health inequities. Addressing this in this population could provide insight for improving the effectiveness of traditional dietary interventions and ultimately reduce the excess burden of CMD in this and similar communities. The hypothesis was that having high sleep apnoea risk, snoring or sleepiness would be associated with lower future diet quality.

Experimental methods

Study design and population

The BHS is a bi-racial (Black/White), community-based cohort study from the semi-rural, southeastern town of Bogalusa, Louisiana, that began in 1972 as a series of surveys in children recruited from the public elementary schools[21]. The study has continued with ongoing repeated assessments in the same individuals through early adulthood to middle age. This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects/patients were approved by the Institutional Review Board of Tulane University, Biomedical IRB (protocol code: 2019-1377). Written informed consent was obtained from all subjects at each visit. The study visit that took place in early middle-age (mean age 42 years), from 2007 to 2010 (baseline for this study), incorporated a brief sleep apnoea questionnaire. Among 914 participants in the 2007–2010 visit, 518 had valid diet data collected at the 2013–2016 follow-up. Additional exclusions were made for those reporting history of heart attack, heart surgery or angina (n 23) or missing covariate data (n 50:21 education, 22 census tract, 7 other variables) at baseline (see Fig. S1 for participant flow chart). There were 445 participants available for this analysis with a mean follow-up time of 5·8 years.

Measures

Sleep apnoea. Sleep apnoea risk was measured in the 2007–2010 BHS visit using the Berlin Questionnaire (Berlin Q.)[22]. The Berlin Q. consists of ten items in three categories. The three categories include snoring, sleepiness and presence of obesity or hypertension (see Table S1 for the Berlin Q. and scoring). Scoring positive on two of the three categories classifies respondents as high risk for sleep apnoea[22]. Validation has shown a positive Berlin score to be 86 % sensitive and 77 % specific for identifying individuals with AHI ≥ 5 (clinically mild sleep apnoea)[22]. The snoring and sleepiness category scores were additionally used as secondary exposures. The snoring category is positive (considered excessive snoring) if one experiences frequent (>1–2 times/week) snoring or breathing pauses during sleep, or their snoring is loud (louder than talking or bothers others). The sleepiness category is positive (considered excessive daytime sleepiness) if two of the following are present: frequent (>1–2 times/week) tiredness after sleeping, frequent tiredness during awake times or falling asleep while driving. The internal validity of the category 1 (snoring) section measured by Cronbach's α was 0·92, and this was 0·63 for the sleepiness section or 0·86 without the falling asleep while driving question[22].

Diet quality. Usual diet was measured at the 2013–2016 BHS visit with the Lower Mississippi Delta Nutrition Intervention Research Initiative (Delta-NIRI) FFQ[23]. This 142-item semi-quantitative FFQ is culturally specific to the southern US population. It was developed and validated in the Jackson Heart Study, representing a nearby population with the same cultural foods as BHS members. The Delta-NIRI measures usual intake by asking participants about frequency (never to 6+ times per d) and portion size (four food-appropriate options) of each food over the previous year and includes locally relevant foods such as okra, grits and jambalaya. The Delta-NIRI was validated against four 24-h dietary recalls, two weekdays and two weekend days, administered over a 6-month period[24]. In the validation study, correlation coefficients were similar to several other FFQ validations (e.g. correlation coefficient = 0·70 for carbohydrates and 0·54 for saturated fat)[24]. The Nutrient Database for Scientific Research was used to convert FFQ responses to average daily nutrient and total energy intakes. The USDA Food Patterns Equivalent Database was used to estimate average daily intakes of thirty-seven food groups common in dietary patterns[25,26]. In accordance with the Delta-NIRI

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validation, those with energy intake <600 or >4800 kcal/d were excluded[23,24].

Diet quality was assessed with three dietary patterns, the Alternate Healthy Eating Index (AHEI) 2010, the Healthy Eating Index (HEI) 2015 and the alternate Mediterranean diet (aMed). Higher scores indicate closer adherence to the prespecified dietary pattern (see Table S2 for scoring details). The AHEI-2010 includes eleven components (10 points each, total score range 0–110) and is based on established epidemiological evidence between dietary components and disease[27]. Higher scores are given for higher consumption of fruits, vegetables, nuts and legumes, whole grains, and healthy fats, while intake of sugar-sweetened beverages, red and processed meats, *trans*-fats and Na are scored inversely, and moderate alcohol intake scores highest. The AHEI-2010 was chosen for this study as a dietary pattern most associated with health, since the scoring is based on predefined ideal intake levels for chronic disease. The HEI-2015 assesses adherence to the 2015 Dietary Guidelines for Americans and consists of thirteen energy-adjusted food or nutrient categories[28]. We included the HEI-2015 since it represents the dietary pattern recommended to Americans. While the HEI-2015 aims to be focused on health outcomes, it is indirectly related to the evidence compared with the AHEI-2010, and so may be less health-promoting overall. The aMed score has nine components and ranges from 0 to 9, emphasising plant-based foods and healthy fats such as nuts, legumes, whole grains and fish representing a Mediterranean-style diet[29]. The aMed scoring is based on sex-specific median cut-offs for each component, such that those above the median receive a score of 1 and those below the median receive a score of 0 for each component, except for red and processed meats (scored inversely), and alcohol (moderate intake scores 1). While the aMed has been extensively studied in relation to many health outcomes, its scoring basis in sex-specific median-splits makes it variable across different populations in which it is calculated. High scores could represent only a moderately healthy diet in certain communities with less access to healthy foods and/or smaller intake ranges, a possibility in the BHS community. We included the aMed in this study despite this potential limitation, since a Mediterranean diet has been most studied in relation to sleep in prior literature.

