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Night-time eating and body weight status among US adults, 2007–2016

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Keywords
adult, body mass index, NHANES, night-time eating, obesity, waist circumference.

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Abstract

Background: The present study assessed the relationship between night-time eating and body weight status among US adults, using in-person 24-h dietary recall data from a nationally representative survey.
Methods: Individual-level data (n = 23 003) came from the 2007–2016 National Health and Nutrition Examination Survey (NHANES) (five waves). Multivariate linear and logistic regressions were performed to estimate the effect of energy, sugar, fat and saturated fat intake during night-time on body mass index (BMI), obesity (BMI ≥30 kg m^{-2}), waist circumference (WC) and abdominal obesity (WC ≥88 cm in women; WC ≥102 cm in men), adjusting for daily total energy intake, physical activity, sleeping and other individual characteristics.
Results: Approximately 36.5% and 56.7% of the NHANES adult participants had obesity and abdominal obesity, respectively. The proportion of energy, total fat, saturated fat and total sugar intake within the time window of 00.00 h to 05.59 h and 22.00 h to 23.59 h averaged 5.7%, 5.3%, 5.7% and 6.8%, respectively. Energy intake within the time window was not found to be associated with BMI, WC, obesity or abdominal obesity in the regression analyses. Sensitivity analyses applying alternative time windows to capture night-time eating found night-time intakes of energy, total fat, saturated fat and total sugar not to be associated BMI, WC, obesity or abdominal obesity.
Conclusions: Night-time eating was not found to be associated with body weight status in a US nationally representative adult sample. Restricting night-time food consumption alone without an overall reduction in daily caloric intake may not prevent obesity. The findings of the present study warrant replication in a future experimental study with habitual dietary behaviour measures.

Introduction

In the past three decades, obesity has evolved from a minor issue, concerning only a few endocrinologists intrigued by the manifestations of the condition, into a leading cause of morbidity and premature mortality in the USA and worldwide [(1–3)]. From 1976–1980 to 2015–2016, the prevalence of obesity more than doubled among adults and tripled among children in the USA [(4–6)]. Obesity is associated with an elevated risk of various chronic diseases, such as type 2 diabetes, hypertension, dyslipidaemia, coronary heart disease and certain types of cancer, and consumes substantial social resources [(7–12)]. Some projections suggest that, by 2030, the US medical expenditure attributable to individuals being overweight and obese will reach $861–957 billion, accounting for 16–18% of the nation's total healthcare costs [13].

Previous research linked night-time eating to overconsumption and an elevated obesity rate and implicated potential metabolic consequences [14]. Hypothesised mechanisms included but were not limited to a lower thermic response to energy consumed at night than consumed in the morning or afternoon [15] and a lower satiety from night-time food intake triggering overeating [16,17]. These hypotheses were supported by some but not all human-based studies. For example, night shift workers were found to have a higher rate of overweight and abdominal obesity compared to day workers [18,19]. Night eating syndrome (NES), characterised by a delayed circadian pattern of food intake, tended to be more prevalent among people with obesity compared to their normal-weight counterparts [20]. Several epidemiological studies reported a higher proportion of energy consumed later in the day (as opposed to earlier in the day) to be associated with weight gain [21–25].

The initial findings on the adverse weight impact of night-time eating have been challenged by more recent research. Data from night shift workers and NES patients often failed to consider the possible confounding effect of sleep issues. Both night shift workers and individuals with NES reported having a higher incidence of sleep disturbances, characterised by difficulty falling asleep, short sleep duration and/or reduced sleep quality [26,27], and sleep disturbances have served as a well-documented risk factor for obesity [28]. Moreover, studies have identified potential benefits of pre-sleep nutrient intake and its relevance to physically-active young and older individuals, as well as people with chronic conditions [29–37]. For example, protein intake close to sleep was found to be well digested and absorbed, which helped improve post-exercise recovery among active young adults and promote overnight muscle protein accretion among older men [29]. In addition, there is evidence that having a structured, post-dinner snack led to lower total daily energy intake, evening energy intake and moderate weight loss in compliant individuals [30]. Another study found that the consumption of macronutrient beverages at night-time resulted in greater satiety and less desire to eat [32]. Finally, there is evidence that exercise training combined with night-time consumption of whey, casein or a carbohydrate beverage increased muscle strength and lean mass, as well as reduced body fat, among overweight and obese women [33].

Despite the above progress in research, gaps remain to be filled, in particular regarding the impact of night-time eating among the general adult population. Most existing studies were small in scale and primarily focused on specific subpopulations such as people undergoing exercise training or adults with existing conditions or functional limitations. The findings from those studies have limited generalisability to the population at large. Building upon previous research, the present study aimed to assess the relationship between night-time eating and obesity among US adults. The study contributes to the literature by the use of multiyear data from a large nationally representative repeated cross-sectional survey, objective measures on body mass index (BMI) and waist circumference (WC), detailed recording of hourly food intake using an in-person 24-h dietary recall, and statistical adjustment for daily duration of physical activity and sleep. We hypothesised that the proportion of energy consumed at night-time would be positively associated with body weight status measures among the adult study sample.

