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Circadian timing of eating and BMI among adults in the American Time Use Survey

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Abstract

Background/Objectives—Experimental studies of time-restricted eating suggest that limiting the daily eating window, shifting intake to the biological morning, and avoiding eating close to the biological night may promote metabolic health and prevent weight gain.

Subjects/Methods—We used the Eating & Health Module of the 2006–2008 and 2014–2016 American Time Use Survey to examine cross-sectional associations of timing of eating in relation to sleep/wake times as a proxy for circadian timing with body mass index (BMI). The analytical sample included 38 302 respondents (18–64 years; BMI 18.5 – 50.0 kg/m^2). A single 24-hour time use diary was used to calculate circadian timing of eating variables: *eating window* (time between first and last eating activity); *morning fast* (time between end of sleep and start of eating window); and *evening fast* (time between end of eating window and start of sleep). Multinomial logistic regression and predictive margins were used to estimate adjusted population prevalences (AP) by BMI categories and changes in prevalences associated with a one-hour change in circadian timing of eating, controlling for sociodemographic and temporal characteristics.

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Results—A one-hour increase in eating window was associated with lower adjusted prevalence of obesity (AP= 27.1%, SE=0.1%). Conversely, a one-hour increase in morning fast (AP= 28.7%, SE=0.1%) and evening fast (AP= 28.5%, SE=0.1%) were each associated with higher prevalence of obesity; interactions revealed differing patterns of association by combination of eating window with morning/evening fast (p<0.0001).

Conclusions—Contrary to hypotheses, longer eating windows were associated with a lower adjusted prevalence of obesity and longer evening fasts were associated with a higher prevalence of obesity. However, as expected, longer morning fast was associated with a higher adjusted prevalence of obesity. Studies are needed to disentangle the contributions of diet quality/quantity and social desirability bias in the relationship between circadian timing of eating and BMI.

Keywords

Eating patterns; temporal eating patterns; meal timing; circadian rhythm; body mass index; BMI; 24-hr behavior; ATUS

Introduction

Experimental evidence suggests that aligning the timing of eating with circadian rhythms, as with some forms of time-restricted eating (TRE), may promote metabolic health and prevent weight gain (1–4), representing an understudied opportunity for intervention (1, 5). However, it is unknown whether these experimental results reflect mechanisms linking behavior and body mass index (BMI; kg/m^2) in the general population.

Evidence from epidemiological studies regarding the association of meal timing with BMI and related health outcomes is mixed (6–8). One limitation of previous studies is a focus on the timing of eating in relation to external clock time (e.g. 8:00 am) or in terms of socially defined meal types (e.g., breakfast). Few studies have examined the timing of eating in relation to internal biological (i.e., circadian) time as it relates to weight (9). The human biological clock is an intrinsically generated timekeeping system, which is synchronized (i.e., entrained) to local clock time. Individuals' chronotype, or phase of entrainment between the circadian system and local clock time (10), can vary by up to 10–12 hours (h) (11, 12), indicating that for a given clock time, individuals may vary widely in their internal circadian time. This potential mismatch between clock and circadian time may contribute to conflicting population-level associations between meal timing and BMI.

Extending the overnight fasting window causes modest weight loss among overweight individuals (6, 13, 14), potentially through improved insulin sensitivity and increased robustness of circadian rhythms (14, 15). For example, free-living adults who reduced their daily eating window from ≥14 h to 10–12 h for 16 weeks lost weight (average reduction: 1.15 kg/m^2), without overt attempts to improve diet quality or decrease energy intake (16). In a seven-year observational study, adults with the longest (≥18 h) overnight fast had modest reductions in their BMI compared to the group of adults with shortest (7–11 h) overnight fast, who experienced increases in BMI over the study period (8). A recent systematic review and meta-analysis of 19 clinical trials of TRE concluded that this dietary strategy induces significant reductions in body weight and fat mass, with preservation of fat-free mass (3).

In addition to the length of the daily eating and fasting windows, the placement of the eating window in relation to biological time may also have implications for BMI (17) due to time-of-day dependent physiological responses to food intake (18). Eating earlier in the biological day in alignment with the circadian peak in metabolism and thermogenesis promotes metabolic health and weight loss among overweight individuals (19). Conversely, eating close to the biological night and melatonin onset may disrupt metabolic homeostasis, induce glucose intolerance (20), increase postprandial triglycerides (21), and has been linked to higher BMI (22) and % body fat (23) in observational studies. There are limited studies examining the effect of early vs. late TRE with identical eating windows on weight outcomes; evidence from a small 1-week cross-over RCT of men at risk for type 2 diabetes found that both early (8:00–17:00) and late (12:00–21:00) TRE improved glycemic control and induced weight loss of approximately 1% with no significant differences in weight loss between the early and late conditions (24). Other studies have suggested that a short eating window placed early in the biological day may be beneficial (25), while a long eating window that extends into the biological night may be particularly detrimental.

While experimental findings suggest a benefit of aligning the timing of food intake with circadian rhythms for metabolism and weight loss among overweight and obese individuals, it is unknown how these experimental results relate to the association between circadian timing of eating and BMI among the general population. To address this gap, the current study used a nationally representative dataset of time use patterns to examine the cross-sectional associations of *eating window* (time between first and last eating activity); *morning fast* (time between end of sleep and start of eating window); and *evening fast* (time between end of eating window and start of sleep), and their interactions, with BMI. BMI was selected as the primary outcome based on experimental evidence that TRE promotes weight loss (2, 26, 27). As in previous studies (9), meal timing relative to the sleep/wake cycle was used to approximate circadian timing of eating, because of the strong relationship between circadian time and sleep/wake timing (28–30). We hypothesized that longer eating window and longer morning fast (delayed food intake after awakening) would be associated with higher and that longer evening fast (avoiding food intake close to bedtime) would be associated with lower prevalence of overweight and obesity. Additionally, we hypothesized an interaction effect such that having a short eating window and short morning fast would be associated with lower prevalence of overweight and obesity.

