ORIGINAL RESEARCH

Variability in Daily Eating Patterns and Eating Jetlag Are Associated With Worsened Cardiometabolic Risk Profiles in the American Heart Association Go Red for Women Strategically Focused Research Network

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BACKGROUND: Sleep variability and social jetlag are associated with adverse cardiometabolic outcomes via circadian disruption. Variable eating patterns also lead to circadian disruption, but associations with cardiometabolic health are unknown.

METHODS AND RESULTS: Women (n=115, mean age: 33±12 years) completed a 1-week food record using the Automated Self-Administered 24-Hour Dietary Assessment Tool at baseline and 1 year. Timing of first and last eating occasions, nightly fasting duration, and %kcal consumed after 5 PM (%kcal 5 PM) and 8 PM (%kcal 8 PM) were estimated. Day-to-day eating variability was assessed from the SD of these variables. Eating jetlag was defined as weekday-weekend differences in these metrics. Multivariable-adjusted linear models examined cross-sectional and longitudinal associations of day-to-day variability and eating jetlag metrics with cardiometabolic risk. Greater jetlag in eating start time, nightly fasting duration, and %kcal 8 PM related to higher body mass index and waist circumference at baseline ($P<0.05$). In longitudinal analyses, a 10% increase in %kcal 8 PM SD predicted increased body mass index (β, 0.52; 95% CI, 0.23–0.81) and waist circumference (β, 1.73; 95% CI, 0.58–2.87); greater %kcal 8 PM weekday-weekend differences predicted higher body mass index (β, 0.25; 95% CI, 0.07–0.43). Every 30-minute increase in nightly fasting duration SD predicted increased diastolic blood pressure (β, 0.95; 95% CI, 0.40–1.50); an equivalent increase in nightly fasting duration weekday-weekend differences predicted higher systolic blood pressure (β, 0.58; 95% CI, 0.11–1.05) and diastolic blood pressure (β, 0.45; 95% CI, 0.10–0.80). Per 10% increase in %kcal 5 PM SD, there were 2.98 mm Hg (95% CI, 0.04–5.92) and 2.37mm Hg (95% CI, 0.19–4.55) increases in systolic blood pressure and diastolic blood pressure; greater %kcal 5 PM weekday-weekend differences predicted increased systolic blood pressure (β, 1.83; 95% CI, 0.30–3.36). For hemoglobin A1c, every 30-minute increase in eating start and end time SD and 10% increase in %kcal 5 PM SD predicted 0.09% (95% CI, 0.03–0.15), 0.06% (95% CI, 0.001–0.12), and 0.23% (95% CI, 0.07–0.39) increases, respectively.

CONCLUSIONS: Variable eating patterns predicted increased blood pressure and adiposity and worse glycemic control. Findings warrant confirmation in population-based cohorts and intervention studies.

Key Words: cardiovascular disease prevention ■ cardiovascular disease risk factors ■ eating jetlag ■ eating pattern variability ■ women

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CLINICAL PERSPECTIVE

What Is New?

- Similar to irregular sleep patterns and social jetlag, variable eating patterns and eating jetlag are ubiquitous; there are limited data on the associations between habitual eating pattern variability and cardiometabolic risk factors in US populations.
- We found that greater day-to-day variability and weekday-weekend differences (ie, eating jetlag) in the timing of energy intake, span of the daily eating period, and extent of evening eating predicted increased blood pressure and body adiposity and worse glycemic control in a racially and ethnically diverse cohort of US women.

What Are the Clinical Implications?

- The timing and regularity of eating patterns may be important targets for cardiometabolic disease prevention in women.
- Adherence to a fixed eating schedule, characterized by regular eating timing and duration, may represent a novel behavioral approach for lowering cardiometabolic risk.
- Additional research on the link between eating pattern variability and cardiometabolic disease is needed in diverse population-based cohorts of men and women and using lifestyle interventions.

Nonstandard Abbreviations and Acronyms

DBP	diastolic blood pressure
NFD	nightly fasting duration
SBP	systolic blood pressure
WC	waist circumference

There is emerging evidence that regularity of sleep patterns plays a role in cardiometabolic health.[1–3] Night-to-night variability in sleep, often quantified as the SD of sleep duration and timing across nights, has been linked to metabolic syndrome and its components, including obesity, glycemic dysregulation, and elevated blood pressure (BP).[1,2] Similarly, social jetlag, a common form of sleep variability characterized by a discrepancy in sleep patterns between weekdays and weekends, has been linked to poor cardiometabolic health.[1,2] Chronic irregularity in sleep/wake cycles leads to circadian disruption, a misalignment between lifestyle behaviors and endogenous circadian rhythms, which is known to have downstream effects on metabolic functions.[1,2] Notably, other lifestyle behaviors, such as eating patterns, are also tightly linked with circadian rhythmicity; therefore, variability in eating patterns could relate to adverse cardiometabolic risk via similar mechanisms.