Materials and methods

Setting and participants

The National Health and Nutrition Examination Survey (NHANES) is conducted by the National Center for Health Statistics (NCHS) to assess the health and nutritional status of children and adults. A multistage probability sampling design is used to select participants representative of the civilian, non-institutionalised US population. Detailed information regarding the NHANES sampling design, questionnaires, clinical measures and individual-level data is available elsewhere [38].

Individual-level data were retrieved from the NHANES 2007–2008, 2009–2010, 2011–2012, 2013–2014 and 2015–2016 waves. Data from earlier waves were not used because relevant measures on daily durations of sleeping and physical activity were only adopted and consistently administered starting from the NHANES 2005–2006 and 2007–2008 waves, respectively. Among the 27 439 adults aged 18 years and older who participated in the NHANES 2007–2008, 2009–2010, 2011–2012, 2013–2014 and 2015–2016 waves, 910 individuals who were pregnant or on a special diet to lose weight at the time of interview and 3526 who had missing data for body weight status, dietary intake, and/or other covariates were excluded from the analyses. This resulted in a total effective sample of 23 003 adult participants.

Dietary measures

Beginning with the NHANES 1999–2000 wave, all participants were asked to complete an in-person 24-h dietary recall (a subsequent telephone-based dietary recall was added in the 2001–2002 wave). In the dietary recall, each food/beverage item and corresponding quantity consumed by a participant from midnight to midnight (denoted in increments between 00.00 h and 23.59 h) on the day before the recall was recorded. The in-person dietary recall was conducted by trained dietary interviewers in the Mobile Examination Center (MEC) with a standard set of measuring guides. Following the dietary recall, the energy and nutrient contents of each reported food/beverage item were systematically coded with the US Department of Agriculture's Food and Nutrient Database for Dietary Studies [39].

The dietary measures that were collected from the NHANES in-person 24-h dietary recalls and used were: daily and hourly intake of total energy (kcal), total fat (g), saturated fat (g) and total sugar (g). Total sugar includes both natural sugar and added sugar. These measures were used to calculate the proportion of energy, total fat, saturated fat and sugar intake during a certain time window within the 24-h dietary recall period (e.g. 00.00 h to 05.59 h and 22.00 h to 23.59 h) over daily total intake.

Anthropometric measures

NHANES respondents' body weight and height were measured by digital scale and stadiometer in the MEC. BMI is defined as weight (kg) divided by squared height (m^2). Adult obesity was classified as BMI $\geq$30 kg m^{-2}. WC was measured by trained staff using a measuring tape. The trained staff first drew a horizontal line with a cosmetic pencil just above the respondent's uppermost lateral border of the right ilium. The staff crossed the mark at the midaxillary line, which extends from the armpit down the side of the torso. Then, the staff extended the measuring tape around the waist and positioned the tape in a horizontal plane at the level of the measurement mark. Abdominal obesity was classified by WC $\geq$88 cm for women and WC $\geq$102 cm for men.

Covariates

The individual characteristics adjusted for in the regression analyses were: a dichotomous variable for sex (female, with male in the reference group); three categorical variables for age groups (35–49 years of age, 50–64 years of age and 65 years of age and above, with 18–34 years of age in the reference group); three categorical variables for race/ethnicity (non-Hispanic black, non-Hispanic other race or multi-race and Hispanic, with non-Hispanic white in the reference group); a dichotomous variable for education attainment (college education and above, with high school or lower education in the reference group); two categorical variables for marital status (divorced/separated/widowed and never married, with married in the reference group); two categorical variables for household income level [130% $\leq$ income to poverty ratio (IPR) < 300% and IPR $\geq$ 300%, with IPR < 130% in the reference group; IPR is the ratio of annual household income to poverty level specified in the Department of Health and Human Services' poverty guidelines] [40]; a continuous variable for daily hours of physical activity, including time spent on work-related moderate-to-rigorous intensity physical activity, active commuting such as biking and walking, and leisure-time moderate-to-rigorous intensity physical activity; a continuous variable for hours of night-time sleeping on a typical workday/weekday; a dichotomous variable for smoking status (former or current smoker, with never smoker in the reference group); a dichotomous variable for self-rated health (good or excellent self-rated health, with poor or fair self-rated health in the reference group); five dichotomous variables for each of the chronic condition diagnoses (i.e. diabetes, arthritis, coronary heart disease, stroke and cancer); a dichotomous variable for the day of the week (a weekend day, i.e. Friday, Saturday or Sunday, with a weekday, i.e. Monday to Thursday, in the reference group) pertaining to the 24-h dietary recall period; and four categorical variables for the NHANES waves (2009–2010, 2011–2012, 2013–2014 and 2015–2016 waves, with 2007–2008 wave in the reference group).

Statistical analysis

Multiple linear regressions were performed to examine night-time eating in relation to BMI and WC and multiple logistic regressions were performed to examine night-time eating in relation to obesity and abdominal obesity among NHANES adult participants. The key independent variables are the proportion of energy, total fat, saturated fat and sugar intake over daily total intake during a certain time window within the 24-h dietary recall period (e.g. 00.00 h to 05.59 h and 22.00 h to 23.59 h). These key independent variables entered the regressions one at a time. All regressions adjusted for daily total energy intake and all the aforementioned covariates. NHANES 2007–2016 multiyear survey design was accounted for in both descriptive statistics and regression analyses using the 'svy' functions in STATA. All statistical procedures were performed in STATA, version 15.1 SE (StataCorp, College Station, TX, USA).