Subjects and Methods

Data for the current study were drawn from the American Time Use Survey (ATUS), a nationally representative, continuously administered survey of the time use patterns of civilian, non-institutionalized US adults age 15 years and older sponsored by the Bureau of Labor Statistics (31). Trained ATUS interviewers administer a single 24 h time use diary via telephone interview, in which respondents sequentially recall each activity engaged in during the previous 24 h period beginning at 4:00 am, along with the start and stop time of each activity. All respondent-reported activities related to sleep (e.g., sleeping, falling asleep, napping, tossing and turning, sleeplessness) were coded as sleep in the ATUS. The ATUS is an anonymized public domain dataset that is not subject to IRB approval. Additional details of the ATUS sampling and study procedures are available at: https://www.bls.gov/tus/.

ATUS Eating and Health Module

In 2006 – 2008 and 2014 −2016, the ATUS included the supplemental Eating and Health Module (ATUS-EHM), sponsored by the United States Department of Agriculture’s Food and Nutrition Service and the National Cancer Institute. Following the time use diary, ATUS-EHM respondents reported all secondary eating activities (i.e., eating that occurred while engaged in another primary activity) and their duration for the same 24 h period. EHM respondents also self-reported their height and weight (without shoes). Female participants between the ages of 18–50 years were asked if they were currently pregnant, and if a respondent indicated current pregnancy, weight was not recorded. Additional details of the EHM are available at: https://www.ers.usda.gov/data-products/eating-and-health-module-atus/.

Data preparation

The ATUS dataset and EHM are available for public download, and the IPUMS ATUS Extract Builder (ATUS-X) (32) was used to extract relevant variables and assemble the activity-level dataset for the current analysis, which included all respondents who completed the ATUS-EHM.

Prior to analysis, all sleep-related activity codes, primary eating/drinking and secondary eating activity codes were identified and used to calculate the three circadian timing of eating variables. Eating window, morning fast, and evening fast were calculated (in h) using the respondent-reported activity start and stop times for eating/drinking and sleep activities (Figure 1). Secondary eating activities were anchored to the midpoint of the primary activity during which the secondary eating occurred (33). For example, 30 minutes (min) of secondary eating during a primary activity occurring from 13:00 – 14:00, would be designated as occurring from 13:15 – 13:45.

The primary outcome was BMI category (normal weight=18.5–24.9 kg/m^2; overweight=25–29.9 kg/m^2; obese ≥ 30.0 kg/m^2), derived from the ATUS BMI variable calculated using respondent-reported height and weight and classified according to World Health Organization cutoffs (34).

Exclusion criteria

The original analytical sample included 70 904 respondents who reported a total of 1 400 200 unique activities. Of the original sample, 1 124 (1.70%) respondents were excluded due to underweight (BMI <18.5 kg/m^2), 327 (0.50%) due to BMI >50.0 kg/m^2, and 4 861 (6.86%) due to missing BMI values (including pregnant women). Additionally, 3 361 (4.74%) respondents age <18 years, and 13,908 (19.62%) age >64 years were excluded due to age-related differences in sleep patterns (35). Respondents with <2 (n=5 958) or >10 (n=165) eating/drinking activities, or <2 (n=2 809) or >4 (n=290) sleep activities (due to suspected shift work or difficulties in determining the circadian timing of eating variables) were excluded. After excluding 1 849 respondents for a-typical schedules (e.g., inverted daily pattern in which eating occurred prior to first sleep activity or following the final sleep activity) and outliers (e.g., circadian timing variables >99% of distribution), 38 302 respondents remained in the final sample. The data cleaning and preparation approach is included in the Supplementary Materials.

Covariates

The following covariates were controlled for in all adjusted analyses: sex, age, age^2 (to test for potential curvilinear relationship with outcome), education, income, race/ethnicity, household size, employment status, total sleep time, bedtime, season of measurement, weekend (vs. weekday), and ATUS-EHM measurement cycle. Prior to analyses, these variables were re-coded. The level of education was re-coded as: less than high school, high school graduate, some college, and graduate of four-year college or greater. Annual household income was re-coded as: <$30 000, $30 000 - $49 999, $50 000 - $74 999, $75 000 - $99 999, and ≥ $100 000. Race and ethnicity were used to create six mutually exclusive race/ethnicity categories: non-Hispanic white, Non-Hispanic black, Hispanic only/ Hispanic mixed, Asian/Pacific Islander, American Indian/Alaska Native, and non-Hispanic mixed. Household size (number of individuals residing in the household) was re-coded as 1, 2, 3–4, and ≥ 5. Employment status was re-coded so that past two-week labor force status of “Employed – at work” or “Employed – absent” were coded as 1 and “Unemployed” or “Not in labor force” were coded as 0. Total sleep time was coded as <7 h, 7–9 h, and >9 h. Bedtime was coded as < 22:00, 22:00–22:59, 23:00–23:59, and >00:00. Season was coded as winter (Dec – Feb), spring (March – May), summer (Jun – Aug), and fall (Sept – Nov). Weekend was defined based on the ATUS interview day of week variable of Saturday or Sunday. ATUS-EHM measurement cycle was coded as 0 (2006 – 2008) and 1 (2014 – 2016).

Statistical Approach

Weighted population means for each circadian timing of eating variable (i.e., eating window, morning fast, evening fast) by demographic and temporal characteristics were assessed using linear regression (Table 1). Predicted margins computed from the multinomial logistic regression were used to estimate unadjusted and adjusted prevalences (AP) of the population in each BMI category and changes in these prevalences with a one-hour increase in each circadian timing of eating variable, controlling for sociodemographic and temporal characteristics (Table 2). Multinomial logistic regression estimated the AP of the population in each BMI category for a given two-way interaction between eating window quartile and morning (Table 3) or evening fast (Table 4) (median of each tertile) and stratified by weekend (Supplementary Table S1) and weekday reporters (Table S2). Multinomial logistic regression was used to estimate ORs for overweight (vs. normal weight) and obesity (vs. normal weight) for each of the circadian timing of eating variables (Table S3). Additional models adjusted for eating window when estimating the ORs of morning/evening fast on overweight or obesity (Table S4), stratified the sample by weekend vs. weekday reporters (Tables S5 and S6), restricted the sample to respondents aged 26–64 (Table S7), and tested BMI as a 5-level outcome (Table S8). Analyses were conducted using SAS statistical software version 9.4 (SAS Institute Inc) and SAS-callable SUDAAN, version 11.0.1 (RTI

International) accounting for the ATUS-EHM survey design (36). R v. 4.0.0 (R Core Team) was used for data visualization. All p-values are two-sided and are not adjusted for multiple comparisons.