Covariates. Demographic information was assessed via questionnaires. Depressive symptoms were determined with the Centers for Epidemiologic Studies Depression scale (CES-D), a twenty-item scale asking the frequency of depressive symptoms over the past week (≥16 indicates the presence of depressive symptoms)[30]. Physical activity was measured with separate questions for work- and non-work-related activity, based on a validated and reliable tool[31] that has also been validated with metabolic syndrome in the BHS sample[32]. Height and weight were measured twice and used to calculate BMI using the average measures of weight in kg/height in m^2, and waist circumference used the average of three measurements.

Neighbourhood-level factors were measured by census tract. Participants' residential addresses were geocoded to latitude and longitude coordinates using QGIS[33,34]. Census tract shape files were used to obtain Federal Information Processing codes. Data such as total population, median income and percentage of households receiving food stamps were obtained from the 2009 American Community Survey (ACS) 5-year estimates[35]. The Index of Concentration at the Extremes (ICE) was used as a measure of racial and economic segregation[36]. The ICE was calculated as the number of White householders reporting ≥$100 000 annual income (the privileged group) minus the number of Black householders reporting <$25 000 annual income (the disadvantaged group), divided by the total number of households reporting income in the tract. A negative ICE (range is –1 to 1) indicates greater numbers of the disadvantaged group relative to the privileged group in the area. The Modified Retail Food Environment Index (MRFEI) indicates the percentage of healthy food retailers in the census tract and was included as a measure of the food environment[37].

Statistical analysis

Descriptive statistics were provided for continuous and categorical variables in the total sample and stratified by sleep apnoea risk. *T* tests and Pearson's χ^2 tests assessed differences by sleep apnoea risk. Additional descriptive tables comparing the included to the excluded sample and describing differences by AHEI quintile are given in the supplement. Normality of the dietary patterns was assessed with Q-Q plots, histograms, boxplots and Shapiro–Wilk test for normality. There were few outliers, and none were removed for the analysis. We did not perform any imputation of missing data.

Multivariable linear regression using generalised estimating equations to account for clustering at census tract estimated adjusted mean differences in dietary pattern scores at follow-up for those with high compared with low baseline sleep apnoea risk. Excessive snoring and sleepiness were used as secondary exposures. Interaction by race, sex and education level was tested by including product terms with the sleep exposures in the fully adjusted models. Additionally, individual components of the dietary patterns were used as secondary outcomes where the full dietary pattern showed a statistically significant association with sleep exposures.

Models were adjusted for potential confounders chosen *a priori* based on established relationships with sleep and diet[38–43], while minimising redundancy by not including highly correlated variables. Selection among highly correlated variables was based on model fit and percentage change in the estimate of interest. Four nested models are shown. The full model included age, sex, race, education, employment, income category, spouse and children in the house, total population in census tract, ICE of census tract, percentage of households receiving food stamps/SNAP benefits in census tract, MRFEI of census tract, smoking history, drinking status, physical activity at work, physical activity when not at work, BMI and depressive symptoms. Race was included as a covariate in this study not because of hypothesised biological relationships with the exposure or outcome but to capture some of the impact of centuries of structural racism on health inequities; the neighbourhood-level factors additionally capture some of structural racisms' influence on poor health and lifestyle. All models estimating dietary pattern outcomes included total energy intake in 2013–2016. The

models using excessive snoring and excessive daytime sleepiness as exposures were mutually adjusted (these were not colinear, $r = 0{\cdot}19$). In a sensitivity analysis, dietary pattern scores measured in 2001–2002 were included in the model for the subset of participants with prior diet data available to emulate a longitudinal design. In an additional sensitivity analysis, the association between excessive snoring and diet quality was estimated separately among the subsamples that live *v.* do not live with a spouse. This was done to try to detect the impact of possibly higher misclassification of snoring among those who do not live with a spouse, a proxy for not having a bed partner. A type 1 error rate of 5 % was used for statistical significance. Data cleaning and analysis were conducted in SAS, version 9 and R, version 4.0.