Sensitivity analysis

Two streams of sensitivity analyses were performed to assess the robustness of modelling results with respect to changes in the definition of the key independent variable and analytic sample. These sensitivity analyses were determined prior to the investigation. In the first stream of sensitivity analyses, we adopted alternative definitions for night-time eating: the proportion of energy, total fat, saturated fat and sugar intake over daily total intake during six different time windows within the 24-h dietary recall period (i.e. 00.00 h to 05.59 h and 22.00 h to 23.59 h, 00.00 to 04.59 h and 22.00 h to 23.59 h, 00.00 h to 05.59 h and 23.00 h to 23.59 h, 00.00 h to 04.59 h and 23.00 h to 23.59 h, 00.00 h to 05.59 h and 00.00 to 04.59 h). Bonferroni corrections for multiple comparisons were performed to adjust the SEs, confidence intervals, and *P*-values estimated from the regression analyses. In the second stream of sensitivity analyses, we excluded the two covariates for daily hours of physical activity and sleeping from the regression.

Human subject protection

National Health and Nutrition Examination Survey was approved by the NCHS Research Ethics Review Board [41]. This study is entirely based upon the de-identified public-use datasets from the NHANES and thus is exempt from ethical approval.

Results

Figure 1 shows the average energy intake by hour during the 24-h dietary recall period among NHANES 2007–2016 adult participants. Energy intake remained low from 00.00 h to 04.:59 h and started to increase and reach a local maximum at around 08.00 h, denoting breakfast time. Since then, energy intake declined slightly but reached a much higher local maximum at around 12.00 h, denoting lunch time. Then, energy intake decreased again but reached another local maximum at around 18.00 h to 19.00 h, denoting dinner time. Afterwards, energy intake declined until midnight.

Table 1 reports the study sample characteristics. The BMI among NHANES 2007–2016 adult participants averaged 29.0 kg m^{-2} and 36.5% of them were obese. Women averaged 96.6 cm of WC and men averaged 101.6 cm of WC, resulting in an abdominal obesity prevalence of 56.7%. Survey participants on average consumed 2 141 kcal within the 24-h dietary recall period, and had 82.1 g, 26.7 g and 113.4 g of total fat, saturated fat and sugar intake, respectively. The proportion of energy, total fat, saturated fat and sugar intake within the time window of 00.00 h to 05.59 h and 22.00 h to 23.59 h averaged 5.7%, 5.3%, 5.7% and 6.8%, respectively.

Table 2 reports the results from regression analyses with BMI, WC, obesity and abdominal obesity as the four dependent variables, in separate regressions, and proportion of energy intake within the time window of 00.00 h to 05.59 h and 22.00 h to 23.59 h over daily total energy intake as the key independent variable. Adjusting for daily total energy intake and the full set of covariates, energy intake within the time window was not found to be associated with BMI, WC, obesity or abdominal obesity ($P > 0.05$).

Table 3 reports the results from sensitivity analyses that applied alternative time windows to comprehensively capture night-time eating behaviour. The findings were fairly comparable to those obtained from the main analyses: night-time intakes of energy, total fat, saturated fat and sugar were not associated BMI, WC, obesity or abdominal obesity ($P > 0.05$).

Table 2 also reports the estimated relationships between individual covariates and body weight status measures including BMI, WC, obesity or abdominal obesity. Compared to young adults aged 18–35 years, middle-aged adults aged 35–49 years had a higher BMI and obesity prevalence, whereas older adults 65 years and above had a lower BMI and obesity prevalence. Compared to non-Hispanic whites, blacks and Hispanic had a

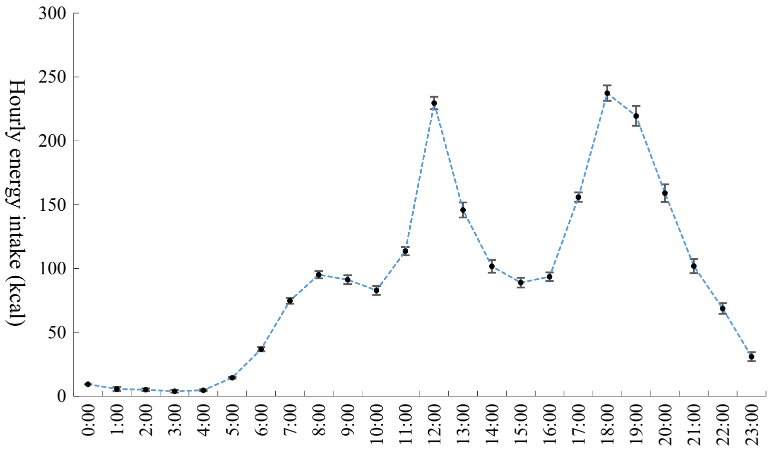

Figure 1 Average energy intake by hour during the 24-h dietary recall period among National Health and Nutrition Examination Survey (NHANES) 2007–2016 adult participants.

