2016

Bisphenol-A and Sleep Adequacy Among Adults in the National Health and Nutrition Examination Surveys

Hind A. Beydoun

May A. Beydoun

Hueiwang Anna Jeng
Old Dominion University, hjeng@odu.edu

Alan B. Zonderman

Shaker M. Eid

Original Publication Citation

Beydoun, H. A., Beydoun, M. A., Jeng, H. A., Zonderman, A. B., & Eid, S. M. (2016). Bisphenol-A and sleep adequacy among adults in the national health and nutrition examination surveys. *Sleep, 39*(2), 467-476. doi:10.5665/sleep.5466

pii: sp-00144-15 http://dx.doi.org/10.5665/sleep.5466

SLEEP DURATION/SLEEP QUALITY

Bisphenol-A and Sleep Adequacy among Adults in the National Health and Nutrition Examination Surveys

Hind A. Beydoun, PhD, MPH[1]; May A. Beydoun, PhD, MPH[2]; Hueiwang Anna Jeng, ScD[3]; Alan B. Zonderman, PhD[2]; Shaker M. Eid, MD, MBA[4]

[1]Graduate Program in Public Health, Eastern Virginia Medical School, Norfolk, VA; [2]Laboratory of Epidemiology and Population Sciences, National Institute on Aging Intramural Research Program, Baltimore, MD; [3]Department of Community & Environmental Health, Old Dominion University, Norfolk, VA; [4]Department of Medicine, Johns Hopkins University School of Medicine, Baltimore, MD

Study Objectives: To evaluate bisphenol-A (BPA) level and its relationship to sleep adequacy in a nationally representative sample of U.S. adults.
Methods: A population-based cross-sectional study was conducted using 2005–2010 National Health and Nutrition Examination Survey whereby data were collected using in-person interviews, physical examination and laboratory testing. BPA level was measured in urine samples and analyzed as $\log_e$-transformed variable and in quartiles (< 0.9 ng/mL; 0.9 to < 1.9 ng/mL; 1.9 to < 3.7 ng/mL; 3.7+ ng/mL). Sleep adequacy was operationalized with three questions: "How much sleep do you usually get at night on weekdays or workdays?", "Have you ever told a doctor or other health professionals that you have trouble sleeping?" and "Have you ever been told by a doctor or other health professional that you have a sleep disorder?" Sleep duration was further categorized as (< 6 h, ≥ 6 h); (< 7 h, 7–8 h, > 8 h); (< 5 h, 5–6 h, 7–8 h, ≥ 9 h). Linear, binary, and ordinal logistic regression models were constructed.
Results: $\log_e$-transformed BPA level was inversely related to sleep duration defined, in hours, as a continuous variable, a dichotomous variable (≥ 6, < 6), or an ordinal variable (≥ 9, 7–8, 5–6, < 5), after adjustment for confounders. Help-seeking behavior for sleep problems and diagnosis with sleep disorders were not significantly associated with $\log_e$-transformed BPA level in fully adjusted models.
Conclusions: $\log_e$-transformed BPA level may be associated with fewer hours of sleep among U.S. adults, with implications for prevention. Further research involving diverse populations are needed to confirm these study findings.
Keywords: bisphenol-A, endocrine disruptor, sleep duration, sleep disorder, survey
Citation: Beydoun HA, Beydoun MA, Jeng HA, Zonderman AB, Eid SM. Bisphenol-A and sleep adequacy among adults in the National Health and Nutrition Examination Surveys. *SLEEP* 2016;39(2):467–476.

Significance
Among U.S. adults who participated in the 2005–2010 National Health and Nutrition Examination Surveys, an inverse relationship may exist between urinary $\log_e$-transformed bisphenol-A level and sleep duration, but not with diagnosis or treatment for sleep problems.

INTRODUCTION

Growing evidence has implicated sleep as a key player in the regulation of appetite, metabolic and immune functions.[1] In recent studies, suboptimal sleep duration has been linked to serious health problems, including obesity, insulin resistance, type 2 diabetes, hypertension, metabolic syndrome, cardiovascular disease, and cancer.[2–41] Sleep disorders, described as difficulty initiating or maintaining sleep or non-restorative sleep, are highly prevalent and often under-diagnosed in the U.S.[42,43] In particular, 10% to 15% of U.S. adults are affected by insomnia.[44] Also, 3% to 7% of men and 2% to 5% of women have diagnoses of obstructive sleep apnea (OSA), whereas 82% of men and 93% of women with moderate to severe OSA may be undiagnosed.[45]

Identification of modifiable risk/protective factors for inadequate sleep is a prerequisite for the design, implementation, and evaluation of preventive strategies aimed at reducing its health impact. Whereas dietary habits[46,47] and sedentary lifestyle[48–54] have recently been correlated with sleep, little research has been done on endocrine disruptors. Bisphenol-A (BPA) is a carbon-based synthetic compound used in the manufacturing of polycarbonate plastics, epoxy resins, and food and beverage containers.[55–59] It is a ubiquitous endocrine disruptor with estrogenic activity and is known to exert a wide variety of metabolic effects leading to reproductive and thyroid hormone dysregulation, weight gain, glucose intolerance, insulin resistance, type 2 diabetes, metabolic syndrome, cardiovascular disease, and fatty liver disease.[60–69] Recent literature reviews have pointed out the heterogeneity of epidemiologic evidence linking BPA exposure to various health outcomes, rendering the magnitude of the association difficult to estimate via meta-analyses.[70–72] BPA may impact suboptimal sleep and sleep disorders indirectly via its potential role in cardiometabolic risk factors and health problems.[60–69] A direct impact of BPA on the muscle function in the upper airway leading to OSA has also been suggested based on analogous findings from biomedical research.[73] Although the link between BPA and sleep appears to be biologically plausible, to date, only one study has correlated sleep issues with high levels of BPA.[73]

The aim of this cross-sectional study is to evaluate level of BPA and its relationship to sleep adequacy (sleep duration, help-seeking behavior for sleep problems, and diagnosis with sleep disorders) in a nationally representative sample of U.S. adults, by performing secondary analyses using 2005–2010 National Health and Nutrition Examination Surveys (NHANES) data. We hypothesize that BPA level is inversely related to sleep duration and has a negative impact on sleep problems and disorders.

METHODS

National Health and Nutrition Examination Surveys 2005–2010

The NHANES is a program of studies conducted by the National Center for Health Statistics, a division of the Centers for Disease Control and Prevention (CDC), to assess the health and nutritional status of U.S. children and adults and to determine the prevalence of major diseases and their risk factors.[74,75] The NHANES uses stratified multistage cluster sampling with

oversampling of African Americans, Asians, Hispanics and adults 60 years and older.[74] Demographic, socioeconomic, and nutritional data were collected through in-person interviews, physical examinations and laboratory tests.[74,75]

Study Participants

Since 1999, NHANES has become a continuous surveillance system. We selected 31,034 NHANES participants from three consecutive waves, namely, 2005–2006 (n = 10,348), 2007–2008 (n = 10,149), and 2009–2010 (n = 10,537).We excluded pregnant women (n = 507), individuals younger than 20 years (n = 13,902), and those with missing data on BPA (n = 23,133) and/or sleep-related questions (n = 11,467). The final sample consisted of adult non-pregnant 2005–2010 NHANES participants who were 20 years or older, and had no missing data on key variables of interest (n = 5,034).