Results

At the 2007–2010 baseline visit, the mean age of the 445 eligible participants was 43·5 years, 34 % were male and 29 % were Black persons (all participants self-reported their race as either Black or White; Table 1). Thirty-seven per cent did not have any education beyond a high school degree and nearly half reported an annual income below $45 000. Based on ACS 2009 5-year estimates, 29 % of households in these census tracts received food stamps. At baseline, 39 % were high risk for sleep apnoea, 42 % had excessive snoring and 22 % had excessive daytime sleepiness. Those with high sleep apnoea risk were more likely to be male, be older, have depressive symptoms, have higher BMI and waist circumference, and report less leisure time physical activity compared with those with low sleep apnoea risk. The mean dietary pattern scores at follow-up were 45·5 (SD = 9·7) for AHEI-2010, 59·7 (SD = 9·3) for HEI-2015 and 3·8 (SD = 1·7) for aMed. There were no differences in dietary patterns by sleep apnoea risk, but those with a high sleep apnoea score had higher total energy intake at follow-up. There were few differences in demographic characteristics across quintile of AHEI-2010, but those with excessive sleepiness were more likely to be in the lower diet quality quintiles (Table S3).

Those who participated in the 2007–2010 visit but were excluded because of missing information or loss to follow-up (no diet data at the 2013–2016 visit) differed from the included group on multiple characteristics (Table S4). Compared with the study sample, excluded participants were more often male, had lower education and incomes, more likely current smokers, and had higher CES-D scores ($P < 0{\cdot}05$ for each comparison). There was no difference in sleep apnoea score or excessive snoring, but those who were excluded were more likely to have excessive sleepiness (30·7 % *v.* 21·8 %). There was no difference in dietary patterns or total energy intake at follow-up between the included and excluded groups.

Those who were classified as high sleep apnoea risk at baseline had lower AHEI-2010 scores at follow-up (Table 2, adjusted mean difference: −2·32, 95 % CI −3·84, −0·79). For the HEI-2015 and aMed dietary patterns, the direction of the association was also negative, but the differences were not statistically significant.

There was an association between baseline excessive daytime sleepiness and diet quality at follow-up, but there were no associations with excessive snoring (Table 2). The difference between those with *v.* without baseline sleepiness in both AHEI-2010 and HEI-2015 were statistically significant in all models (adjusted mean differences (95 % CI): AHEI-2010: −4·03 (–5·56, −2·50); HEI-2015: −3·79 (–5·51, −2·06)). The difference in aMed by sleepiness followed the same direction but did not reach statistical significance. There were no significant interactions by sex, race or education with the sleep exposures for any of the dietary patterns (Table S5).

After identifying significant associations between sleep apnoea symptoms and AHEI-2010 and HEI-2015, we estimated mean differences in the individual components of these dietary patterns as exploratory outcomes to see which aspects of diet have the strongest associations with sleep apnoea and sleepiness (Table 3). Higher scores on each component contribute to higher overall scores and better diet quality. High sleep apnoea risk showed negative associations with AHEI-2010 whole grains and sugar-sweetened beverages components and the HEI-2015 whole grains component. Excessive sleepiness was negatively associated with the AHEI-2010 fruits, vegetables, red and processed meats, and Na components, and the HEI-2015 total vegetables, greens and beans, and seafood and plant proteins components. Excessive sleepiness also showed a positive association with the total protein foods HEI-2015 component. Although this seems counterintuitive, the total protein foods component of the HEI-2015 includes red meat, so this is consistent with the AHEI-2010 red meat component score. In addition, if the total proteins component is comprised mostly of red meat or other animal-based proteins (as opposed to plant- and seafood-based proteins), it is not counterintuitive that the association is in the opposite direction compared with the seafood and plant proteins component.

In the sensitivity analysis among those with previously collected diet data in 2001–2002 (*n* 386), there was minimal change in the results when previous diet measurements were included in the adjusted model (Fig. 1, Table S6). The associations detected in the main analysis remained statistically significant. In the sensitivity analysis of the association between excessive snoring and diet quality in the subsample that lives with their spouse (*n* 299), we observed an inverse association with AHEI in all models but the fully adjusted model (Table S7). In the subsample that does not live with a spouse (*n* 146), the results were inconsistent with the main analysis and in the unexpected direction. Associations in this sample were not statistically significant for the AHEI and HEI, but those with excessive snoring who do not live with a spouse had statistically significantly higher aMed scores in all models.