Table 1 Characteristics of 2007–2016 NHANES adults

Variables	Mean (SE)
Sample size	23 003
Body weight status	
BMI (kg m^{-2})	28.97 (0.09)
Obesity (BMI ≥30 kg m^{-2}) (%)	36.46 (0.57)
WC (cm) among women	96.64 (0.26)
WC (cm) among men	101.60 (0.29)
Abdominal obesity (men: WC ≥102 cm; women: WC ≥88 cm) (%)	56.65 (0.75)
Energy intake	
Energy intake in the 24-h time period (kcal)	2140.52 (9.28)
% Energy intake during 00.00 h to 05.59 h and 22.00 h to 23.59 h	5.65 (0.14)
% Energy intake during 00.00 h to 04.59 h and 22.00 h to 23.59 h	5.04 (0.14)
% Energy intake during 00.00 h to 05.59 h and 23.00 h to 23.59 h	2.77 (0.10)
% Energy intake during 00.00 h to 04.59 h and 23.00 h to 23.59 h	2.16 (0.09)
% Energy intake during 00.00 h to 05.59 h	1.56 (0.07)
% Energy intake during 00.00 h to 04.59 h	0.95 (0.05)
Sugar intake	
Sugar intake in the 24-h time period (g)	113.38 (0.78)
% Sugar intake during 00.00 h to 05.59 h and 22.00 h to 23.59 h	6.75 (0.16)
% Sugar intake during 00.00 h to 04.59 h and 22.00 h to 23.59 h	5.74 (0.16)
% Sugar intake during 00.00 h to 05.59 h and 23.00 h to 23.59 h	3.58 (0.12)
% Sugar intake during 00.00 h to 04.59 h and 23.00 h to 23.59 h	2.57 (0.10)
% Sugar intake during 00.00 h to 05.59 h	2.14 (0.09)
% Sugar intake during 00.00 h to 04.59 h	1.13 (0.06)
Total fat intake	
Total fat intake in the 24-h time period (g)	82.08 (0.47)
% Total fat intake during 00.00 h to 05.59 h and 22.00 h to 23.59 h	5.32 (0.15)
% Total fat intake during 00.00 h to 04.59 h and 22.00 h to 23.59 h	4.82 (0.14)
% Total fat intake during 00.00 h to 05.59 h and 23.00 h to 23.59 h	2.50 (0.11)
% Total fat intake during 00.00 h to 04.59 h and 23.00 h to 23.59 h	1.99 (0.10)
% Total fat intake during 00.00 h to 05.59 h	1.34 (0.07)
% Total fat intake during 00.00 h to 04.59 h	0.83 (0.06)
Saturated fat intake	
Saturated fat intake in the 24-h time period (g)	26.74 (0.18)
% Saturated fat intake during 00.00 h to 05.59 h and 22.00 h to 23.59 h	5.65 (0.16)
% Saturated fat intake during 00.00 h to 04.59 h and 22.00 h to 23.59 h	5.08 (0.15)
% Saturated fat intake during 00.00 h to 05.59 h and 23.00 h to 23.59 h	2.64 (0.12)
% Saturated fat intake during 00.00 h to 04.59 h and 23.00 h to 23.59 h	2.08 (0.10)
% Saturated fat intake during 00.00 h to 05.59 h	1.42 (0.08)
% Saturated fat intake during 00.00 h to 04.59 h	0.85 (0.06)
Sex (%)	
Male	47.76 (0.38)
Female	52.24 (0.38)
Age group (%)	
18–34 years of age	27.93 (0.71)
35–49 years of age	27.40 (0.60)
50–64 years of age	26.93 (0.56)
65 years of age and above	17.75 (0.47)
Race/ethnicity (%)	
White, non-Hispanic	68.31 (1.57)
Black, non-Hispanic	10.90 (0.81)
Other race/multi-race, non-Hispanic	7.34 (0.46)
Hispanic	13.44 (1.10)
Education (%)	
High school and below	37.73 (1.08)
College education and above	62.27 (1.08)
Marital status (%)	
Married	62.42 (0.83)
Divorced, separated, or widowed	18.43 (0.47)
Never married	19.15 (0.81)
Income to poverty ratio (IPR) (%)	
IPR < 130%	22.77 (0.88)
130% ≤ IPR < 300%	28.28 (0.65)
IPR ≥ 300%	48.95 (1.18)
Physical activity (h)	
Daily physical activity (work + commuting + leisure-time)	2.54 (0.04)
Sleep (h)	
Night-time sleeping on weekdays and/or workdays	7.12 (0.02)
Smoking (%)	
Nonsmoker	55.27 (0.73)
Former or current smoker	44.73 (0.73)
Self-rated health (%)	
Good or excellent health	82.57 (0.51)
Fair or poor health	17.43 (0.51)
Chronic condition (%)	
Diabetes	9.26 (0.30)
Arthritis	25.60 (0.57)
Coronary artery disease	3.26 (0.17)
Stroke	2.73 (0.14)
Cancer	10.32 (0.27)
Day of the week (%)	
Weekdays (Monday to Thursday)	57.63 (0.56)
Weekends (Friday, Saturday and Sunday)	42.37 (0.56)
Survey wave (%)	
2007–2008	18.86 (1.00)
2009–2010	19.50 (1.03)
2011–2012	20.32 (1.12)
2013–2014	20.81 (1.12)
2015–2016	18.86 (1.08)

NHANES multi-wave sampling design was accounted for in estimating the above descriptive statistics.
BMI, body mass index; WC, waist circumference.