Variable Definitions

Bisphenol-A Level

Spot urine samples were obtained from a one-third random subset of NHANES participants. Total urinary BPA, both conjugated and free, was analyzed by online solid-phase extraction coupled to high performance liquid chromatography (HPLC)-isotope dilution tandem mass spectrometry by the Division of Environmental Health Laboratory Sciences at the National Center for Environmental Health, CDC.[68] The details of quality assurance and quality control procedures, including coefficients of variation (CV of 8.1% to 18.6% for the low BPA quality control pools and 5.7% to 12.1% for the high BPA quality control pools) and lower limits of detection (LLOD/$\sqrt{2}$ or 0.28 ng/mL), were described elsewhere.[68] After careful examination of its distributional properties, we analyzed BPA level as a $\log_e$-transformed continuous variable and in quartiles (< 0.9 ng/mL; 0.9 to < 1.9 ng/mL; 1.9 to < 3.7 ng/mL; 3.7+ ng/mL). We used quartiles instead of tertiles or quintiles to maximize our ability to detect a relative risk of ~1.3, assuming that the proportion having the outcome is 0.1 with $\alpha = 0.05$ and $\beta = 0.2$.

Sleep Adequacy

Three questions related to sleep adequacy were available in all 3 waves (2005–2006, 2007–2008, and 2009–2010) of NHANES data as follows: "How much sleep do you usually get at night on weekdays or workdays?" (Q1: Sleep duration), "Have you ever told a doctor or other health professionals that you have trouble sleeping?"(Q2: Help-seeking behavior for sleep problems) and "Have you ever been told by a doctor or other health professional that you have a sleep disorder?" (Q3: Diagnosis with sleep disorders). Responses to Q1 were measured on a continuous scale as number of hours, and responses to Q2 and Q3 were dichotomous "yes" or "no"[76]; Q1 was also analyzed as a categorical variable using 3 distinct definitions based on recent studies of NHANES data, namely: definition 1 ("short sleep (yes): < 6 h," "short sleep (no): ≥ 6 h");[43] definition 2 ("short sleep: < 7 h," "normal sleep: 7–8 h," "long sleep: > 8 h");[76] definition 3 ("very short sleep: < 5 h," "short sleep: 5–6 h," "normal sleep: 7–8 h," "long sleep: ≥ 9 h").[77]

Covariates

Selected demographic, socioeconomic, lifestyle, and health characteristics were considered as a priori confounders for the hypothesized relationships between BPA level and sleep adequacy, based on the literature.[42,43,45,74–83] These include sex (male, female), *age* (< 30, 30–39, 40–49, 50–59, 60+ years), race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Hispanic, Other), education (less than high school, high school, more than high school), marital status (married/cohabiting, not married), poverty income ratio (continuous; < 100%, 100% to < 200%, ≥ 200%), smoking status (Current smoker, Ex-smoker, Never smoker), alcohol consumption (≥ 12 glasses in the past 12 months) (yes/no), body mass index (BMI) (< 25, 25 to < 30, 30+ kg/m^2), waist circumference (High: ≥ 102 cm (40 in) in men or ≥ 88 cm (35 in) in women vs. Low: < 102 cm (40 in) in men or < 88 cm (35 in) in women), self-rated health (excellent/very good/good, fair/poor), depressive symptoms based on the 9-item Patient Health Questionnaire (PHQ) total score (High: ≥ 10, Low: < 10), and adjusted creatinine level which was calculated based on equations described by Silver and coworkers.[68] Of note, the normal creatinine levels are estimated to be 0.6 to 1.2 mg/dL in adult males and 0.5 to 1.1 mg/dL in adult females.

Statistical Analysis

Statistical analyses were performed using STATA version 12 (STATA Corporation, College Station, TX). Whereas frequencies and percentages were computed for categorical variables, means and standard errors of the mean (SEM) were computed for continuous variables. Unadjusted (Model I), age- and sex-adjusted (Model II) as well as fully adjusted (Model III) models were constructed for BPA as a predictor of sleep adequacy, using 'svy:reg' for continuous outcomes, 'svy:logit' for binary outcomes and 'svy:ologit' for ordinal outcomes. Measures of association were presented as beta coefficients with their 95% confidence intervals (CI) for linear regression models and odds ratios (OR) with their 95% CI for logistic regression models. Sampling weights were used to produce correct population estimates accounting for differential probabilities of selection and adjusting for non-coverage, non-response, and over-sampling of subpopulations. Two-sided statistical tests were performed at an α level of 0.05.

RESULTS

Between 2005 and 2010, 5,034 participants met inclusion criteria in this study; 2,564 were men and 2,470 were women. Table 1 details the demographic, socioeconomic, lifestyle, and health characteristics of the study participants by sex. Overall, the mean (± SEM) for age, BMI, waist circumference, depressive symptoms, and adjusted creatinine level were 47.0 ± 0.35 years, 28.7 ± 0.1 kg/m^2, 97.9 ± 0.4 cm, 2.8 ± 0.08, and 909614.2 ± 13896.9 mg/dL, respectively. Furthermore, 24% were ≥ 60 years, 70% were non-Hispanic White, 57% had more than high school education, 58% were married, 63% had poverty income ratio > 2, 53% never smoked, and 76% drank alcohol in the past 12 months. Also, 35% had BMI ≥ 30 kg/m^2, 52% had a high waist circumference, 84% had excellent, very good, or good self-rated health, and 6% had high

Table 1—Demographic, socioeconomic, lifestyle and health characteristics of study sample by sex: National Health and Nutrition Examination Surveys 2005–2010 (n = 5,034).

	Total (n = 5,034)	Males (n = 2,564)	Females (n = 2,470)	P value
Age (years)	n = 5,034	n = 2,564	n = 2,470	
Mean ± SEM	47.0 ± 0.35	45.9 ± 0.5	48.1 ± 0.4	0.001
Categorical				0.03
< 30	18.2	19.9	16.6	
30–39	18.2	18.9	17.4	
40–49	21.1	20.9	21.3	
50–59	18.7	18.6	18.8	
≥ 60	23.8	21.6	25.9	
Race	n = 5,034	n = 2,564	n = 2,470	0.1
White	70.5	70.3	70.7	
Black	11.3	10.5	12.1	
Hispanic	12.4	13.5	11.4	
Other	5.8	5.7	5.9	
Education	n = 5,028	n = 2,562	n = 2,466	0.5
Less than high school	18.4	19.0	17.9	
High school	24.9	24.3	25.5	
More than high school	56.6	56.7	56.6	
Marital status	n = 5,030	n = 2,562	n = 2,468	0.0001
Married	58.3	61.9	54.7	
Not married	41.7	38.1	45.3	
Poverty income ratio	n = 5,025	n = 2,561	n = 2,464	0.0007
< 1	18.5	16.6	20.3	
1–2	18.9	18.1	19.7	
≥ 2	62.6	65.2	60.0	
Smoking status	n = 5,030	n = 2,562	n = 2,468	< 0.0001
Current smoker	22.8	24.9	20.7	
Ex-smoker	24.8	28.0	21.6	
Never smoker	52.5	47.1	57.7	
Alcohol (past 12 months)	n = 4,608	n = 2,365	n = 2,243	< 0.0001
Yes	76.0	85.6	66.5	
No	23.9	14.4	33.5	
Body mass index (kg/m^2)	n = 4,987	n = 2,534	n = 2,453	
Mean ± SEM	28.7 ± 0.1	28.8 ± 0.2	28.5 ± 0.2	0.2
Categorical				< 0.0001
< 25	32.0	26.6	37.2	
25–30	32.9	38.4	27.8	
≥ 30	34.9	34.9	34.9	
Waist circumference (cm)*	n = 5,034	n = 2,564	n = 2,470	
Mean ± SEM	97.9 ± 0.4	101.4 ± 0.5	94.7 ± 0.4	< 0.0001
Categorical				< 0.0001
High	51.8	43.3	60.0	
Low	48.2	56.7	39.9	
Self-rated health	n = 4,622	n = 2,373	n = 2,249	0.6
Excellent/Very good/Good	83.5	83.8	83.1	
Fair/Poor	16.5	16.2	16.9	
Depressive symptoms	n = 5,034	n = 2,564	n = 2,470	
Mean ± SEM	2.8 ± 0.08	2.3 ± 0.08	3.2 ± 0.1	< 0.0001
Categorical				0.0001
High (≥ 10)	5.9	4.4	7.3	
Low (< 10)	94.1	95.6	92.7	
Creatinine (mg/dL) – adjusted	n = 5,034	n = 2,564	n = 2,470	< 0.0001
Mean ± SEM	909614.2 ± 13896.9	1092170 ± 18177.8	731908.2 ± 18516.82	