The timing of energy intake helps to maintain robust circadian rhythms[4–6]; food intake is a dominant cue that entrains peripheral clocks in organ systems, including those involved in metabolism, with the central pacemaker.[4,5] Intervention studies demonstrate that later meal times lead to metabolic dysfunction, potentially via circadian misalignment.[4,5,7] This is supported by epidemiological studies demonstrating that delayed eating, larger caloric intakes in the evening, and intradaily variability of the daily rhythm of energy intake are associated with higher risk for obesity.[6,7] However, these findings have not been extended to other key cardiometabolic risk factors, such as measures of glycemic regulation and BP. Further, epidemiologic data on day-to-day variability and weekday versus weekend differences in eating patterns, in free-living populations, are limited owing to the lack of multiple days of time-stamped diet data in most population-based cohort studies. Only 1 previous study in Spanish adults, aged 18 to 25 years, showed that eating jetlag, defined as the weekday versus weekend difference in the timing of energy intake, is related to higher body mass index (BMI).[8] Indeed, a scientific statement from the American Heart Association (AHA) highlighted that irregular meal patterns could be detrimental to metabolic health via mechanisms related to circadian disruption but that additional studies are warranted to better characterize these relations.[7]

To our knowledge, there are no observational studies that comprehensively examine eating pattern regularity metrics in relation to cardiometabolic risk factors in US populations. Thus, the purpose of this 1-year prospective study was to investigate the cross-sectional and longitudinal associations of day-to-day variability and eating jetlag (ie, weekday versus weekend differences) in modifiable eating pattern metrics previously linked to cardiometabolic health including (1) timing of the first and last eating occasions; (2) nightly fasting duration (NFD), as a proxy for span of the daily eating duration; and (3) timing and extent of evening eating, with clinically relevant cardiometabolic risk factors (ie, measures of adiposity, glycemic control indicators, and BP) in a racially and ethnically diverse cohort of US women. We hypothesized that greater day-to-day variability in eating patterns and eating jetlag would be associated with worsened cardiometabolic risk profiles, characterized by higher adiposity, glycemic control indicators, and BP.

METHODS

Study Design and Population

The data that support the findings of this study are available from the corresponding author upon reasonable request. The present analysis is based on data from an ancillary study of the AHA Go Red for Women Strategically Focused Research Network at Columbia University Irving Medical Center. The network is a community-based 1-year prospective cohort study of 506 racially and ethnically diverse women encompassing different life stages (aged 20–76 years), designed to evaluate associations between psychosocial factors, sleep patterns, and cardiometabolic risk. English- and Spanish-speaking women living in New York City were recruited between July 2016 and January 2018. Design, recruitment, and study procedures for the AHA Go Red for Women Strategically Focused Research Network at Columbia University Irving Medical Center have been described in detail elsewhere.[9,10]

A subset of 120 women, aged 20 to 64 years, from the AHA Go Red for Women Strategically Focused Research Network cohort consented to participate in this ancillary study, designed to investigate fasting/eating cycles and meal timing patterns in relation to cardiometabolic risk. Recruitment for this ancillary study began in May 2017. In addition to baseline and 1-year follow-up assessments completed as part of their participation in the main study, women were asked to complete a 7-day electronic food record. Baseline visits for this ancillary study were completed between May 2017 and January 2018, and 1-year follow-up visits were completed between May 2018 and February 2019. Overall, 115 of the 120 enrolled women met criteria for inclusion in this analysis by providing ≥4 days of complete diet data at baseline, and 99 of these women returned for the 1-year follow-up visit (Figure).

Measurement of Diet and Estimation of Day-to-Day Eating Pattern Variability and Eating Jetlag Metrics

Dietary intakes were assessed over 1 week using the National Institutes of Health Automated Self-Administered 24-Hour Dietary Assessment tool. This is a research-grade, web-based tool modeled upon the US Department of Agriculture Automated Multiple-Pass Method with demonstrated validity and reliability that enables automatically coded food diaries.[11] Participants received e-mail reminders from study staff throughout the week to maximize diet data completeness. Overall, of the 115 and 99 women who were included in the analytic sample at baseline and 1 year, 105 and 95 provided at least 6 days of diet data, respectively. The resulting Automated Self-Administered

24-Hour outputs included detailed time-stamped diet data files, enabling the assessment of caloric intake, fasting/eating duration, and timing of energy intake patterns.