Table 2 Results from regression analyses

	BMI Coefficient (95% CI)	Obesity Odds ratio (95% CI)	WC (cm) Coefficient (95% CI)	Abdominal obesity (WC ≥102 cm for men; WC ≥88 cm for women) Odds ratio (95% CI)
Energy intake				
% Energy intake during 00.00 h to 05.59 h and 22.00 h to 23.59 h	−0.15 (−0.32, 0.01)	0.98 (0.92, 1.04)	−0.33 (−0.73, 0.06)	0.97 (0.92, 1.02)
Daily total energy intake (unit: 100 kcal)	0.01 (−0.01, 0.02)	1.00 (0.99, 1.01)	0.01 (−0.03, 0.05)	1.00 (0.99, 1.01)
Sex				
Male	Reference	Reference	Reference	Reference
Female	−0.03 (−0.33, 0.28)	1.03 (0.91, 1.18)	−5.90*** (−6.72, −5.08)	2.28*** (2.01, 2.58)
Age group				
18–34 years of age	Reference	Reference	Reference	Reference
35–49 years of age	1.03*** (0.50, 1.55)	1.23** (1.05, 1.44)	3.96*** (2.64, 5.27)	1.66*** (1.39, 1.97)
50–64 years of age	0.61 (−0.04, 1.26)	1.16 (0.94, 1.43)	5.15*** (3.67, 6.64)	2.20*** (1.83, 2.65)
65 years of age and above	−0.89* (−1.61, −0.18)	0.75* (0.59, 0.96)	3.32*** (1.66, 4.97)	2.14*** (1.67, 2.76)
Race/ethnicity				
White, non-Hispanic	Reference	Reference	Reference	Reference
Black, non-Hispanic	1.76*** (1.25, 2.27)	1.58*** (1.36, 1.84)	1.15 (−0.07, 2.36)	1.12 (0.95, 1.31)
Other race/multi-race, non-Hispanic	−2.15*** (−2.80, −1.50)	0.53*** (0.40, 0.70)	−6.78*** (−8.44, −5.12)	0.40*** (0.32, 0.51)
Hispanic	0.85** (0.34, 1.35)	1.30*** (1.12, 1.52)	0.06 (−1.14, 1.26)	1.10 (0.94, 1.29)
Education				
High school and below	Reference	Reference	Reference	Reference
College education and above	−0.16 (−0.60, 0.28)	0.98 (0.84, 1.14)	−0.42 (−1.44, 0.60)	0.87 (0.76, 1.00)
Marital status				
Married	Reference	Reference	Reference	Reference
Divorced, separated, or widowed	−0.10 (−0.61, 0.40)	1.01 (0.88, 1.17)	−0.24 (−1.53, 1.05)	1.02 (0.83, 1.26)
Never married	−0.31 (−0.80, 0.18)	0.96 (0.84, 1.11)	−1.33* (−2.49, −0.18)	0.85* (0.74, 0.99)
Income to poverty ratio (IPR)				
IPR < 130%	Reference	Reference	Reference	Reference
130% ≤ IPR < 300%	0.25 (−0.18, 0.69)	1.08 (0.95, 1.23)	0.24 (−0.75, 1.22)	1.01 (0.89, 1.17)
IPR ≥ 300%	−0.25 (−0.79, 0.29)	0.97 (0.82, 1.15)	−0.87 (−2.21, 0.47)	0.91 (0.77, 1.09)
Physical activity (hours)				
Daily physical activity (work + commuting + leisure-time)	−0.09** (−0.15, −0.04)	0.97* (0.96, 0.99)	−0.31*** (−0.42, −0.20)	0.97** (0.95, 0.99)
Sleep (hours)				
Night-time sleeping on weekdays and/or workdays	−0.09* (−0.17, −0.01)	0.98 (0.94, 1.01)	−0.16** (−0.29, −0.03)	0.98 (0.96, 1.01)
Smoking				
Nonsmoker	Reference	Reference	Reference	Reference
Former or current smoker	−0.38* (−0.77, −0.01)	0.93 (0.82, 1.05)	0.29 (−0.48, 1.05)	1.06 (0.94, 1.18)
Self-rated health				
Good or excellent health	−1.71*** (−2.33, −1.09)	0.69*** (0.58, 0.82)	−3.91*** (−5.39, −2.42)	0.77*** (0.64, 0.94)
Fair or poor health	Reference	Reference	Reference	Reference
Chronic condition				
Diabetes	3.66*** (2.98, 4.33)	2.85*** (2.31, 3.51)	9.49*** (8.02, 10.95)	3.13*** (2.50, 3.52)
Arthritis	2.00*** (1.54, 2.45)	1.75*** (1.51, 2.03)	4.34*** (3.33, 5.35)	1.48*** (1.29, 1.71)