*"High" refers to waist circumference > 102 cm in males and > 88 cm in females.

Table 2—Urinary bisphenol level and sleep adequacy of study sample by sex: National Health and Nutrition Examination Surveys 2005–2010 (n = 5,034).

	Total (n = 5,034)	Males (n = 2,564)	Females (n = 2,470)	P value
Bisphenol-A (ng/ml)	n = 5,034	n = 2,564	n = 2,470	
Mean ± SEM	4.2 ± 0.4	4.4 ± 0.5	4.0 ± 0.4	< 0.0001†
Quartiles				0.0001
< 0.9	23.3	19.4	27.1	
0.9–1.9	26.1	27.0	25.2	
1.9–3.7	25.9	28.3	23.6	
≥ 3.7	24.7	25.3	24.2	
Sleep duration	n = 5,023	n = 2,560	n = 2,463	
Mean ± SEM	6.9 ± 0.03	6.8 ± 0.03	6.9 ± 0.03	0.002
Categorical 1	n = 5,023	n = 2,560	n = 2,463	0.11
< 6	12.8	13.8	11.8	
≥ 6	87.2	86.2	88.2	
Categorical 2	n = 5,023	n = 2,560	n = 2,463	0.001
< 7	37.9	39.3	36.6	
7–8	55.3	55.3	55.3	
> 8	6.8	5.4	8.1	
Categorical 3	n = 5,023	n = 2,560	n = 2,463	0.004
< 5	4.6	4.7	4.4	
5–6	33.3	34.6	32.2	
7–8	55.3	55.3	55.3	
≥ 9	6.8	5.4	8.1	
Ever told doctor had trouble sleeping	n = 5,029	n = 2,561	n = 2,468	< 0.0001
Yes	24.2	19.9	28.3	
No	75.8	80.1	71.7	
Ever told by doctor had sleeping disorder	n = 5,026	n = 2,558	n = 2,468	0.03
Yes	7.7	8.8	6.6	
No	92.3	91.2	93.4	

†Log-transformed values were compared according to sex.

depressive symptoms. All these characteristics differed significantly by sex, with the exception of race, education, and self-rated health.

BPA levels and sleep adequacy of the study participants by sex are presented in Table 2. Overall, the mean (± SEM) for BPA level and duration of sleep were 4.2 ± 0.4 ng/mL and 6.9 ± 0.03 h, respectively. Furthermore, 87% reported sleeping ≥ 6 h, 55% 7 to 8 h, and 7% ≥ 9 h. Moreover, 24% reported ever telling a doctor that they had trouble sleeping, and only 8% were ever diagnosed with a sleep disorder. All these characteristics were significantly different among men and women, with the exception of the binary definition (< 6 h vs. ≥ 6 h) of sleep duration.

Table 3 presents urinary BPA level as a predictor of sleep duration defined as a continuous or categorical variable in unadjusted (Model I), sex- and age-adjusted (Model II), and fully adjusted (Model III) models. As expected, an inverse relationship was observed between sleep duration, defined as a continuous variable, and $\log_e$-transformed BPA level in all three models (Model I: −0.06 [−0.09, −0.02]; Model II: −0.06 [−0.09, −0.02]; Model III: −0.05 [−0.09, −0.002]). Taking the lowest quartile as a referent group, the upper quartile of BPA was inversely related to sleep duration, defined as a continuous variable, in the unadjusted (β = −0.2, 95% CI: −0.3, −0.03) as well as sex- and age-adjusted model (β = −0.2, 95% CI: −0.3, −0.03), but not the fully adjusted model (β = −0.12, 95% CI: −0.3, 0.02). The categorical definitions 1 (short sleep (yes): < 6 h, short sleep (no): ≥ 6 h) and 3 (very short sleep: < 5 h, short sleep: 5–6 h, normal sleep: 7–8 h, long sleep: ≥ 9 h) for sleep duration were inversely and significantly related to $\log_e$-transformed BPA level in unadjusted, sex- and age-adjusted and fully adjusted models. By contrast, the categorical definition 2 (short sleep: < 7 h, normal sleep: 7–8 h, long sleep: > 8 h) for sleep duration was inversely and significantly related to $\log_e$-transformed BPA level only in the unadjusted and sex- and age-adjusted models. When defined as quartiles, BPA level was inversely and significantly related to categorical definition 1 of sleep duration in the unadjusted model as well as categorical definitions 2 and 3 of sleep duration in the unadjusted and sex- and age-adjusted models.

Table 4 presents urinary BPA level as a predictor of self-reported sleep problems in unadjusted, sex- and age-adjusted and fully adjusted models. Clearly, only unadjusted models yielded significant and positive relationships between having told a doctor that he/she had trouble sleeping and urinary BPA level defined either as a continuous variable (OR = 1.08, 95% CI: 1.01, 1.16) or in quartiles (Q4 vs. Q1: OR = 1.24, 95% CI: 1.01, 1.52). By contrast, no significant relationship was observed between urinary BPA level and ever being told by a doctor that he/she had a sleeping disorder in the 3 models.

Table 3—Urinary bisphenol level as a predictor of sleep duration defined as a continuous or categorical variable.