Discussion

In this study, having a high sleep apnoea risk based on the Berlin Q. was associated with lower diet quality after a mean follow-up of 5·8 years (mean AHEI-2010 score −2·3). Excessive sleepiness but not snoring was also associated with lower future diet quality. Mean differences in AHEI-2010 and HEI-2015 were −4·0 and −3·8 points, respectively, for those with compared to without excessive daytime sleepiness.

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Table 1. Description of participants in the total sample and by sleep apnoea risk at baseline (2007–2010), the Bogalusa Heart Study

	Total[a]		Sleep apnoea risk: low[b]		Sleep apnoea risk: high[b]		
	n 445		*n* 270		*n* 175		
	Mean	SD	Mean	SD	Mean	SD	*P*[c]
	Demographic characteristics at baseline (2007–2010)						
Age (years)	43·47	4·37	42·95	4·52	44·28	3·99	0·002
Male (%)	34·16		30·00		40·57		0·022
Black persons (%)	28·76		30·00		26·86		0·474
Education, high school or less (%)	36·63		34·44		40·00		0·235
Income at baseline							
<$15 000	19·78		18·15		22·29		0·390
$15 000–$30 000	17·30		18·89		14·86		
$30 000–$45 000	12·36		11·11		14·29		
>$45 000	50·56		51·85		48·57		
Employed (%)	65·17		65·19		65·14		0·993
Has health insurance (%)	72·58		70·37		76·00		0·194
Household size	3·30	1·29	3·39	1·34	3·15	1·20	0·061
Lives with spouse (%)	67·19		65·56		69·71		0·361
Children in house (%)	71·91		73·70		69·14		0·296
	Neighbourhood characteristics (census tract level, 2009 5-year American Community Survey)						
Total population (households)	2026·17	783·82	1964·74	696·96	2120·95	895·46	0·051
Median household income	33 374·16	13 295·03	33 232·84	13 834·19	33 487·71	12 418·18	0·844
% of households receiving food stamps	28·69	10·06	29·00	10·17	28·19	9·89	0·407
% of households with no vehicle	9·57	6·30	9·83	6·26	9·16	6·35	0·278
Index of Concentration at the Extremes	–0·10	0·20	–0·10	0·20	–0·10	0·20	0·888
MRFEI	11·46	9·20	11·87	9·27	10·83	9·08	0·246
	Health and lifestyle factors at baseline (2007–2010)						
Smoking status (%)							
Never	63·37		64·44		61·71		0·316
Former	14·61		12·59		17·71		
Current	22·02		22·96		20·58		
Current alcohol use (%)							
Non-drinker	34·61		33·70		36·00		0·732
Occasional drinker	40·00		39·63		40·57		
Regular drinker	25·39		26·67		23·43		
Physically active at work (%)	28·54		31·85		23·43		0·055
Physically active not at work (%)	25·62		32·22		15·43		<0·0001
Depressive symptoms (%)	26·29		20·37		35·43		0·0004
CES-D score	11·30	9·27	9·77	8·41	13·66	10·04	<0·0001
BMI (kg/m^2)	30·81	7·78	28·15	6·11	34·91	8·29	<0·0001
Obesity (%)	47·87		30·00		75·43		<0·0001
Waist circumference (cm)	98·66	16·24	92·76	13·20	107·76	16·31	<0·0001
	Diet at follow-up (2013–2016)						
AHEI-2010	45·50	9·74	46·16	9·65	44·47	9·81	0·073
HEI-2015	59·69	9·31	60·35	9·45	58·68	9·02	0·065
aMed	3·81	1·72	3·79	1·79	3·83	1·62	0·786
Total energy intake (kcal/d)	2195·30	946·66	2121·79	928·35	2308·71	965·96	0·042

MRFEI, Modified Retail Food Environment Index; CES-D, Center for Epidemiologic Studies Depression Scale; AHEI, Alternative Healthy Eating Index; HEI, Healthy Eating Index; aMed, alternate Mediterranean diet.
[a] Frequency (%) or mean ± SD among total sample.
[b] Frequency (%) or mean ± SD among column total (total in quintile).
[c] *P*-value from *t* test for continuous covariates and from Pearson's χ^2 test for independence for categorical covariates testing for differences by sleep apnoea risk.
Physically active: self-rating of 4 or 5 (active or very active) on five-point scale.
Index of Concentration at the Extremes: (((number of White householders with >$100 000 annual income) - (number of Black householders with <$25 000 annual income))/total households reporting income).
Occasional drinker: less than once a week; regular drinker: once or twice a week, or more.
Depressive symptoms are defined as CES-D ≥ 16.
Obesity is defined as BMI ≥ 30 kg/m^2.
High risk for sleep apnoea: positive on two of three categories on the Berlin Questionnaire.