Results

Descriptive Results

Respondents reported an average of 2.80 eating activities per day (SD: 1.53), and an average of 101.12 min (SD: 113.32) spent in primary and secondary eating. Mean wake-up time was 7:15 (SD: 25 min), mean eating start time was 9:20 (SD: 40 min), mean eating stop time was 19:30 (SD: 33 min), and mean sleep time was 22:49 (SD: 24 min) (data not shown). Mean eating window was 10.06 h (95% CI: 10.01–10.10), mean morning fast was 2.26 h (95% CI: 2.22–2.29), and mean evening fast was 3.35 h (95% CI: 3.32–3.38).

Differences in circadian timing of eating variables by demographic characteristics

There were small but statistically significant differences in the circadian timing of eating by all sociodemographic and temporal characteristics considered (Table 1). Circadian timing of eating variables also differed by BMI category ($p<0.0001$ for all) with shorter eating windows, longer morning fast, and longer evening fast among individuals with obesity (Figure 2).

Results for associations of circadian timing of eating with BMI

Association of eating window with BMI category.—In adjusted multinomial logistic regression models, a one-hour increase in eating window duration was associated with a 0.9% higher adjusted prevalence of the population classified as normal weight (AP= 37.5%, SE= 0.1%), a 0.2% lower prevalence of overweight (AP= 35.4%, SE= 0.1%) and a 0.7% lower prevalence of obesity (AP= 27.1%, SE= 0.1%) ($p<0.0001$ for all) (Table 2).

Association of morning fast with BMI category.—A one-hour increase in morning fast was associated with a 1.2% lower adjusted prevalence of normal weight (AP= 35.4%, SE= 0.1%), a 0.4% higher prevalence of overweight (AP= 35.9%, SE= 0.1%) and a 0.8% higher prevalence of obesity (AP= 28.7%, SE= 0.1%) ($p<0.0001$ for all) (Table 2).

Association of evening fast with BMI category.—A one-hour increase in evening fast duration was associated with a 0.6% lower adjusted prevalence of normal weight (AP= 35.9%, SE= 0.1%, $p<0.0001$), a 0.02% non-significantly higher prevalence of overweight (AP= 35.6%, SE= 0.1%, $p=0.7$), and a 0.6% higher prevalence of obesity (AP= 28.5%, SE= 0.1%, $p<0.0001$) (Table 2).

Stratification by Weekend/Weekday.—Results from weekend only models (Tables S1 and S5) were largely consistent with the full sample for the normal weight and obesity outcomes and remained highly significant, however for overweight was attenuated (Table S1) or non-significant (Table S5). Results from the weekday only models (Tables S2 and 6) largely mirrored the full model, except for the association of evening fast with overweight which was non-significant (Table S6).

Interaction effects.—There were highly significant interactions between eating window quartiles and morning (Table 3) and evening fast (Table 4) across the three weight categories (global Wald F-test $p<0.0001$). This interaction is manifest in apparent differences in the association of eating window by the length of the morning or evening fast; for example, while a short morning fast was associated with lower prevalence of obesity, within the shortest morning fast tertile (tertile 1), the prevalence of obesity is lowest in the longest eating window quartile (24.16% in Q4 vs. 30.72% in Q1) (Table 3). Additionally, while a short evening fast was associated with higher prevalence of normal weight, within the shortest evening fast tertile, the prevalence of normal weight is higher with longer eating window quartiles (40.58% in Q4 vs. 31.85% in Q1) (Table 4).

Discussion

This study used a large, nationally representative time use dataset to investigate cross-sectional associations between the timing of eating in relation to the sleep/wake cycle (a proxy for circadian timing) and BMI. Based on emerging evidence for metabolic and weight benefits of time-restricted eating (3, 4), we hypothesized that shorter eating window, shorter morning fast and longer evening fast would be associated with lower predicted prevalence of obesity. Our results largely contradicted these hypotheses. Although individuals with normal weight reported the shortest morning fast (2.11 h), they also reported longer eating windows (by 25 min) and shorter evening fasts (by 15 min) compared to individuals with overweight and obesity. Our analysis also revealed significant interactions of eating window with morning and evening fast which were largely contrary to our hypotheses.

Eating window and BMI

Compared to individuals with normal weight, individuals with obesity reported a shorter daily eating window, and a longer eating window was associated with a higher adjusted prevalence of the population classified as normal weight. Previous studies examining the association between eating window and BMI have had mixed results. One study used a smartphone app to measure free-living timing of eating for three weeks and found a weak correlation between mean eating window and BMI; however, among a subset of 8 participants with >14 h eating duration and BMI >25, a 16 week pilot intervention to reduce eating window to 10–12 h resulted in a reduction in BMI by an average of 1.15 kg/m^2 (16). However, a TRE intervention among overweight individuals found a positive association of both cross-sectional baseline eating window with BMI (r=0.45; $p=0.04$), as well as prospective reductions in weight and fat mass among participants who were randomized to an 8 h eating window (37). A growing body of literature describes a reduction of approximately 1–3% of body weight in RCTs of TRE with study duration ranging from several days to several weeks (3, 38). These findings suggest that while reducing one’s usual eating window may lead to prospective reductions in BMI, the cross-sectional association between free-living eating patterns and BMI may be less robust, particularly without information on the content of the diet and energy intake, as well as history of weight and weight change. For example, among the general population, individuals with overweight or obesity may exhibit altered eating patterns due to altered appetitive hormones (39), while individuals actively attempting to lose weight may restrict their eating window and/or shift the timing of eating as a weight-loss strategy (40), which may further complicate the association between eating patterns and BMI.

Morning fast and BMI

Individuals with obesity reported a delay in their first morning meal by about 20 min compared to individuals with normal weight. Although a longer morning fast was associated with a higher adjusted prevalence of the population classified as overweight or obese, the higher odds of obesity (vs. normal weight) were attenuated when accounting for the effect of eating window. While a longer morning fast was associated with higher prevalence of obesity, interaction analysis found that among those with the longest morning fast, the prevalence of obesity was higher among those with longer eating windows. Previous epidemiological studies have generally supported the importance of breakfast consumption for the maintenance of healthy weight (7, 41, 42), however a recent meta-analysis of RCTs found that breakfast skipping was associated with modest weight loss (43). The focus in this study was on morning fast duration, which may present an advantage over previous studies, in which the definition of breakfast varies widely across studies and is often not defined based on the time of day or proximity to wake time. Initiating eating relatively earlier in the biological morning may be protective against obesity due to alignment with the peak in glucose metabolism and thermogenesis (25), as well as through beneficial downstream effects on the frequency, timing, and content of subsequent eating occasions that day (44).