Table 2 Continued

	BMI Coefficient (95% CI)	Obesity Odds ratio (95% CI)	WC (cm) Coefficient (95% CI)	Abdominal obesity (WC ≥102 cm for men; WC ≥88 cm for women) Odds ratio (95% CI)
Coronary artery disease	0.15 (−0.56, 0.87)	1.18 (0.91, 1.51)	1.40 (−0.24, 3.03)	1.15 (0.85, 1.55)
Stroke	−0.59 (−1.54, 0.36)	0.92 (0.67, 1.27)	−0.73 (−3.02, 1.55)	0.89 (0.63, 1.26)
Cancer	−0.45 (−1.07, 0.17)	0.84 (0.68, 1.03)	−0.61 (−2.04, 0.83)	0.92 (0.75, 1.13)
Day of the week				
Weekdays	Reference	Reference	Reference	Reference
Weekends	0.08 (−0.22, 0.37)	1.02 (0.92, 1.14)	0.50 (−0.22, 1.23)	1.02 (0.90, 1.14)
Survey wave				
2007–2008	Reference	Reference	Reference	Reference
2009–2010	0.41 (−0.11, 0.92)	1.23* (1.04, 1.47)	0.77 (−0.54, 2.08)	1.13 (0.94, 1.37)
2011–2012	0.24 (−0.39, 0.87)	1.08 (0.88, 1.32)	0.89 (−0.59, 2.37)	1.16 (0.92, 1.47)
2013–2014	0.55 (−0.08, 1.18)	1.20 (0.99, 1.44)	1.50* (0.02, 2.97)	1.22* (1.02, 1.45)
2015–2016	1.02* (0.19, 1.85)	1.39** (1.09, 1.77)	2.83** (0.89, 4.77)	1.47*** (1.12, 1.93)

NHANES multi-wave sampling design was accounted for in the above regression analyses. 95% CIs are adjusted for multiple comparisons using Bonferroni correction. *0.01 ≤ *P*-value < 0.05; **0.001 ≤ *P*-value < 0.01; and ****P*-value < 0.001.
BMI, body mass index. CI, confidence interval.

higher BMI and obesity prevalence, whereas other race/multi-race had a lower BMI and obesity prevalence. Daily duration of physical activity was inversely associated with BMI and obesity, and daily duration of night-time sleeping was inversely associated with BMI. Being a former or current smoker was inversely associated with BMI. Poor self-rated health and presence of diabetes and arthritis were associated with higher BMI and obesity prevalence. Women were more likely to have abdominal obesity than men. Older age was positively associated with WC and abdominal obesity. Compared to non-Hispanic whites, other race/multi-race was associated with lower WC and abdominal obesity prevalence. Compared to those who were married, those who never married had a lower WC and abdominal obesity prevalence. Daily duration of physical activity was inversely associated with WC and abdominal obesity, and daily duration of night-time sleeping was inversely associated with WC. Poor self-rated health and presence of diabetes and arthritis were associated with a higher WC and abdominal obesity prevalence.

In the sensitivity analyses (not shown), we excluded the two covariates for daily hours of physical activity and sleeping from the regression. The modelling results were almost identical to those obtained from the regressions that adjusted for daily physical activity and sleeping duration. This indicates a lack of the mediating effect from physical activity and sleeping on the relationship between night-time eating and body weight status.

Discussion

Previous research on night-time eating in relation to obesity produced rather mixed findings [14]. Using data from a nationally representative health survey, the present study assessed the cross-sectional relationship between night-time eating and body weight status among US adults. The hourly patterns of total energy and macronutrient intakes within the 24-h dietary recall period resembled that reported in De Castro [17]. Adjusting for daily total energy intake, physical activity, sleeping and other individual characteristics, the proportion of energy, sugar, fat and saturated fat intake during night-time was not associated with BMI, WC, obesity or abdominal obesity.

By contrast to our hypothesis, despite the use of a large-scale national sample, we found no evidence linking night-time eating to adult weight gain. The findings are at odds with some early work reporting a positive influence of food intake during night-time on body weight [18–25], although they tend to be in favour of more recent research reporting either a null or negative relationship between night-time eating and weight [29–37]. Importantly, the possible confounding effects from physical activity and sleeping were not considered in the early work [14,26–28]. The present study adjusted for daily duration of physical activity and sleeping in the regression analyses, and both were negatively associated with BMI and WC, as expected. As the sensitivity analyses indicated, the null relationship between night-time eating and body weight status held even in absence of statistical adjustment for daily hours of physical activity and sleeping.