Although we did not observe differences by sleep apnoea symptoms in the aMed dietary pattern, this may relate to the population-specific scoring used for the aMed (see online Supplementary Table S2). The BHS represents a largely rural, lower-income community that has less access to fresh and healthy foods. As a result, the aMed scores generated in this population may reflect a lower quality diet compared with the same aMed scores generated in a population with higher access to and intakes of healthy foods on average. Moreover, the differences observed between the AHEI-2010 and the HEI-2015 may reflect the AHEI-2010 as a more health-promoting diet compared with the HEI-2015. As described above, the HEI-2015 includes some components that contribute to a higher score that may health-neutral or even harmful such as the dairy products

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Table 2. Mean differences (95 % CI) in dietary pattern scores and total energy intake at follow-up (2013–2016 visit) for those with high sleep apnoea risk (*v.* low), excessive snoring (*v.* no excess snoring) and excessive sleepiness (*v.* no excess sleepiness) at baseline (2007–2010 visit) in the Bogalusa Heart Study (*n* 445)

		Model 1[a]		Model 2[b]		Model 3[c]		Model 4[d]	
Exposure	Outcome	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
High risk for sleep apnoea	AHEI	−1·70*	−3·34, −0·06	−1·85*	−3·33, −0·37	−1·95**	−3·35, −0·56	−2·32**	−3·84, −0·79
	HEI	−1·67	−3·38, 0·05	−1·64	−3·36, 0·08	−1·47	−3·16, 0·23	−1·49	−3·14, 0·16
	aMed	0·05	−0·17, 0·27	−0·08	−0·32, 0·15	−0·09	−0·32, 0·14	−0·13	−0·39, 0·13
Excessive snoring	AHEI	−1·15	−2·81, 0·51	−1·28	−2·90, 0·33	−1·27	−2·80, 0·27	−0·76	−2·38, 0·85
	HEI	−0·12	−2·36, 2·13	0·09	−2·08, 2·25	0·28	−1·95, 2·51	1·08	−1·02, 3·17
	aMed	0·02	−0·21, 0·26	−0·03	−0·29, 0·23	−0·02	−0·29, 0·26	0·03	−0·23, 0·29
Excessive daytime sleepiness	AHEI	−3·76**	−6·10, −1·42	−3·61**	−5·90, −1·32	−3·99***	−5·97, −2·00	−4·03***	−5·56, −2·50
	HEI	−3·46***	−5·46, −1·46	−3·47***	−5·40, −1·55	−3·36***	−5·24, −1·48	−3·79***	−5·51, −2·06
	aMed	−0·28	−0·81, 0·25	−0·41	−0·99, 0·18	−0·46	−1·03, 0·12	−0·53	−1·07, 0·00

AHEI, Alternate Healthy Eating Index, HEI, Healthy Eating Index; aMed, alternate Mediterranean diet; CES-D, Center for Epidemiologic Studies Depression Scale.
* $P<0.05$, ** $P<0.01$, *** $P<0.001$.
[a] Model 1: unadjusted.
[b] Model 2: total energy intake, age, sex and race.
[c] Model 3: model 2 + education (some college or more), employed, income category, spouse lives in house, children live is house, total population (households) in census tract, Index of Concentration at the Extremes (ICE) of census tract, percentage of households receiving food stamps/SNAP benefits in census tract and Modified Retail Food Environment Index of census tract.
[d] Model 4: model 3 + smoking status (never, former and current), drinking status (non-, occasional and regular drinker), physically active at work (4 or 5 on five-point scale), physically active when not at work (4 or 5 on five-point scale), BMI (kg/m^2), depressive symptoms (CES-D ≥ 16), excessive sleepiness is included when excessive snoring is the exposure of interest, excessive snoring is included in the model when excessive sleepiness is the exposure of interest.

and portions of the total proteins' components. Therefore, the AHEI-2010 may be a more sensitive outcome measure to capture lower diet quality and may explain why this dietary pattern was more strongly associated with sleep apnoea symptoms and sleepiness.

There is limited evidence from prospective observational studies for the influence of sleep disorders on future diet quality. Men in the HPFS with insomnia symptoms at baseline had lower AHEI-2010 scores, lower intakes of vegetables and higher total energy intake after 2 years of follow-up[9]. Our study looked at sleep apnoea and its symptoms rather than insomnia, but the results are in concordance given that we found associations between a common sleep disorder and a major symptom of insufficient sleep (sleepiness, which is also a primary symptom of insomnia) with lower AHEI-2010, HEI-2015 and vegetable intake. We did not use total energy intake as an outcome in this study since estimation of energy intake from FFQ may be unreliable[44].