Evening fast and BMI

Individuals with normal weight reported a shorter evening fast than individuals with obesity, and a longer evening fast was associated with a higher adjusted prevalence of the population classified as overweight or obese. Additionally, our interaction analysis found that this association differed by eating window quartile. Among eating window Q1 and Q2, the prevalence of each weight category did not significantly differ by evening fast tertile (as illustrated by the overlapping 95% CIs) whereas among eating window Q3 and Q4 the prevalence of obesity was lowest in evening fast tertile 1. This is contrary to our hypothesis that a longer evening fast and shorter eating window would be associated with lower prevalence of obesity. Previous observational studies have found that food intake close to melatonin onset (a marker of biological night) is associated with higher BMI and % body fat (23). Additionally, a randomized cross-over trial study found that a late (10pm) vs. routine (6pm) dinner with isocaloric meal content led to a delayed postprandial period, nocturnal glucose intolerance and reduced fatty acid oxidization (20), which may contribute to metabolic disfunction and weight gain (18, 19). One potential interpretation is that, while overweight and obese individuals may report ceasing food consumption relatively earlier in their day compared to individuals of normal weight, their diet quality and overall energy intake may be a stronger contributor to higher BMI. This unexpected pattern of findings may be partially attributed to the underreporting of non-main meal snack and beverage intake within the ATUS-EHM compared to other nationally representative samples (33). Further, later timing of eating may be particularly stigmatized (45), which may have contributed to underreporting of after-dinner snacking and biased estimates of evening fast, particularly for individuals with overweight and obesity.

Strengths and Limitations

The current study has several strengths. The ATUS is a nationally representative sample, allowing results to be generalized to the US adult population. The 24 h period of the ATUS-EHM is suited to capture a 'metabolic day' (16), and the short-term recall period may be less subject to errors and biases than other self-report methods for assessing sleep/wake patterns and meal timing. Although not specific to ATUS, diverse 24 h recalls have been validated using a variety of approaches (46–48) and display high levels of reliability and validity. Additionally, compared to other dietary recall methods, such as the 24 h dietary recall used in the National Health and Nutrition Examination Survey (NHANES), which collects only the start time, the ATUS-EHM assesses both start and stop time of eating occasions (33), which is needed to calculate the duration of eating activities.

There are several limitations to this study. First, ATUS is a cross-sectional study, limiting inference about causality. Future longitudinal observational studies could build upon the current study by examining prospective associations between BMI and weight-related behaviors and eating patterns (49). Time use surveys measure a single randomly selected day of activities, and thus are subject to day-to-day variability and are valid for the estimation of group rather than individual level estimates of associations between behavior and BMI (50). The time-use approach to estimating sleep time also differs from other stylized approaches to estimating sleep time and is known to produce relatively higher estimates of sleep (51). Additionally, this study presents combined results from across weekends and weekdays, with stratified models in the Supplementary Materials showing a similar patten of findings for the association of timing of eating with BMI.

A further key limitation of this study is lack of data on diet composition, which would have strengthened the analysis. Energy intake, macronutrient composition of meals, and overall diet quality contribute to weight status and may also interact or act synergistically with the timing of eating to influence BMI (9, 19, 52–54). Given the strong circadian control of the sleep-wake cycle, using the timing of eating in relation to self-reported sleep/wake timing as a proxy for circadian timing of eating is a practical approach for approximating circadian time (9, 30) particularly in a large sample where a biological measure (i.e., dim-light melatonin onset) would be impractical. However, inter-individual differences in the correlation between sleep/wake timing and endogenous circadian phase, as well as the varying influence of external factors (e.g., work schedules) (29) may weaken the correlation between circadian timing and the proxy used in the current analysis. Biological measures of circadian time and availability of covariates such as illness, menstrual phase, or use of certain medications (i.e., birth control) that are not assessed in ATUS may strengthen future studies examining timing of eating and BMI.

Reporting bias is a potentially significant limitation of the use of the ATUS dataset for analyzing the timing of eating, and eating activities are underreported in ATUS-EHM compared to NHANES (33). In the current analysis, the average eating window was 10 h, which is markedly shorter than estimates from NHANES 2009–2014, in which the average eating duration for adults age ≥20 years was 12.2 ± 0.06 h (55). Although ATUS-EHM captures the majority of main meals (e.g., breakfast), there is substantial underreporting of non-main meals (e.g., snacks) (33) compared to NHANES, which may contribute to biased estimates of circadian timing of eating. Underreporting of morning intake is likely, given the large difference in mean eating start time within the current analysis (9:20) compared to the mean breakfast time (7:41 for men; 7:54 for women) reported by adults in NHANES (56). Social desirability bias may have contributed to differential underreporting of weight and eating; this is of particular concern among individuals with overweight or obesity (57, 58), as well as for high-fat foods, which are often consumed as non-main meals (57, 58), and which are underreported in ATUS-EHM compared to NHANES. There is much to learn about the extent of measurement error related to timing and frequency of eating, and this may have affected estimates of BMI, morning/evening fast, and eating duration (59).