	Model I: Unadjusted	Model II: Age-and-Sex Adjusted	Model III: Fully Adjusted
Sleep duration (hours) – Continuous	β (95% CI)	β (95% CI)	β (95% CI)
Urinary bisphenol level (ng/mL) – Continuous	−0.06 (−0.09, −0.02)	−0.06 (−0.09, −0.02)	−0.05 (−0.09, −0.002)
Urinary bisphenol level (ng/mL) – Quartiles	P = 0.007	P = 0.006	P = 0.1
< 0.9	Ref.	Ref.	Ref.
0.9–1.9	−0.05 (−0.18, 0.08)	−0.05 (−0.18, 0.09)	−0.08 (−0.2, 0.06)
1.9–3.7	−0.1 (−0.3, −0.01)	−0.1 (−0.2, 0.008)	−0.09 (−0.2, 0.04)
≥ 3.7	−0.2 (−0.3, −0.03)	−0.2 (−0.3, −0.03)	−0.12 (−0.3, 0.02)
Hours of sleep – Categorical 1	OR (95% CI)	OR (95% CI)	OR (95% CI)
Urinary bisphenol level (ng/mL) – Continuous	0.87 (0.79, 0.94)	0.87 (0.79, 0.95)	0.88 (0.79, 0.98)
Urinary bisphenol level (ng/mL) – Quartiles	P = 0.02	P = 0.03	P = 0.1
< 0.9	Ref.	Ref.	Ref.
0.9–1.9	1.03 (0.78, 1.36)	1.04 (0.79, 1.38)	0.94 (0.70, 1.26)
1.9–3.7	0.77 (0.57, 1.04)	0.79 (0.58, 1.08)	0.79 (0.57, 1.11)
≥ 3.7	0.73 (0.53, 0.99)	0.73 (0.52, 1.02)	0.76 (0.52, 1.11)
	Model I: Unadjusted	**Model II: Age-and-Sex Adjusted**	**Model III: Fully Adjusted***
Sleep duration (hours) – Categorical 2	OR (95% CI)	OR (95% CI)	OR (95% CI)
Urinary bisphenol level (ng/mL) – Continuous	0.93 (0.88, 0.98)	0.93 (0.88, 0.98)	0.97 (0.91, 1.03)
Urinary bisphenol level (ng/mL) – Quartiles	P < 0.0001	P = 0.02	P = 0.44
< 0.9	Ref.	Ref.	Ref.
0.9–1.9	0.88 (0.69, 1.12)	0.88 (0.69, 1.12)	0.85 (0.65, 1.12)
1.9–3.7	0.91 (0.73, 1.13)	0.91 (0.73, 1.14)	0.99 (0.75, 1.32)
≥ 3.7	0.77 (0.63, 0.93)	0.77 (0.63, 0.93)	0.86 (0.68, 1.08)
Sleep duration (h) – Categorical 3	OR (95% CI)	OR (95% CI)	OR (95% CI)
Urinary bisphenol level (ng/mL) – Continuous	0.81 (0.70, 0.93)	0.78 (0.67, 0.91)	0.79 (0.67, 0.94)
Urinary bisphenol level (ng/mL) – Quartiles	P = 0.03	P = 0.02	P = 0.06
< 0.9	Ref.	Ref.	Ref.
0.9–1.9	0.98 (0.57, 1.69)	0.94 (0.55, 1.62)	0.92 (0.49, 1.75)
1.9–3.7	0.71 (0.42, 1.19)	0.65 (0.38, 1.13)	0.69 (0.39, 1.22)
≥ 3.7	0.62 (0.39, 0.99)	0.56 (0.34, 0.93)	0.63 (0.35, 1.12)

*Adjusted for sex (male, female), age (< 30, 30–39, 40–49, 50–59, ≥ 60 years), race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Hispanic, Other), education (less than high school, high school, more than high school), marital status (married/cohabiting, not married), poverty income ratio (continuous; < 100%, 100%–200%, ≥ 200%), smoking status (current smoker, ex-smoker, never smoker), alcohol consumption (at least 12 glasses in the past 12 months) (yes, no), body mass index (BMI) (< 25, 25–30, ≥ 30 kg/m^2), waist circumference (High: ≥ 102 cm (40 in) in men or ≥ 88 cm (35 in) in women vs. Low: < 102 cm (40 in) in men or < 88 cm (35 in) in women), self-rated health (excellent/very good/good, fair/poor), depressive symptoms based on the 9-item Patient Health Questionnaire (PHQ) total score (high: ≥ 10, low: < 10) and adjusted creatinine level.

DISCUSSION

In this cross-sectional study, we investigated whether BPA was associated with sleep adequacy in a nationally representative sample of U.S. adults in whom self-reported sleep duration, help-seeking behavior for sleep problems, and diagnosis with sleep disorders were considered as the main outcomes of interest. Consistent with our hypotheses, the results indicated that $\log_e$-transformed BPA level was inversely related to sleep duration defined, in hours as a continuous variable, a dichotomous variable (≥ 6 vs. < 6) or an ordinal variable (≥ 9, 7–8, 5–6, < 5), after adjustment for confounders. By contrast, help-seeking behavior for sleep problems and diagnosis with sleep disorders were not significantly associated with $\log_e$-transformed BPA level in the fully adjusted models. Also, when BPA level was defined in quartiles, its relationship with sleep adequacy did not reach statistical significance after controlling for demographic, lifestyle, and health characteristics of the study sample. The latter finding suggests a complex nonlinear relationship between BPA and indicators of sleep adequacy.

Emerging evidence suggests that BPA, atrazine, dichlorodiphenyltrichloroethane, diethylstilbestrol, dioxin, phthalates, polychlorinated biphenyls, organotins, and other endocrine disruptors may have negative health effects.[84–91] Endocrine disruptors are lipophilic substances that usually act as transcription factors for nuclear hormone receptor superfamily and can either mimic or block the action of endogenous sex hormones, resulting in irreversible alterations or reversible alterations in patterns of gene expression.[84,86–91] Sex steroids (androgens and estrogens) play an important role in establishing and maintaining adipose tissue[84,85] and in conjunction with growth hormones can mobilize lipids and have anti-adipogenic effects; their effects are counteracted by insulin and cortisol that have

Table 4—Urinary bisphenol level as a predictor of self-reported sleep problems.

	Model I: Unadjusted	Model II: Age-and-Sex Adjusted	Model III: Fully Adjusted*
Ever told doctor had trouble sleeping	OR (95% CI)	OR (95% CI)	OR (95% CI)
Urinary bisphenol level (ng/mL) – Continuous	1.08 (1.01, 1.16)	1.03 (0.96, 1.11)	1.08 (0.99, 1.19)
Urinary bisphenol level (ng/mL) – Quartiles	P = 0.1	P = 0.9	P = 0.4
< 0.9	Ref.	Ref.	Ref.
0.9–1.9	1.19 (0.94, 1.52)	1.08 (0.85, 1.39)	1.13 (0.86, 1.49)
1.9–3.7	1.11 (0.88, 1.39)	0.96 (0.75, 1.22)	1.03 (0.77, 1.39)
≥ 3.7	1.24 (1.01, 1.52)	1.06 (0.85, 1.34)	1.19 (0.89, 1.59)
Ever told by doctor had sleeping disorder	OR (95% CI)	OR (95% CI)	OR (95% CI)
Urinary bisphenol level (ng/mL) – Continuous	1.02 (0.89, 1.16)	0.98 (0.86, 1.12)	1.05 (0.89, 1.24)
Urinary bisphenol level (ng/mL) – Quartiles	P = 0.9	P = 0.6	P = 0.8
< 0.9	Ref.	Ref.	Ref.
0.9–1.9	1.01 (0.66, 1.54)	0.98 (0.63, 1.52)	1.18 (0.74, 1.88)
1.9–3.7	0.85 (0.56, 1.28)	0.79 (0.51, 1.22)	0.95 (0.58, 1.57)
≥ 3.7	1.09 (0.72, 1.67)	0.97 (0.62, 1.52)	1.18 (0.71, 1.98)