There are several potential mechanisms by which sleep apnoea or its symptoms could lead to lower diet quality. Sleep apnoea often coincides with a deficiency in sleep quantity or quality, and daytime sleepiness is a primary symptom of sleep deficiency. Experimental evidence suggests several potential pathways that sleep deficiency may influence diet. Insufficient sleep may increase hunger by decreasing leptin and increasing ghrelin, appetite-regulating hormones[7,10,45,46]. Additionally, sleep deficiency may decrease reward sensitivity in the brain, stimulating a desire for higher intakes of energy-dense foods to achieve typical reward response from eating when eating for pleasure, also known as hedonic eating, which increases following sleep loss[47–51]. Emotional dysregulation/psychological distress is another potential mediator between inadequate sleep and diet quality[52]. Randomised crossover trials have shown that shortened sleep may influence preference for sweet-tasting foods and increase consumption of carbohydrates or energy-dense snacks, especially in the evening hours[7,8]. Another crossover trial found decreased intakes of added sugars after sleep extension among habitual short sleepers[53]. Although the evidence for these potential mechanisms stem from studies of sleep deficiency in general, rather than insufficient sleep or sleepiness caused specifically by sleep apnoea, we hypothesise that these same mechanisms would operate in the presence of sleep apnoea. In addition, it is possible that the chronic intermittent hypoxemia induced by sleep apnoea that inflicts neural injury associated with conditions such as sleepiness, depression and impaired memory may also influence dietary choices[54].

This study has several strengths. First, the prospective design greatly adds to the dearth of evidence for the relationship between any sleep domain or disorder and future diet quality. Although there was no simultaneous measure of diet at the baseline (sleep apnoea assessment time) for this study, we adjusted for an earlier measure of diet quality in sensitivity analyses to emulate a longitudinal design with repeated measures of the outcome and found no change in the overall findings. Second, we used the validated Berlin Q. which is easily adopted in clinical settings or other studies and diet was measured with a validated, culturally specific, quantitative FFQ.

Table 3. Mean differences (95 % CI) in AHEI-2010 component scores at follow-up (2013–2016 visit) by sleep apnoea risk and excessive sleepiness at baseline (2007–2010 visit) in the Bogalusa Heart Study (*n* 445)

		Exposure			
Outcome		High sleep apnoea risk (*v.* low sleep apnoea risk)		Excessive sleepiness (*v.* no excessive sleepiness)	
Component of AHEI-2010 dietary pattern	Score range	Mean	95 % CI	Mean	95 % CI
1. Fruits	0–10	−0·03	−0·44, 0·37	−0·72*	−1·37, −0·07
2. Vegetables (not potatoes)	0–10	−0·09	−0·50, 0·31	−0·97*	−1·86, −0·07
3. Nuts and legumes	0–10	−0·06	−0·25, 0·80	0·12	−0·32, 0·57
4. Whole grains	0–10	−0·59***	−0·91, −0·26	−0·37	−0·88, 0·13
5. Long chain (*n*-3) fats	0–10	−0·41	−0·83, 0·00	−0·39	−0·97, 0·18
6. Polyunsaturated fats	0–10	−0·05	−0·49, 0·39	0·29	−0·14, 0·72
7. Sugar-sweetened beverages and fruit juice	0–10	−0·68**	−1·16, −0·19	−0·74	−1·58, 0·11
8. Red and processed meats	0–10	−0·08	−0·36, 0·20	−0·54*	−0·98, −0·09
9. *trans*-fats	0–10	−0·22	−0·57, 0·13	−0·19	−0·45, 0·07
10. Na	0–10	−0·25	−0·73, 0·22	−0·41*	−0·79, −0·02
11. Alcohol	0–10	0·16	−0·39, 0·71	−0·13	−0·85, 0·60
Component of HEI-2015 dietary pattern					
1. Total fruits	0–5	0·03	−0·28, 0·35	−0·47	−0·96, 0·01
2. Whole fruits	0–5	0·03	−0·36, 0·43	−0·30	−0·66, 0·05
3. Total vegetables	0–5	−0·10	−0·34, 0·14	−0·39*	−0·78, −0·01
4. Greens and beans	0–5	−0·14	−0·46, 0·19	−0·52**	−0·88, −0·16
5. Whole grains	0–10	−0·50**	−0·82, −0·19	−0·27	−0·76, 0·23
6. Dairy products	0–10	−0·20	−0·60, 0·20	0·13	−0·52, 0·77
7. Total protein foods	0–5	−0·00	−0·10, 0·09	0·13**	0·05, 0·21
8. Seafood and plant proteins	0–5	−0·15	−0·37, 0·07	−0·23*	−0·42, −0·04
9. Fatty acids ratio	0–10	−0·06	−0·53, 0·40	−0·25	−0·72, 0·23
10. Refined grains	0–10	−0·28	−0·70, 0·13	−0·34	−0·74, 0·06
11. Added sugars	0–10	0·12	−0·32, 0·55	−0·18	−0·92, 0·56
12. Saturated fats	0–10	−0·16	−0·67, 0·34	−0·73	−1·54, 0·08
13. Na	0–10	−0·07	−0·81, 0·66	−0·37	−0·95, 0·22