In conclusion, the current study found that longer eating windows were associated with lower adjusted prevalence of obesity, and longer morning and evening fasts were associated with higher prevalence of obesity. However, given the cross-sectional design, single measurement day and lack of data on diet composition in the ATUS-EHM, findings should be interpreted with caution. Future studies should consider how energy intake, macronutrient profile, and dietary quality intersect with circadian timing of eating to influence metabolism, energy balance, and weight trajectories over time.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

BMI	Body mass index
ATUS	American Time Use Survey
EHM	Eating and Health Module
NHANES	National Health and Nutrition Examination Survey
TRE	Time-restricted eating

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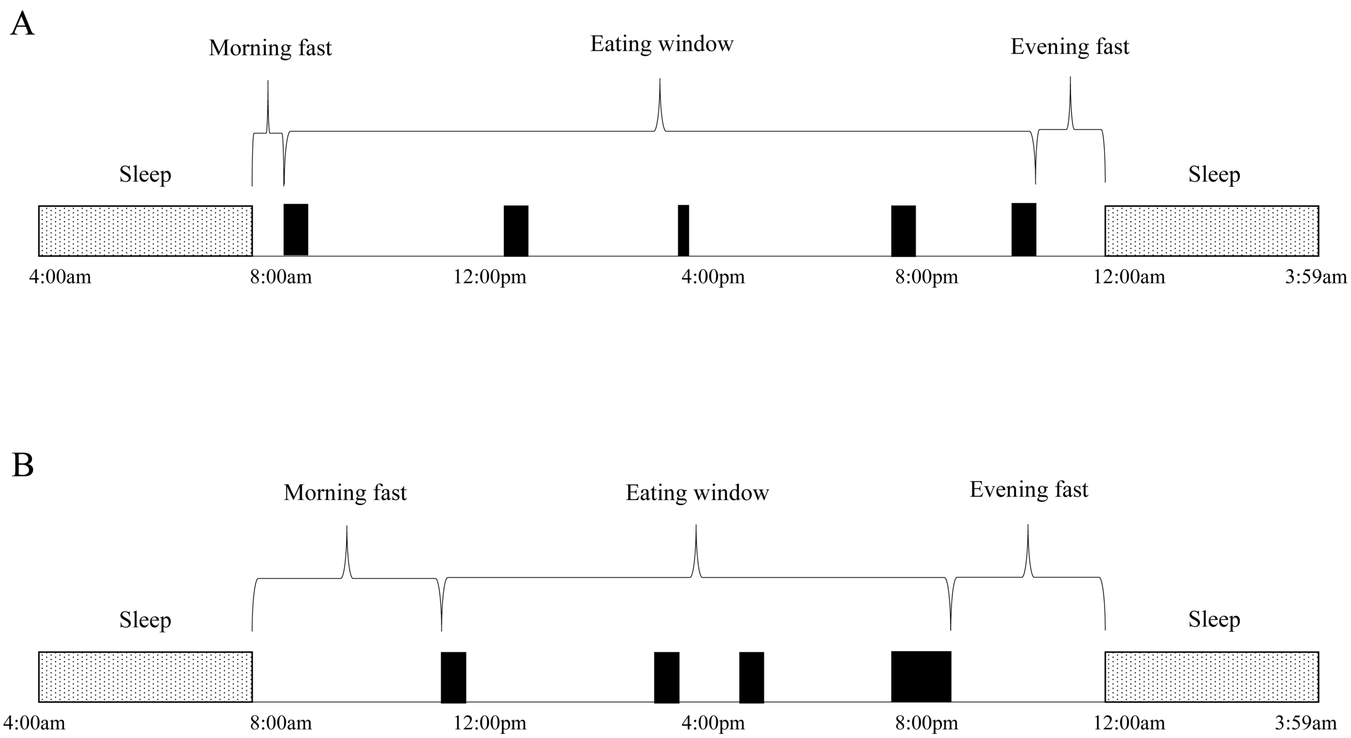

Figure 1.

Illustration of circadian timing of eating variables from two hypothetical days in the American Time Use Survey Eating and Health Module (ATUS-EHM), from 4:00 on Day 1 to 3:59 on Day 2. The solid black bars indicate eating activities, and their width indicates duration, and the dotted bars indicate sleep. While Panel A and Panel B both have the same sleep/wake activity pattern, the timing of eating in relation to sleep and wake (i.e., circadian timing of eating) show different patterns. In Panel A, morning fast is short, eating window lasts about 14 h, and eating continues until approximately an hour before bedtime. In contrast, Panel B displays a longer morning fast, a shorter eating window and a longer evening fast.