*Adjusted for sex (male, female), age (< 30, 30–39, 40–49, 50–59, ≥ 60 years), race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Hispanic, Other), education (less than high school, high school, more than high school), marital status (married/cohabiting, not married), poverty income ratio (continuous; < 100%, 100%–200%, ≥ 200%), smoking status (current smoker, ex-smoker, never smoker), alcohol consumption (at least 12 glasses in the past 12 months) (yes, no), body mass index (BMI) (< 25, 25–30, ≥ 30 kg/m^2), waist circumference (high: ≥ 102 cm (40 in) in men or ≥ 88 cm (35 in) in women vs. low: < 102 cm (40 in) in men or < 88 cm (35 in) in women), self-rated health (excellent/very good/good, fair/poor), depressive symptoms based on the 9-item Patient Health Questionnaire (PHQ) total score (high: ≥ 10, low: < 10) and adjusted creatinine level.

adipogenic effects.[84] Exposure to endocrine disruptors such as BPA is thought to promote adiposity typical of Cushing syndrome, polycystic ovary syndrome, growth hormone deficiency, menopause, aging, alcoholism, and depression.[84,88]

Since the 1960s, BPA has been produced in large quantities for the manufacturing of flame retardants, dental sealants and fillings, adhesives, protective coatings, infant feeding bottles, food and mineral water storage containers, and food and beverage can linings.[84,92–98] Although studies have suggested that low-dose BPA exposure may be associated with increased reproductive and cancer risks,[99–105] regulatory bodies in the U.S., Canada, and Europe have distinct views on whether BPA should be considered a hazardous substance.[106]

So far, a limited number of studies have used a nationally representative sample to investigate health effects of BPA, and several of these studies, most of which used NHANES data, have linked high BPA to obesity-related cardiometabolic risk factors and conditions.[69,92,93,107–109] The finding of an inverse relationship between sleep duration and BPA level is consistent with the current evidence that BPA is a chemical substance that has the capacity to bind nuclear and membrane surface estrogen receptors, resulting in obesity-related disturbances which can potentially mediate suboptimal sleep.[58,59,64,66,69] However, our results also suggest that BPA level may be negatively associated with sleep duration, independently of BMI or waist circumference, both of which are indices of obesity-related disturbances. Therefore, it is also plausible that BPA may have an adverse impact on muscular function in the upper airway, causing sleep disorders such as OSA, as suggested by biomedical researchers.[41] In-depth analyses are needed to evaluate the mediating role of obesity-related cardiometabolic risk factors and conditions, including components of the metabolic syndrome, in the observed relationship between BPA and sleep duration. While the proposed biological mechanisms are plausible, reverse causality cannot be ruled out as a potential explanation for the observed associations. In fact, it is also plausible that individuals who experience shorter sleep are more likely to experience environmental BPA exposure which, in turn, assumes a state of wakefulness.

To our knowledge, this is the first study examining whether BPA may be causally or non-causally linked to adequacy of sleep in a nationally representative sample of U.S. adults. Previous studies have used NHANES data to examine correlates of sleep, including race/ethnicity,[43,83] socioeconomic status,[83] eating behaviors,[80] nutritional biomarkers,[77,79] alcohol use,[74] obesity,[76] pre-diabetes,[78] diabetes,[76] hypertension,[82] homocysteine,[45] inflammatory biomarkers,[43,81] cardiovascular disease,[42] anxiety,[75] and functional health.[43] In a recent study, Erden and colleagues[41] evaluated the associations among OSA, BPA, vitamin D, and parathyroid hormone levels using a sample of 128 subjects who had undergone polysomnography and were classified as control (n = 43), moderate OSA (n = 23), or severe OSA (n = 62).[41] Consistent with our findings, their results indicated that while vitamin D level was lower in both OSA groups and PTH was higher in OSA groups than in the control subjects, and BPA levels were higher in severe OSA than moderate OSA and controls.[41]

Nevertheless, our findings should be interpreted with caution and in light of several limitations. First, the study design is cross-sectional, which precludes establishing cause-and-effect relationships among variables under study. Second, analyses were based on previously collected data reducing flexibility in the definition of outcome, exposure, and covariate variables. Third, BPA metabolites were assessed by a single assay in

NHANES, which may not represent diurnal changes in BPA levels. Fourth, the study sample was selected on the basis of availability of exposure and outcome data, which may have resulted in selection bias. In particular, the inclusion and exclusion criteria that define the selected subset of NHANES 2005–2010 subjects may have influenced the effectiveness of weighting variables. Further analyses suggested that the selected and non-selected adult subjects differed significantly on sex, age, race/ethnicity, and education. Fifth, NHANES assessed adequacy of sleep using self-report rather than polysomnography or medical records data, which may have led to non-differential misclassification of the outcome variables of interest, potentially biasing measures of association towards the null value. Moreover, the question pertaining to sleep duration was limited in scope as it only considered week or workdays. Considering the existence of sleep compensation (short sleep during week or workdays and longer sleep on weekends or free days), the general sleep time is underestimated. Also, at least one of the sleep-related outcomes is a rare event with a prevalence of less than 10%, reducing our ability to detect an association with BPA exposure.

Sixth, although numerous covariates were included in the multivariable models, we cannot rule out residual confounding as an explanation for the observed associations due to uncontrolled factors such as area of residence and diet quality. Seventh, although sex differences were observed, we could not conduct stratified analyses according to sex as a result of sample size limitations. Finally, our findings can only be generalized to adult men and women, and further research is needed to evaluate these relationships in adolescents and children.

In conclusion, secondary analyses of 2005–2010 NHANES data involving U.S. adults suggests that sleep duration, but not help-seeking behaviors related to poor sleep, may be inversely related to BPA level, with implications for primary and secondary prevention. Regulation of environmental BPA level could potentially reduce the risk of adverse health outcomes, including poor sleep. Also, monitoring of BPA level by healthcare professionals could help identify patients at high risk for poor sleep and aid in the management of patients experiencing poor sleep. Our results support the idea that excessively high levels of BPA may, directly or indirectly, be linked to poor sleep. Further research is needed to better understand what specific environmental exposures may have led to excessive levels of BPA and consequently adverse outcomes such as inadequate sleep.

ABBREVIATIONS

BMI, body mass index
BPA, Bisphenol-A
CDC, Centers for Disease Control and Prevention
CI, confidence interval
CV, coefficient of variation
HPLC, high performance liquid chromatography
LLOD, lower limit of detection
NHANES, National Health and Nutrition Examination Surveys
OR, odds ratio
OSA, obstructive sleep apnea
PHQ, Patient Health Questionnaire
SEM, standard error of the mean