Several reasons might at least partially explain the null finding on the relationship between night-time eating and adiposity. At the population level, night-time eating could be largely compensatory for insufficient energy intake during regular mealtimes rather than in the form of binge or excessive eating [29–33]. In addition, people who

Table 3 Estimated relationships between proportion of energy, sugar, total fat and saturated fat intake during early or late hours and body weight status

	BMI (kg m^{-2}) Coefficient (95% CI)	Obesity (BMI ≥ 30 kg m^{-2}) Odds ratio (95% CI)	WC (cm) Coefficient (95% CI)	Abdominal obesity (WC ≥102 cm for men; WC ≥88 cm for women) Odds ratio (95% CI)
Energy intake				
% Energy intake during 00.00 h to 05.59 h and 22.00 h to 23.59 h (%)	−0.15 (−0.32, 0.01)	0.98 (0.92, 1.04)	−0.33 (−0.73, 0.06)	0.97 (0.92, 1.02)
% Energy intake during 00.00 h to 04.59 h and 22.00 h to 23.59 h (%)	−0.11 (−0.28, 0.06)	0.99 (0.93, 1.05)	−0.26 (−0.68, 0.15)	0.98 (0.93, 1.04)
% Energy intake during 00.00 h to 05.59 h and 23.00 h to 23.59 h (%)	−0.14 (−0.30, 0.03)	0.97 (0.92, 1.02)	−0.35 (−0.71, 0.01)	0.96 (0.91, 1.01)
% Energy intake during 00.00 h to 04.59 h and 23.00 h to 23.59 h (%)	−0.11 (−0.26, 0.03)	0.98 (0.93, 1.04)	−0.27 (−0.66, 0.11)	0.98 (0.93, 1.03)
% Energy intake during 00.00 h to 05.59 h (%)	−0.12 (−0.27, 0.02)	0.97 (0.93, 1.02)	−0.28 (−0.61, 0.04)	0.96 (0.92, 1.01)
% Energy intake during 00.00 h to 04.59 h (%)	−0.08 (−0.22, 0.07)	0.99 (0.94, 1.04)	−0.17 (−0.54, 0.20)	0.99 (0.95, 1.04)
Sugar intake				
% Sugar intake during 00.00 h to 05.59 h and 22.00 h to 23.59 h (%)	−0.03 (−0.18, 0.12)	1.00 (0.95, 1.06)	0.01 (−0.37, 0.39)	1.00 (0.95, 1.06)
% Sugar intake during 00.00 h to 04.59 h and 22.00 h to 23.59 h (%)	0.01 (−0.14, 0.16)	1.02 (0.96, 1.08)	0.09 (−0.32, 0.49)	1.02 (0.96, 1.08)
% Sugar intake during 00.00 h to 05.59 h and 23.00 h to 23.59 h (%)	−0.08 (−0.22, 0.07)	0.99 (0.94, 1.04)	−0.12 (−0.49, 0.24)	0.97 (0.93, 1.03)
% Sugar intake during 00.00 h to 04.59 h and 23.00 h to 23.59 h (%)	−0.03 (−0.20, 0.13)	1.00 (0.94, 1.06)	−0.04 (−0.45, 0.37)	1.00 (0.94, 1.06)
% Sugar intake during 00.00 h to 05.59 h (%)	−0.08 (−0.21, 0.06)	0.99 (0.94, 1.04)	−0.12 (−0.50, 0.25)	0.97 (0.92, 1.02)
% Sugar intake during 00.00 h to 04.59 h (%)	−0.02 (−0.18, 0.14)	1.01 (0.95, 1.07)	−0.02 (−0.44, 0.40)	1.00 (0.97, 1.05)
Total fat intake				
% Total fat intake during 00.00 h to 05.59 h and 22.00 h to 23.59 h (%)	−0.15 (−0.31, 0.02)	0.99 (0.93, 1.05)	−0.35 (−0.76, 0.05)	0.96 (0.91, 1.01)
% Total fat intake during 00.00 h to 04.59 h and 22.00 h to 23.59 h (%)	−0.12 (−0.29, 0.05)	0.99 (0.94, 1.06)	−0.30 (−0.73, 0.12)	0.97 (0.92, 1.02)
% Total fat intake during 00.00 h to 05.59 h and 23.00 h to 23.59 h (%)	−0.12 (−0.25, 0.02)	0.98 (0.93, 1.03)	−0.27 (−0.63, 0.10)	0.97 (0.92, 1.02)
% Total fat intake during 00.00 h to 04.59 h and 23.00 h to 23.59 h (%)	−0.08 (−0.23, 0.06)	0.99 (0.94, 1.05)	−0.20 (−0.60, 0.20)	0.98 (0.93, 1.04)
% Total fat intake during 00.00 h to 05.59 h (%)	−0.09 (−0.21, 0.04)	0.99 (0.94, 1.04)	−0.17 (−0.50, 0.16)	0.97 (0.92, 1.02)
% Total fat intake during 00.00 h to 04.59 h (%)	−0.04 (−0.18, 0.09)	1.00 (0.95, 1.05)	−0.07 (−0.44, 0.30)	1.00 (0.95, 1.05)
Saturated fat intake				
% Saturated fat intake during 00.00 h to 05.59 h and 22.00 h to 23.59 h (%)	−0.15 (−0.32, 0.02)	0.98 (0.92, 1.04)	−0.36 (−0.78, 0.06)	0.96 (0.91, 1.02)
% Saturated fat intake during 00.00 h to 04.59 h and 22.00 h to 23.59 h (%)	−0.13 (−0.30, 0.05)	0.99 (0.93, 1.05)	−0.29 (−0.73, 0.15)	0.98 (0.93, 1.03)
% Saturated fat intake during 00.00 h to 05.59 h and 23.00 h to 23.59 h (%)	−0.12 (−0.26, 0.02)	0.98 (0.93, 1.03)	−0.29 (−0.66, 0.07)	0.97 (0.91, 1.02)
% Saturated fat intake during 00.00 h to 04.59 h and 23.00 h to 23.59 h (%)	−0.08 (−0.24, 0.07)	0.99 (0.93, 1.05)	−0.20 (−0.61, 0.21)	0.99 (0.94, 1.05)
% Saturated fat intake during 00.00 h to 05.59 h (%)	−0.09 (−0.22, 0.04)	0.98 (0.93, 1.04)	−0.20 (−0.55, 0.14)	0.97 (0.91, 1.02)
% Saturated fat intake during 00.00 h to 04.59 h (%)	−0.04 (−0.18, 0.10)	1.00 (0.95, 1.05)	−0.07 (−0.44, 0.30)	1.00 (0.95, 1.05)