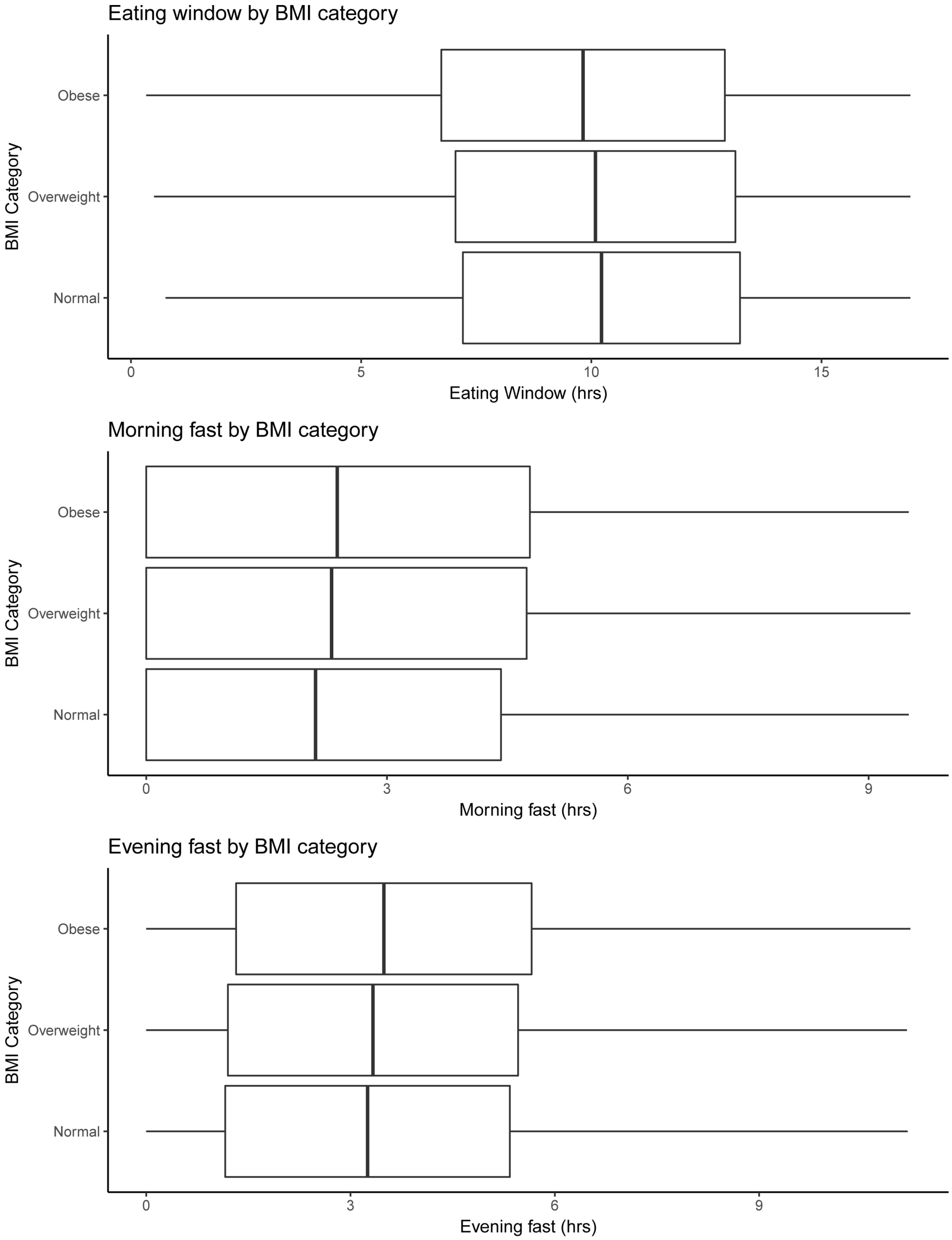

Figure 2.

Population-adjusted mean, standard deviation, and range of circadian timing of eating characteristics by BMI category among N= 38 302 respondents from the American Time Use Survey Eating and Health Module (ATUS-EHM). The top panel displays eating window duration, the middle panel displays morning fast duration, and the lower panel displays evening fast duration by BMI category (i.e., obese, overweight, normal weight). In each panel, the vertical center line indicates the population-adjusted mean value, the lower and upper box boundaries indicate the standard deviation of the mean, and the horizontal line indicates the range.

Table 1.

Weighted population proportions and means of circadian timing of eating by sociodemographic and temporal characteristics among N=38 302 respondents in the 2006–2008 & 2014–2016 American Time Use Survey Eating & Health Module (ATUS-EHM)

			Eating Window		Morning Fast		Evening Fast	
	n	**Weighted % (SE)**	**Mean (SE)**	**p-value** ^{a}	**Mean (SE)**	**p-value**	**Mean (SE)**	**p-value**
Sex								
Male	17488	49.79 ± 0.19	10.21 ± 0.03	<0.0001	2.19 ± 0.02	<.0001	3.29 ± 0.02	<0.0001
Female	20814	50.21 ± 0.19	9.91 ± 0.03		2.33 ± 0.02		3.41 ± 0.02	
Age (years)								
18–24	2859	14.26 ± 0.18	9.41 ± 0.08	<0.0001	2.21 ± 0.05	<0.0001	3.41 ± 0.05	<0.0001
25–34	7979	21.40 ± 0.17	9.90 ± 0.05		2.46 ± 0.04		3.24 ± 0.03	
35–44	10548	21.98 ± 0.14	10.10 ± 0.04		2.40 ± 0.03		3.29 ± 0.02	
45–54	9151	22.78 ± 0.15	10.28 ± 0.04		2.25 ± 0.04		3.32 ± 0.03	
55–64	7765	19.68 ± 0.16	10.40 ± 0.04		1.92 ± 0.04		3.52 ± 0.03	
Highest level of education								
Less than HS	2669	8.22 ± 0.21	9.43 ± 0.07	<0.0001	2.24 ± 0.06	<0.0001	3.38 ± 0.06	<0.0001
HS Graduate	9053	28.14 ± 0.28	9.68 ± 0.05		2.37 ± 0.04		3.47 ± 0.03	
Some College	11127	28.06 ± 0.31	9.96 ± 0.04		2.31 ± 0.03		3.38 ± 0.03	
College Graduate	15453	35.57 ± 0.33	10.58 ± 0.03		2.12 ± 0.03		3.22 ± 0.02	
Income ($)								
< $30,000	8639	21.22 ± 0.29	9.73 ± 0.05	<0.0001	2.20 ± 0.03	0.0515	3.49 ± 0.05	<0.0001
$30,000 - $49,999	8625	21.50 ± 0.27	9.80 ± 0.04		2.32 ± 0.03		3.42 ± 0.03	
$50,000 - $74,999	7192	19.44 ± 0.26	10.14 ± 0.05		2.29 ± 0.04		3.31 ± 0.03	
$75,000 - $99,999	5142	13.68 ± 0.22	10.14 ± 0.06		2.29 ± 0.05		3.33 ± 0.04	
≥ $100,000	8704	24.20 ± 0.30	10.47 ± 0.04		2.21 ± 0.03		3.20 ± 0.03	
Race/Ethnicity								
Non-Hispanic white only	26301	68.88 ± 0.26	10.24 ± 0.03	<0.0001	2.17 ± 0.02	<0.0001	3.35 ± 0.02	<0.0001
Non-Hispanic black only	4157	9.61 ± 0.16	9.40 ± 0.07		2.66 ± 0.05		3.54 ± 0.05	
Hispanic only/Hispanic mixed	5559	15.01 ± 0.16	9.59 ± 0.05		2.39 ± 0.04		3.32 ± 0.03	
Asian/Pacific Islander only	876	2.83 ± 0.13	10.25 ± 0.13		2.23 ± 0.11		2.90 ± 0.08	