REFERENCES

1. Engeda J, Mezuk B, Ratliff S, Ning Y. Association between duration and quality of sleep and the risk of pre-diabetes: evidence from NHANES. Diabet Med 2013;30:676–80.
2. Carrillo-Larco RM, Bernabe-Ortiz A, Miranda JJ. Short sleep duration and childhood obesity: cross-sectional analysis in peru and patterns in four developing countries. PloS One 2014;9:e112433.
3. Gildner TE, Liebert MA, Kowal P, Chatterji S, Snodgrass J. Sleep duration, sleep quality, and obesity risk among older adults from six middle-income countries: findings from the study on global AGEing and adult health (SAGE). Am J Hum Biol 2014;26:803–12.
4. Gutierrez-Repiso C, Soriguer F, Rubio-Martin E, et al. Nighttime sleep duration and the incidence of obesity and type 2 diabetes. Findings from the prospective Pizarra study. Sleep Med 2014;15:1398–404.
5. Logue EE, Scott ED, Palmieri PA, Dudley P. Sleep duration, quality, or stability and obesity in an urban family medicine center. J Clin Sleep Med 2014;10:177–82.
6. Suglia SF, Kara S, Robinson WR. Sleep duration and obesity among adolescents transitioning to adulthood: do results differ by sex? J Pediatr 2014;165:750–4.
7. Vgontzas AN, Fernandez-Mendoza J, Miksiewicz T, et al. Unveiling the longitudinal association between short sleep duration and the incidence of obesity: the Penn State Cohort. Int J Obes 2014;38:825–32.
8. Wu Y, Zhai L, Zhang D. Sleep duration and obesity among adults: a meta-analysis of prospective studies. Sleep Med 2014;15:1456–62.
9. Androutsos O, Moschonis G, Mavrogianni C, et al. Identification of lifestyle patterns, including sleep deprivation, associated with insulin resistance in children: the Healthy Growth Study. Eur J Clin Nutr 2014;68:344–9.
10. Baburao A, Souza GD. Insulin resistance in moderate to severe obstructive sleep apnea in nondiabetics and its response to continuous positive airway pressure treatment. N Am J Med Sci 2014;6:500–4.
11. de Oliveira EM, Visniauskas B, Sandri S, et al. Late effects of sleep restriction: potentiating weight gain and insulin resistance arising from a high-fat diet in mice. Obesity (Silver Spring) 2015;23:391–8.
12. Kritikou I, Basta M, Vgontzas AN, et al. Sleep apnoea, sleepiness, inflammation and insulin resistance in middle-aged males and females. Eur Respir J 2014;43:145–55.
13. Lam DC, Lam KS, Ip MS. Obstructive sleep apnoea, insulin resistance and adipocytokines. Clin Endocrinol (Oxf) 2015;82:165–77.
14. Morgenstern M, Wang J, Beatty N, Batemarco T, Sica AL, Greenberg H. Obstructive sleep apnea: an unexpected cause of insulin resistance and diabetes. Endocrinol Metab Clin North Am 2014;43:187–204.
15. Ohkuma T, Fujii H, Iwase M, et al. U-shaped association of sleep duration with metabolic syndrome and insulin resistance in patients with type 2 diabetes: the Fukuoka Diabetes Registry. Metabolism 2014;63:484–91.
16. Pyykkonen AJ, Isomaa B, Pesonen AK, et al. Sleep duration and insulin resistance in individuals without type 2 diabetes: the PPP-Botnia study. Ann Med 2012;46:324–9.
17. Shamsuzzaman A, Szczesniak RD, Fenchel MC, Amin RS. Glucose, insulin, and insulin resistance in normal-weight, overweight and obese children with obstructive sleep apnea. Obes Res Clin Pract 2014;8:e584–91.
18. Holliday EG, Magee CA, Kritharides L, Banks E, Attia J. Short sleep duration is associated with risk of future diabetes but not cardiovascular disease: a prospective study and meta-analysis. PLoS One 2013;8:e82305.
19. Wang X, Bi Y, Zhang Q, Pan F. Obstructive sleep apnoea and the risk of type 2 diabetes: a meta-analysis of prospective cohort studies. Respirology 2013;18:140–6.
20. Kawada T. The definition of sleep duration and the risk for hypertension: caution for meta-analysis. Sleep Med 2013;14:1431.