AHEI, Alternate Healthy Eating Index, HEI, Healthy Eating Index; CES-D, Center for Epidemiologic Studies Depression Scale.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
Model adjusted for: total energy intake, age, sex, race, education (some college or more), employed, income category, spouse lives in house, children live is house, total population (households) in census tract, Index of Concentration at the Extremes (ICE) of census tract, percentage of households receiving food stamps/SNAP benefits in census tract, Modified Retail Food Environment Index (MRFEI) of census tract, smoking status (never, former, current), drinking status (non-, occasional, regular drinker), physically active at work (4 or 5 on 5-point scale), physically active when not at work (4 or 5 on 5-point scale), BMI (kg/m^2), depressive symptoms (CES-D ≥ 16), excessive snoring is included in the model when excessive sleepiness is the exposure of interest.

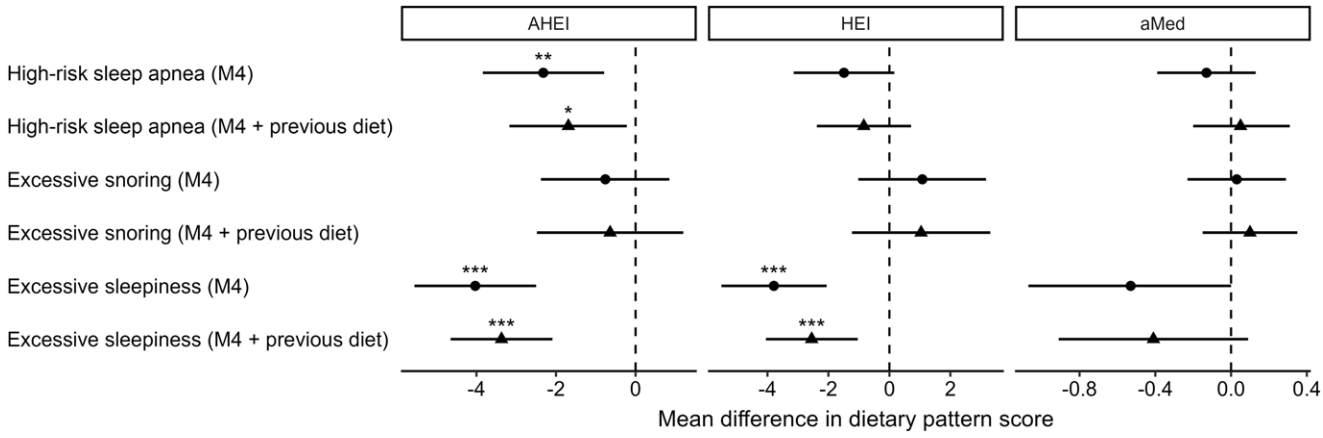

Fig. 1. Adjusted mean differences in dietary pattern scores comparing those with high risk for sleep apnoea, excessive snoring or excessive sleepiness to those without. The figure compares estimates from the fully adjusted model 4 (M4), indicated by circles, to a model with further adjustment for the dietary pattern scores measured at a visit prior to the sleep apnoea assessment (diet measured at the 2001 visit), indicated by triangles. Estimates and 95 % CI are from multivariable linear regression to estimate mean differences in the continuous dietary pattern scores: the Alternate Healthy Eating Index 2010 (AHEI), the Healthy Eating Index 2015 (HEI) and the aMed dietary pattern. Sample size for model 4 was 445; sample size for model 4 + previous diet was 386. The following covariates were included in model 4 (labelled M4 in figure): total energy intake, age, sex, race, education (some college or more), employed, income category, spouse lives in house, children live is house, total population (households) in census tract, Index of Concentration at the Extremes (ICE) of census tract, percentage of households receiving food stamps/SNAP benefits in census tract, Modified Retail Food Environment Index (MRFEI) of census tract, smoking status (never, former and current), drinking status (non-, occasional and regular drinker), physically active at work (4 or 5 on five-point scale), physically active when not at work (4 or 5 on five-point scale), BMI (kg/m^2), depressive symptoms (CES-D ≥ 16), excessive snoring is included in the model when excessive sleepiness is the exposure of interest and vice versa. Statistical significance indicated as follows: * $P < 0{\cdot}05$; ** $P < 0{\cdot}01$; *** $P < 0{\cdot}001$. CES-D, Center for Epidemiologic Studies Depression Scale.