			Eating Window		Morning Fast		Evening Fast	
	n	Weighted % (SE)	Mean (SE)	p-value [a]	Mean (SE)	p-value	Mean (SE)	p-value
American Indian/Alaska Native	424	1.15 ± 0.08	9.78 ± 0.18		2.38 ± 0.14		3.64 ± 0.13	
Non-Hispanic mixed	985	2.52 ± 0.11	10.25 ± 0.11		2.22 ± 0.10		3.11 ± 0.08	
Household Size								
1	7215	11.54 ± 0.23	10.03 ± 0.04	<0.0001	2.17 ± 0.03	<0.0001	3.45 ± 0.04	0.0304
2	8934	30.06 ± 0.27	10.27 ± 0.04		2.09 ± 0.03		3.34 ± 0.03	
3–4	16399	41.06 ± 0.36	9.99 ± 0.03		2.34 ± 0.03		3.32 ± 0.02	
≥ 5	5754	16.34 ± 0.25	9.87 ± 0.06		2.43 ± 0.05		3.35 ± 0.03	
Employment status								
Employed	29604	76.96 ± 0.26	10.17 ± 0.03	<0.0001	2.36 ± 0.02	<0.0001	3.27 ± 0.02	<0.0001
Unemployed	8698	23.04 ± 0.26	9.69 ± 0.05		1.92 ± 0.03		3.61 ± 0.03	
Total sleep time (h)								
<7	6758	19.73 ± 0.29	11.11 ± 0.05	<0.0001	2.82 ± 0.04	<0.0001	3.97 ± 0.03	<0.0001
7–9	14631	40.09 ± 0.36	10.49 ± 0.03		2.38 ± 0.03		3.30 ± 0.02	
>9	16913	40.18 ± 0.34	9.11 ± 0.03		1.86 ± 0.02		3.09 ± 0.02	
Bedtime								
<22:00	9221	24.07 ± 0.29	9.58 ± 0.04	<0.0001	2.33 ± 0.03	<0.0001	2.51 ± 0.02	<0.0001
22:00–22:59	12060	31.11 ± 0.33	10.12 ± 0.04		2.24 ± 0.03		3.09 ± 0.02	
23:00–23:59	8752	22.79 ± 0.29	10.27 ± 0.04		2.17 ± 0.04		3.51 ± 0.03	
>00:00	8269	22.03 ± 0.27	10.28 ± 0.05		2.29 ± 0.04		4.46 ± 0.04	
Season [b]								
Winter	9940	24.98 ± 0.28	9.94 ± 0.04	0.0007	2.27 ± 0.03	0.2871	3.41 ± 0.03	0.1090
Spring	9761	25.13 ± 0.24	10.17 ± 0.04		2.23 ± 0.03		3.31 ± 0.03	
Summer	9433	25.26 ± 0.27	10.11 ± 0.04		2.22 ± 0.04		3.32 ± 0.03	
Fall	9168	24.63 ± 0.25	10.00 ± 0.05		2.31 ± 0.03		3.35 ± 0.03	
Day of the week [c]								
Weekday	18929	71.23 ± 0.14	10.20 ± 0.03	<0.0001	2.43 ± 0.02	<0.0001	3.32 ± 0.02	0.0006
Weekend day	19373	28.77 ± 0.14	9.71 ± 0.02		1.83 ± 0.02		3.41 ± 0.02	
Survey cycle								
2006–2008	21136	48.62 ± 0.19	10.08 ± 0.03	0.1982	2.31 ± 0.02	0.0010	3.40 ± 0.02	0.0033

			Eating Window		Morning Fast		Evening Fast	
	n	**Weighted % (SE)**	**Mean (SE)**	**p-value** [a]	**Mean (SE)**	**p-value**	**Mean (SE)**	**p-value**
2014–2016	17166	51.38 ± 0.19	10.03 ± 0.03		2.21 ± 0.02		3.30 ± 0.02	
Body Mass Index [d]								
Normal weight	13834	36.56 ± 0.35	10.22 ± 0.04	<0.0001	2.11 ± 0.02	<0.0001	3.25 ± 0.02	<0.0001
Overweight	13659	35.52 ± 0.31	10.09 ± 0.04		2.31 ± 0.03		3.33 ± 0.02	
Obese	10809	27.93 ± 0.29	9.82 ± 0.04		2.38 ± 0.03		3.49 ± 0.03	

Note: Total N= 38 302.

[a] p-values from global Wald F-test for survey data for testing for equality of mean circadian timing across level of the covariate.

[b] Season coded as winter (Dec-Feb), Spring (Mar-May), Summer (Jun-Aug), Fall (Sept-Nov).

[c] Weekday defined as a recalled day beginning on Monday-Friday; Weekend day defined as a recalled day beginning on Saturday or Sunday.

[d] Body mass index (BMI) calculated from self-reported height and weight, and categories were created based on WHO cut-offs (normal weight = 18.5–24.9 kg/m^2; overweight = 25–29.9 kg/m^2; obese ≥ 30.0 kg/m^2).

Table 2.

Adjusted prevalence of normal weight, overweight, and obesity by mean and with one-hour increase in circadian timing of eating variables in the American Time Use Survey Eating and Health Module (ATUS-EHM)

	Normal Weight			Overweight			Obese		
	Prevalence (%)	**SE**	**p-value**[a]	**Prevalence (%)**	**SE**	**p-value**	**Prevalence (%)**	**SE**	**p-value**
Unadjusted									
Eating window									
Mean (10.06)	36.6%	0.1%	<0.0001	35.6%	0.1%	0.0212	27.9%	0.1%	<0.0001
1 h increase (11.06)	37.2%	0.1%		35.7%	0.1%		27.2%	0.1%	
Difference	0.6%	0.1%		0.1%	0.1%		−0.7%	0.1%	
Morning fast									
Mean (2.260)	36.5%	0.1%	<0.0001	35.6%	0.1%	<0.0001	27.9%	0.1%	<0.0001
1 h increase (3.260)	35.6%	0.1%		35.9%	0.1%		28.6%	0.1%	
Difference	−0.9%	0.1%		0.3%	0.1%		0.6%	0.1%	
Evening fast									
Mean (3.35)	36.6%	0.1%	<0.0001	35.6%	0.1%	0.0592	27.9%	0.1%	<0.0001
1 h increase (4.35)	35.8%	0.1%		35.5%	0.1%		28.8%	0.1%	
Difference	−0.8%	0.1%		−0.1%	0.1%		0.9%	0.1%	
Adjusted									
Eating window									
Mean (10.06)	36.6%	0.1%	<0.0001	35.6%	0.1%	0.0001	27.9%	0.1%	<0.0001
1 h increase (11.06)	37.5%	0.1%		35.4%	0.1%		27.1%	0.1%	
Difference	0.9%	0.1%		−0.2%	0.1%		−0.7%	0.1%	
Morning fast									
Mean (2.260)	36.5%	0.1%	<0.0001	35.5%	0.1%	<0.0001	27.9%	0.1%	<0.0001
1 h increase (3.260)	35.4%	0.1%		35.9%	0.1%		28.7%	0.1%	
Difference	−1.2%	0.1%		0.4%	0.1%		0.8%	0.1%	
Evening fast									
Mean (3.35)	36.6%	0.1%	<0.0001	35.6%	0.1%	0.6659	27.9%	0.1%	<0.0001
1 h increase (4.35)	35.9%	0.1%		35.6%	0.1%		28.5%	0.1%	

	Normal Weight			Overweight			Obese		
	Prevalence (%)	SE	p-value[a]	Prevalence (%)	SE	p-value	Prevalence (%)	SE	p-value
Difference	−0.6%	0.1%		0.0%	0.1%		0.6%	0.1%	

Note: N=38 302 respondents. Population-weighted prevalences. Multinomial logistic regression estimated the adjusted prevalence of normal weight, overweight, and obesity with a one-hour increase from the mean of each circadian timing of eating variable. Adjusted models controlled for sex, age, age^2, education, income, race/ethnicity, household size, employment status, total sleep time, bedtime, ATUS survey cycle, season, and day of week.