21. Meng L, Zheng Y, Hui R. The relationship of sleep duration and insomnia to risk of hypertension incidence: a meta-analysis of prospective cohort studies. Hypertens Res 2013;36:985–95.
22. Wang Q, Xi B, Liu M, Zhang Y, Fu M. Short sleep duration is associated with hypertension risk among adults: a systematic review and meta-analysis. Hypertens Res 2012;35:1012–8.
23. Akbaraly TN, Jaussent I, Besset A, et al. Sleep complaints and metabolic syndrome in an elderly population: the Three-City study. Am J Geriatr Psychiatry 2015;23:818–28.
24. Korcarz CE, Stein JH, Peppard PE, Young TB, Barnet JH, Nieto FJ. Combined effects of sleep disordered breathing and metabolic syndrome on endothelial function: the Wisconsin Sleep Cohort study. Sleep 2014;37:1707–13.
25. Lee JA, Park HS. Relation between sleep duration, overweight, and metabolic syndrome in Korean adolescents. Nutr Metab Cardiovasc Dis 2014;24:65–71.
26. Lin QC, Chen LD, Yu YH, Liu KX, Gao SY. Obstructive sleep apnea syndrome is associated with metabolic syndrome and inflammation. Eur Arch Otorhinolaryngol 2014;271:825–31.
27. Mesas AE, Guallar-Castillon P, Lopez-Garcia E, et al. Sleep quality and the metabolic syndrome: the role of sleep duration and lifestyle. Diabetes Metab Res Rev 2014;30:222–31.
28. Okubo N, Matsuzaka M, Takahashi I, et al. Relationship between self-reported sleep quality and metabolic syndrome in general population. BMC Public Health 2014;14:562.
29. Saleh D, Janssen I. Interrelationships among sedentary time, sleep duration, and the metabolic syndrome in adults. BMC Public Health;14:666.
30. Seetho IW, Wilding JP. Sleep-disordered breathing, type 2 diabetes and the metabolic syndrome. Chron Respir Dis 2014;11:257–75.
31. Xi B, He D, Zhang M, Xue J, Zhou D. Short sleep duration predicts risk of metabolic syndrome: a systematic review and meta-analysis. Sleep Med Rev 2014;18:293–7.
32. Ali SS, Oni ET, Warraich HJ, et al. Systematic review on noninvasive assessment of subclinical cardiovascular disease in obstructive sleep apnea: new kid on the block! Sleep Med Rev 2014;18:379–91.
33. Hoevenaar-Blom MP, Spijkerman AM, Kromhout D, Verschuren WM. Sufficient sleep duration contributes to lower cardiovascular disease risk in addition to four traditional lifestyle factors: the MORGEN study. Eur J Prev Cardiol 2014;21:1367–75.
34. Johansson P, Svensson E, Alehagen U, Jaarsma T, Brostrom A. The contribution of hypoxia to the association between sleep apnoea, insomnia, and cardiovascular mortality in community-dwelling elderly with and without cardiovascular disease. Eur J Cardiovasc Nurs 2015;14:222–31.
35. Michal M, Wiltink J, Kirschner Y, et al. Complaints of sleep disturbances are associated with cardiovascular disease: results from the Gutenberg Health Study. PloS One 2014;9:e104324.
36. Surani SR. Diabetes, sleep apnea, obesity and cardiovascular disease: why not address them together? World J Diabetes 2014;5:381–4.
37. Xie W, Zheng F, Song X. Obstructive sleep apnea and serious adverse outcomes in patients with cardiovascular or cerebrovascular disease: a PRISMA-compliant systematic review and meta-analysis. Medicine (Baltimore) 2014;93:e336.
38. Ge B, Guo X. Short and long sleep durations are both associated with increased risk of stroke: a meta-analysis of observational studies. Int J Stroke 2015;10:177–84.
39. Zhao H, Yin JY, Yang WS, et al. Sleep duration and cancer risk: a systematic review and meta-analysis of prospective studies. Asian Pac J Cancer Prev 2013;14:7509–15.
40. Qin Y, Zhou Y, Zhang X, Wei X, He J. Sleep duration and breast cancer risk: a meta-analysis of observational studies. Int J Cancer 2014;134:1166–73.
41. Erden ES, Genc S, Motor S, et al. Investigation of serum bisphenol A, vitamin D, and parathyroid hormone levels in patients with obstructive sleep apnea syndrome. Endocrine 2014;45:311–8.
42. Vozoris NT. Sleep apnea-plus: prevalence, risk factors, and association with cardiovascular diseases using United States population-level data. Sleep Med 2012;13:637–44.
43. Zhang J, Lamers F, Hickie IB, He JP, Feig E, Merikangas KR. Differentiating nonrestorative sleep from nocturnal insomnia symptoms: demographic, clinical, inflammatory, and functional correlates. Sleep 2013;36:671–9.
44. Bertisch SM, Herzig SJ, Winkelman JW, Buettner C. National use of prescription medications for insomnia: NHANES 1999-2010. Sleep 2014;37:343–9.
45. Thakre TP, Mamtani M, Ujaoney S, Kulkarni H. Association of plasma homocysteine with self-reported sleep apnea is confounded by age: results from the national health and nutrition examination survey 2005-2006. Sleep Disord 2012;2012:634920.
46. Chaput JP. Sleep patterns, diet quality and energy balance. Physiol Behav 2014;134:86–91.
47. Stern JH, Grant AS, Thomson CA, et al. Short sleep duration is associated with decreased serum leptin, increased energy intake and decreased diet quality in postmenopausal women. Obesity (Silver Spring) 2014;22:E55–61.
48. Guallar-Castillon P, Bayan-Bravo A, Leon-Munoz LM, et al. The association of major patterns of physical activity, sedentary behavior and sleep with health-related quality of life: a cohort study. Prev Med 2014;67:248–54.
49. Holfeld B, Ruthig JC. A longitudinal examination of sleep quality and physical activity in older adults. J Appl Gerontol 2014;33:791–807.
50. Kitano N, Tsunoda K, Tsuji T, et al. Association between difficulty initiating sleep in older adults and the combination of leisure-time physical activity and consumption of milk and milk products: a cross-sectional study. BMC Geriatr 2014;14:118.
51. McClain JJ, Lewin DS, Laposky AD, Kahle L, Berrigan D. Associations between physical activity, sedentary time, sleep duration and daytime sleepiness in US adults. Prev Med 2014;66:68–73.
52. McNeil J, Tremblay MS, Leduc G, et al. Objectively-measured sleep and its association with adiposity and physical activity in a sample of Canadian children. J Sleep Res 2015;24:131–9.
53. Orsey AD, Wakefield DB, Cloutier MM. Physical activity (PA) and sleep among children and adolescents with cancer. Pediatr Blood Cancer 2014;61:956.
54. Wennman H, Kronholm E, Partonen T, et al. Physical activity and sleep profiles in Finnish men and women. BMC Public Health 2014;14:82.
55. Lakind JS, Levesque J, Dumas P, Bryan S, Clarke J, Naiman DQ. Comparing United States and Canadian population exposures from National Biomonitoring Surveys: bisphenol A intake as a case study. J Expo Sci Environ Epidemiol 2012;22:219–26.
56. Lakind JS, Naiman DQ. Bisphenol A (BPA) daily intakes in the United States: estimates from the 2003-2004 NHANES urinary BPA data. J Expo Sci Environ Epidemiol 2008;18:608–15.
57. Lakind JS, Naiman DQ. Daily intake of bisphenol A and potential sources of exposure: 2005-2006 National Health and Nutrition Examination Survey. J Expo Sci Environ Epidemiol 2011;21:272–9.
58. Nelson JW, Scammell MK, Hatch EE, Webster TF. Social disparities in exposures to bisphenol A and polyfluoroalkyl chemicals: a cross-sectional study within NHANES 2003-2006. Environ Health 2012;11:10.
59. You L, Zhu X, Shrubsole MJ, et al. Renal function, bisphenol A, and alkylphenols: results from the National Health and Nutrition Examination Survey (NHANES 2003-2006). Environ Health Perspect 2011;119:527–33.
60. Bhandari R, Xiao J, Shankar A. Urinary bisphenol A and obesity in U.S. children. Am J Endocrinol 2013;177:1263–70.
61. Carwile JL, Michels KB. Urinary bisphenol A and obesity: NHANES 2003-2006. Environ Res 2011;111:825–30.
62. Casey MF, Neidell M. Disconcordance in statistical models of bisphenol A and chronic disease outcomes in NHANES 2003-08. PloS One 2013;8:e79944.