Third, we estimated differences in future diet quality after controlling for many potential confounders, including BMI, depressive symptoms, physical activity and socio-economic factors at multiple levels, incorporating relevant neighbourhood-level including measures of segregation, the food environment and the proportion of households relying on supplemental nutrition assistance. Additionally, the BHS cohort is unique in that it represents a lower-income, semi-rural community with a high proportion from a minoritised population. This population is illustrative of many communities in the southeastern USA that collectively share a disproportionately high burden of CMD. These results should be generalisable to many such communities. Although replication is needed, these results could inform intervention approaches in such communities where it has been especially difficult to implement effective dietary changes and reduce CMD risk.

This study has some limitations, particularly the lack of baseline measures of diet at the time of the sleep assessment. Although we cannot determine that sleep apnoea risk and symptoms came before the onset of poor diet quality, as required for any causal conclusions, the results were robust to controlling for an earlier measure of diet quality. Nonetheless, additional studies are needed with true longitudinal designs. We used validated instruments for sleep apnoea and dietary intake, but they are not objective measures and may be subject to recall bias. The FFQ requires individuals to recall their usual diet over the past year. While this method may not capture absolute individual-level intakes with perfect accuracy, it has been recognised as a good approach to measure habitual diet in large samples and conduct group-level comparisons[55]. Sleep apnoea is a heterogeneous sleep disorder, and the Berlin Q. is not a diagnostic tool for sleep apnoea. These results should be interpreted relevant to the specific symptom descriptions of snoring and sleepiness in the questionnaire and likely does not represent a gold standard polysomnographic diagnosis of sleep apnoea. Snoring in particular may be biased when relying on self-report, since some people do not know if they snore, especially when they live alone (although our primary analysis controls for the presence of spouse and children in the house)[39]. Although it is difficult to know the full extent or true impact of this, in a hypothetical scenario where more married participants accurately reported sleep apnoea symptoms than unmarried participants and if marital status associated with higher diet quality, then it is possible that the association reported here is an underestimate of the true association. Our sensitivity analysis in the subsample who lives with their spouse supports this, where we observed the hypothesised inverse relationship between snoring and lower AHEI diet quality which was statistically significant in all models until the fully adjusted model. If the assessment of snoring was more accurate in this subsample, it is possible that the observed associations for both snoring and sleep apnoea risk were diluted in the full sample by the less accurate identification of snoring in the sample not living with a spouse. While we adjusted for many potential confounders, including several area-level environmental factors, observational designs can never eliminate the possibility of residual confounding. For example, physical activity is particularly difficult to measure without bias using self-report tools[56], as done here, which potentially contributed residual confounding. However, we cannot know how this may have impacted the results. Even if we assumed participants over-reported physical activity, we cannot know if this misclassification was differential across any groups that also differed on the exposure or outcome. Other potential sources of confounding are environmental factors that increase risk of sleep apnoea, such as poor air quality, which may be higher in the same areas that have minimal access to healthy foods. Our inability to control all such factors could lead to residual confounding. However, including the area-level MRFEI and ICE measures in the adjusted model greatly minimises this risk. The results for differences in individual components of dietary patterns should be interpreted cautiously, since the larger number of tests performed increases our potential type 1 error. However, these tests were planned *a priori*. In addition, our available sample size may have limited our power to detect some associations, especially among smaller strata when assessing interaction effects. Finally, there were differences in certain characteristics between the included sample and those who were excluded for missing follow-up dietary data or baseline covariate information. These exclusions limit the generalisability of our results slightly from what the entire BHS cohort represents but does not impact the validity of these findings.

High sleep apnoea risk and excess sleepiness were associated with lower diet quality after an average of 5·8 years of follow-up in the community-based BHS cohort. Future research should include true longitudinal designs with repeated measures of both exposure and outcome, assessment of potential mediating mechanisms such as impacts on appetite and food cravings, and eventually an interventional study to see if treatment of sleep apnoea and its symptoms resulted in an improvement in diet quality. If replicated and determined to be a causal association, these results suggest that individuals with sleep apnoea or who regularly experience excessive sleepiness should be monitored for diet quality and may be targeted for dietary interventions to improve risk for many chronic diseases. In addition, it may be important to address sleep health, for example, sleep apnoea and sleepiness, among participants of dietary interventions to improve success.

Acknowledgements

Funding was provided by the National Heart, Lung, And Blood Institute of the National Institutes of Health under Award Number F31HL151232 and T32HL007901 (K.S.P.), the National Institute of Aging, grant number R01AG041200 (L.A.B. and K.S.P.), and the National Institute of General Medical Studies, grant number 2P20GM109036. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

The authors' responsibilities were as follows: K. S. P., M. E. W., J. G., S. H. L., L. Q. and L. A. B. designed research; K. S. P. and L. A. B. conducted research; K. S. P. analysed data; K. S. P. and L. A. B. wrote the paper. K. S. P. had primary responsibility for final content. All authors read and approved the final manuscript.

The authors declare none.

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114524001387

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