[a] p-values for test of the difference in adjusted prevalence of each weight category for a 1-hr increase in each eating variable

Table 3.

Adjusted prevalence of normal weight, overweight, and obesity by interaction of eating window and morning fast in the American Time Use Survey Eating and Health Module (ATUS-EHM)[a]

	Normal Weight		Overweight		Obese	
	Prevalence (%)	**95% CI**	**Prevalence (%)**	**95% CI**	**Prevalence (%)**	**95% CI**
Eating window Q1[b]						
Morning fast tertile 1	34.60%	33.68 – 35.50	34.68%	33.73 – 35.65	30.72%	29.94 – 31.51
Morning fast tertile 2	34.10%	33.39 – 34.94	35.07%	34.27 – 35.87	30.77%	30.11 – 31.44
Morning fast tertile 3	32.45%	31.99 – 32.91	36.61%	36.19 – 37.03	30.94%	30.52 – 31.37
Eating window Q2						
Morning fast tertile 1	38.33%	37.51 – 39.17	32.54%	31.83 – 33.20	29.12%	28.45 – 29.80
Morning fast tertile 2	37.42%	36.76 – 38.08	33.31%	32.74 – 33.89	29.27%	28.74 – 29.81
Morning fast tertile 3	33.82%	33.15 – 34.50	36.42%	35.73 – 37.12	29.76%	29.19 – 30.33
Eating window Q3						
Morning fast tertile 1	38.66%	37.99 – 39.32	35.82%	35.15 – 36.50	25.52%	25.01 – 26.05
Morning fast tertile 2	37.86%	37.36 – 38.37	36.03%	35.57 – 36.49	26.11%	25.69 – 26.54
Morning fast tertile 3	34.73%	33.44 – 36.05	36.76%	35.55 – 37.99	28.51%	27.40 – 29.65
Eating window Q4						
Morning fast tertile 1	40.91%	40.31 – 41.52	34.93%	34.35 – 35.52	24.16%	23.71 – 24.62
Morning fast tertile 2	39.44%	38.95 – 39.93	34.90%	34.37 – 35.44	25.66%	25.21 – 26.11
Morning fast tertile 3	33.56%	31.53 – 35.65	34.28%	32.21 – 36.42	32.16%	29.96 – 34.44

Note: N=38 302 respondents. Population-weighted adjusted prevalences. Multinomial logistic regression estimated the adjusted prevalence of normal weight, overweight, and obesity for a given interaction between eating window quartile and morning fast (median of each tertile), adjusting for sex, age, age^2, education, income, race/ethnicity, household size, employment status, total sleep time, bedtime, ATUS survey cycle, season, and day of week.

[a] $p < 0.0001$ from the global Wald F test for the interaction between morning fast and eating window quartile across all three weight categories.

[b] Q1 indicates quartile 1

Table 4.

Adjusted prevalence of normal weight, overweight, and obesity by interaction of eating window and evening fast in the American Time Use Survey Eating and Health Module (ATUS-EHM)[a]

	Normal Weight		Overweight		Obese	
	Prevalence (%)	**95% Cl**	**Prevalence (%)**	**95% Cl**	**Prevalence (%)**	**95% Cl**
Eating window Q1 [b]						
Evening fast tertile 1	31.85%	31.14–32.57	36.81%	31.14–32.57	31.34%	30.65 – 32.04
Evening fast tertile 2	32.23%	31.70 – 32.76	36.65%	31.70 –32.76	31.13%	30.63 – 31.63
Evening fast tertile 3	32.70%	32.23 – 33.17	36.44%	32.23 –33.17	30.87%	30.45 –31.29
Eating window Q2						
Evening fast tertile 1	35.77%	35.01 – 36.50	34.94%	35.01 –36.57	29.29%	28.63 –29.96
Evening fast tertile 2	35.75%	35.22 – 36.28	34.81%	35.22 –36.28	29.44%	29.02 – 29.87
Evening fast tertile 3	35.73%	35.12 – 36.34	34.64%	35.12 –36.34	29.63%	29.11 – 30.16
Eating window Q3						
Evening fast tertile 1	36.62%	35.89 – 3|7.36	37.15%	35.89 –37.36	26.22%	25.57–26.8S
Evening fast tertile 2	37.55%	37.05 –38.04	36.16%	37.05 – 38.04	26.30%	25.87– 26.73
Evening fast tertile 3	38.71%	37.95 –39.48	34.92%	37.95 – 39.48	26.37%	25.71 – 27.04
Eating window Q4						
Evening fast tertile 1	40.58%	40.04–41.13	34.66%	40.04–41.13	24.76%	24.31 –25.21
Evening fast tertile 2	39.59%	39.03 –40.14	34.85%	39.03 –40.14	25.57%	25.08–26.06
Evening fast tertile 3	38.34%	37.27 –39.42	34.85%	37.27 – 39.42	26.60%	25.63 –27.59

Note: N=38 302 respondents. Population-weighted adjusted prevalences. Multinomial logistic regression estimated the adjusted prevalence of normal weight, overweight, and obesity for a given interaction between eating window quartile and evening fast (median of each tertile), adjusting for sex, age, age^2, education, income, race/ethnicity, household size, employment status, total sleep time, bedtime, ATUS survey cycle, season, and day of week.

[a] p <0.0001 from the global Wald F test for the interaction between eating window quartile and evening fast across all

[b] Q1 indicates quartile 1