63. Eng DS, Lee JM, Gebremariam A, Meeker JD, Peterson K, Padmanabhan V. Bisphenol A and chronic disease risk factors in US children. Pediatrics 2013;132:e637–45.
64. Melzer D, Osborne NJ, Henley WE, et al. Urinary bisphenol A concentration and risk of future coronary artery disease in apparently healthy men and women. Circulation 2012;125:1482–90.
65. Melzer D, Rice NE, Lewis C, Henley WE, Galloway TS. Association of urinary bisphenol a concentration with heart disease: evidence from NHANES 2003/06. PloS One 2010;5:e8673.
66. Shankar A, Teppala S, Sabanayagam C. Urinary bisphenol a levels and measures of obesity: results from the national health and nutrition examination survey 2003-2008. ISRN Endocrinol 2012;2012:965243.
67. Shankar A, Teppala S, Sabanayagam C. Bisphenol A and peripheral arterial disease: results from the NHANES. Environ Health Perspect 2012;120:1297–300.
68. Silver MK, O'Neill MS, Sowers MR, Park SK. Urinary bisphenol A and type-2 diabetes in U.S. adults: data from NHANES 2003-2008. PloS One 2011;6:e26868.
69. Teppala S, Madhavan S, Shankar A. Bisphenol A and metabolic syndrome: results from NHANES. Int J Endocrinol 2012;2012:598180.
70. Mirmira P, Evans-Molina C. Bisphenol A, obesity, and type 2 diabetes mellitus: genuine concern or unnecessary preoccupation? Transl Res 2014;164:13–21.
71. Lakind JS, Goodman M, Mattison DR. Bisphenol A and indicators of obesity, glucose metabolism/type 2 diabetes and cardiovascular disease: a systematic review of epidemiologic research. Crit Rev Toxicol 2014;44:121–50.
72. Rezg R, El-Fazaa S, Gharbi N, Mornagui B. Bisphenol A and human chronic diseases: current evidences, possible mechanisms, and future perspectives. Environ Int 2014;64:83–90.
73. Erden ES, Genc S, Motor S, et al. Investigation of serum bisphenol A, vitamin D, and parathyroid hormone levels in patients with obstructive sleep apnea syndrome. Endocrine 2014;45:311–8.
74. Chakravorty S, Jackson N, Chaudhary N, et al. Daytime sleepiness: associations with alcohol use and sleep duration in Americans. Sleep Disord 2014;2014:959152.
75. Shapiro AL, Culp S, Azulay Chertok IR. OSA symptoms associated with and predictive of anxiety in middle-aged men: secondary analysis of NHANES data. Arch Psychiatr Nurs 2014;28:200–5.
76. Liu J, Hay J, Faught BE. The association of sleep disorder, obesity status, and diabetes mellitus among US adults-The NHANES 2009-2010 Survey Results. Int J Endocrinol 2013;2013:234129.
77. Grandner MA, Jackson N, Gerstner JR, Knutson KL. Dietary nutrients associated with short and long sleep duration. Data from a nationally representative sample. Appetite 2013;64:71–80.
78. Alshaarawy O, Teppala S, Shankar A. Markers of sleep-disordered breathing and prediabetes in US adults. Int J Endocrinol 2012;2012:902324.
79. Beydoun MA, Gamaldo AA, Canas JA, et al. Serum nutritional biomarkers and their associations with sleep among US adults in recent national surveys. PloS One 2014;9:e103490.
80. Kant AK, Graubard BI. Association of self-reported sleep duration with eating behaviors of American adults: NHANES 2005-2010. Am J Clin Nutrition 2014;100:938–47.
81. Liu R, Liu X, Zee PC, et al. Association between sleep quality and C-reactive protein: results from national health and nutrition examination survey, 2005-2008. PloS One 2014;9:e92607.
82. Walia H, Strohl K, Koo B, Seicean A, Seicean S. Are sleep symptoms predictors of resistant hypertension in a population-based sample? Findings from the National Health and Nutritional Examination Survey. J Clin Hypertens 2012;14:530–6.
83. Whinnery J, Jackson N, Rattanaumpawan P, Grandner MA. Short and long sleep duration associated with race/ethnicity, sociodemographics, and socioeconomic position. Sleep 2014;37:601–11.
84. Grun F, Blumberg B. Perturbed nuclear receptor signaling by environmental obesogens as emerging factors in the obesity crisis. Rev Endocr Metab Disord 2007;8:161–71.
85. Newbold RR, Padilla-Banks E, Jefferson WN. Environmental estrogens and obesity. Mol Cell Endocrinol 2009;304:84–9.
86. Karoutsou E, Polymeris A. Environmental endocrine disruptors and obesity. Endocr Regul 2012;46:37–46.
87. Aubert ML, Nef S, Soto AM. Special issue on the topic: role of endocrine disruptors from the environment in the aetiology of obesity and diabetes. Mol Cell Endocrinol 2009;304:1–2.
88. Elobeid MA, Allison DB. Putative environmental-endocrine disruptors and obesity: a review. Curr Opin Endocrinol Diabetes Obes 2008;15:403–8.
89. Hatch EE, Nelson JW, Stahlhut RW, Webster TF. Association of endocrine disruptors and obesity: perspectives from epidemiological studies. Int J Androl 2010;33:324–32.
90. Heindel JJ. Endocrine disruptors and the obesity epidemic. Toxicol Sci 2003;76:247–9.
91. Newbold RR, Padilla-Banks E, Jefferson WN, Heindel JJ. Effects of endocrine disruptors on obesity. Int J Androl 2008;31:201–8.
92. Melzer D, Rice NE, Lewis C, Henley WE, Galloway TS. Association of urinary bisphenol a concentration with heart disease: evidence from NHANES 2003/06. PLoS One 2010;5:e8673.
93. Lang IA, Galloway TS, Scarlett A, et al. Association of urinary bisphenol A concentration with medical disorders and laboratory abnormalities in adults. JAMA 2008;300:1303–10.
94. Kang JH, Kondo F, Katayama Y. Human exposure to bisphenol A. Toxicology 2006;226:79–89.
95. Mahalingaiah S, Meeker JD, Pearson KR, et al. Temporal variability and predictors of urinary bisphenol A concentrations in men and women. Environ Health Perspect 2008;116:173–8.
96. Brede C, Fjeldal P, Skjevrak I, Herikstad H. Increased migration levels of bisphenol A from polycarbonate baby bottles after dishwashing, boiling and brushing. Food Addit Contam 2003;20:684–9.
97. Factor A. Mechanisms of thermal and photodegredations of bisphenol A polycarbonate. In: Clough RL, Billingham NC, Gillen KT, eds. Polymer durability, degradation, stabilization, and lifetime prediction. New York: Oxford University Press, 1998:59–76.
98. Kang JH, Kito K, Kondo F. Factors influencing the migration of bisphenol A from cans. J Food Prot 2003;66:1444–7.
99. Yang M, Ryu JH, Jeon R, Kang D, Yoo KY. Effects of bisphenol A on breast cancer and its risk factors. Arch Toxicol 2009;83:281–5.
100. Fernandez M, Bourguignon N, Lux-Lantos V, Libertun C. Neonatal exposure to bisphenol a and reproductive and endocrine alterations resembling the polycystic ovarian syndrome in adult rats. Environ Health Perspect 2010;118:1217–22.
101. Goodman JE, Witorsch RJ, McConnell EE, et al. Weight-of-evidence evaluation of reproductive and developmental effects of low doses of bisphenol A. Crit Rev Toxicol 2009;39:1–75.
102. LaRocca J, Boyajian A, Brown C, Smith SD, Hixon M. Effects of in utero exposure to Bisphenol A or diethylstilbestrol on the adult male reproductive system. Birth Defects Res B Dev Reprod Toxicol 2011;92:526–33.
103. Maffini MV, Rubin BS, Sonnenschein C, Soto AM. Endocrine disruptors and reproductive health: the case of bisphenol-A. Mol Cell Endocrinol 2006;254-255:179–86.
104. Mendiola J, Jorgensen N, Andersson AM, et al. Are environmental levels of bisphenol a associated with reproductive function in fertile men? Environ Health Perspect 2011;118:1286–91.
105. Spivey A. Prenatal preview: early bisphenol a exposure may spawn late-life reproductive problems. Environ Health Perspect 2009;117:A256.
106. Ginsberg G, Rice DC. Does rapid metabolism ensure negligible risk from bisphenol A? Environ Health Perspect 2009;117:1639–43.
107. Carwile JL, Michels KB. Urinary bisphenol A and obesity: NHANES 2003-2006. Environ Res 2011;111:825–30.
108. Shankar A, Teppala S. Urinary Bisphenol A and hypertension in a multiethnic sample of US adults. J Environ Public Health;2012:481641.

109. Silver MK, O'Neill MS, Sowers MR, Park SK. Urinary bisphenol A and Type-2 diabetes in U.S. adults: data from NHANES 2003-2008. PLoS One 2011;6:e26868.

SUBMISSION & CORRESPONDENCE INFORMATION

Submitted for publication March, 2015
Submitted in final revised form August, 2015
Accepted for publication August, 2015
Address correspondence to: Hind A. Beydoun, PhD – Graduate Program in Public Health, Eastern Virginia Medical School, 651 Colley Avenue Room 401, Norfolk, Virginia, USA, 23501-1980; Tel: (757) 446-7142; Fax (757) 446-6121; Email: baydouha@evms.edu

DISCLOSURE STATEMENT

This was not an industry supported study. This work was supported in part by the Intramural Research Program of the National Institutes of Health, National Institute on Aging (NIA/NIH/IRP). The authors have indicated no financial conflicts of interest. The work was performed at the Eastern Virginia Medical School, Norfolk, VA.