All regressions controlled for daily total energy intake and individual characteristics listed in Table 2. NHANES multi-wave sampling design was accounted for in the above regression analyses. 95% CIs are adjusted for multiple comparisons using Bonferroni correction.
BMI, body mass index; CI, confidence interval; WC, waist circumference.

consumed a larger proportion of energy during night-time might also stay awake longer, which facilitated food digestion and increased energy expenditure [14,29]. The relationship between NES and obesity remains inconclusive [42]. On the one hand, NES does not always lead to weight gain and is also present among normal-weight individuals [14]. Circadian genes may play a role in NES, resulting in certain individuals possibly being more susceptible to night-time eating related weight gain [43,44]. On the other hand, weight loss via surgical and behavioural interventions has been successful in alleviating NES [43,44], which indicates that obesity could serve as a cause rather than consequence of NES.

The strengths of the present study include the use of data from a large nationally representative health survey, objective anthropometric measures and detailed food consumption data using an in-person 24-h dietary recall. In addition to the strengths, there are several limitations. NHANES is a probability sample of the US noninstitutionalised population, although patients in penal/mental facilities, institutionalised older adults and/or military personnel on active duty are not represented. Dietary intakes in NHANES were self-reported and subject to measurement error and social desirability bias [45]. Survey respondents might not accurately recall all of the food items consumed in different time windows of any one particular day, and could deliberately under-report or over-report consumption given certain circumstances. Change in body weight is a cumulative process. However, the cross-sectional study design was unable to track the change in weight and obesity status over time in response to night-time eating. Moreover, the 24-h dietary recall could not reliably capture habitual dietary behaviour, which often serves as an essential predictor for weight change. The present study only assessed night-time eating in relation to weight-rated anthropometric measures including BMI, WC, obesity and abdominal obesity. Previous studies examined night-time eating in relation to cancer [46,47], weight loss [48,49] and systemic inflammation biomarker C-reactive protein [50]. Other important biomarkers such as fasting glucose, haemoglobin A1C, low- and high-density lipoprotein cholesterol, and triglycerides were not examined as a result of the scope of the study. Investigation of these biomarkers is warranted. Data on work schedules (e.g. night-time, shift work) were not collected in the NHANES and so we were unable to adjust for them in the regression analyses.

A few caveats may be needed regarding the study findings. Despite a null relationship being revealed between night-time eating and body weight status, it would be risky to assume that the consumption of a substantial proportion of daily energy during night-time, especially of energy-dense, nutrient poor food products, would be a sensible choice. The present study only assessed night-time eating in relation to body weight status, whereas nocturnal food intake might adversely affect other aspects of cardiometabolic health in the absence of weight gains. In addition, the proportion of energy, sugar and fat intake during night-time has been modest (approximately 5%–7%) among the NHANES study sample. Study findings based on this sample may not be applicable to NES and/or binge eating behaviour in which a substantial percentage and/or amount of energy is consumed during night-time.

In conclusion, the present study examined night-time eating in relation to body weight status among US adults, using data from a nationally representative health survey. Adjusting for daily total energy intake, physical activity and sleeping duration, percentage of energy, sugar, fat and saturated fat intake during night-time was not associated with BMI, WC, obesity or abdominal obesity. Restricting night-time food consumption alone without an overall reduction in daily caloric intake may not help weight management and obesity prevention. The present study has limitations pertaining to its observational study design and measurement error. A future experimental study with measures on habitual dietary behaviour is warranted to replicate the null finding on the relationship between night-time eating and body weight status.

Conflict of interests, source of funding and authorship

The authors declare that they have no conflicts of interest.

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RA designed the study and conducted statistical analysis. RA and SZ wrote the manuscript. SZ took primary responsibility to revise the manuscript. All authors were involved in the study design, analysis of the results, and reviewed and contributed to the content in manuscript. All authors critically reviewed the manuscript and approved the final version submitted for publication.

Transparency declaration

All authors affirm that this manuscript is an honest, accurate and transparent account of the study being reported, that no important aspects of the study have been omitted and that any discrepancies from the study as planned have been explained. The reporting of this work is compliant with STROBE guidelines.

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