The following metrics, previously linked to cardiometabolic health in the present cohort[12] and in other studies [7] and representing modifiable behavioral factors, were assessed to capture day-to-day variability in eating patterns: (1) time of the first eating occasion, (2) time of the last eating occasion, (3) NFD, and (4) evening caloric intake. Time-stamped diet data were used to ascertain the times of first and last eating occasions (≥25 kcal consumed) for each day, as reported previously.[12–14] These values were subsequently used to compute NFD, representing the inverse of the daily eating span (24 hours minus eating duration). To evaluate the timing and extent of evening eating, we computed the percentage of daily calories consumed after 5 PM (%kcal 5 PM) and 8 PM (%kcal 8 PM). Given that we had the advantage of having 7 consecutive days of diet data, we were able to account for eating occasions that occurred after midnight. We considered eating occasions that occurred before 4 AM and were labeled by participants as "dinner" or "snack" as part of the previous day's eating period.

To capture eating jetlag, the difference between weekday versus weekend average time of first and last eating occasions, NFD, and %kcal consumed after 5 PM and 8 PM were estimated such that a greater difference would be indicative of greater eating jetlag. In addition, to assess overall day-to-day variability in timing of energy intake, eating span, and extent of evening eating, the SD of the aforementioned variables was used.

Assessment of Cardiometabolic Risk Factors

Anthropometric measurements were obtained by trained staff. Height and weight were measured via stadiometer and a research-grade scale, and values were used to compute BMI (kg/m^2). Waist circumference (WC; inches) was measured directly above the iliac crest to the nearest 0.10-inch using a flexible tape measure. Fasting plasma glucose was evaluated from a whole blood sample by the Biomarker Core Laboratory at Columbia University Irving Medical Center, and a drop of whole blood was used to measure hemoglobin A1c (HbA1c) using a DCA vantage analyzer (Siemens Diagnostics STARTA1C DCA Vantage® Analyzer). Clinic systolic BP (SBP) and diastolic BP (DBP) were measured using a hospital-grade automated BP monitor (Omron 5 Series Upper Arm [BP742]); measurements were obtained with participants in the seated position, legs uncrossed, and after at least 5 minutes to

habituate to the setting. Two measures of BP were obtained, and the average of the 2 readings was used.

Assessment of Covariates

Sociodemographic and lifestyle factors including age, education level (≤ college degree versus > college degree), health insurance status (have 1 or more types of private health insurance and/or Medicare versus does not have health insurance and/or has Medicaid), and smoking status (current versus never/former smoker) were self-reported on a standard health questionnaire. Women also reported race (American Indian or Alaska Native, Asian, Black or African American, Native Hawaiian or Other Pacific Islander, or White) and ethnicity (Hispanic or non-Hispanic) on the standardized health questionnaire. Participants were classified as a racial and/or ethnic minority (binary variable) if they reported Hispanic ethnicity and/or being American Indian or Alaska Native, Asian, Black or African American, Native Hawaiian or other Pacific Islander as their race. Habitual sleep duration was obtained from the Pittsburgh Sleep Quality Index.[15]

Ethics

All research activities were approved by the Columbia University Irving Medical Center Institutional Review Board (protocol number AAAQ8196). Study procedures were in accordance with the Helsinki Declaration of 1975 as revised in 1983. Participants provided written informed consent and were compensated for their participation.

Statistical Analysis

Descriptive characteristics of the sample at baseline are described as mean±SD for continuous variables and as % of the total sample for categorical variables. Linear regression models were used to evaluate baseline cross-sectional associations between exposure variables and cardiometabolic outcomes in 115 women. Exposure variables of interest were (1) eating jetlag metrics (per 30-minute increase in weekday versus weekend differences in eating start time, eating end time, and NFD as well as per 10% increase in weekday versus weekend differences in %kcal 5 PM and 8 PM) and (2) day-to-day variability in eating pattern metrics (per 30-minute increase in SD of NFD, eating start time, and eating end time as well as per 10% increase in SD of %kcal 5 PM and 8 PM). We determined a priori that eating jetlag and day-to-day variability in eating pattern metrics would be evaluated per 30-minute increments for eating timing and span variables and per 10% increments for nighttime eating metrics, consistent with the literature on sleep duration and timing in relation to cardiometabolic risk[1-3] and representing realistic,

meaningful changes that are translational for public health recommendations. Outcome variables included BMI, WC, SBP, DBP, fasting plasma glucose, and HbA1c, assessed on the continuous scale. Multivariable-adjusted linear regression models were also used to investigate longitudinal associations between change in each of the exposure variables over the 1-year follow-up period and change in each of the cardiometabolic outcomes in 99 women. Age, race/ethnicity, health insurance (as a measure of socioeconomic status in this cohort), and sleep duration were selected a priori as covariates and included in all models. Models with BP, fasting plasma glucose, and HbA1c as outcomes were additionally adjusted for BMI. Analyses were conducted using SAS version 9.4 (SAS Institute, Inc., Cary, NC), and a P value <0.05 was considered significant.

RESULTS

Descriptive Characteristics of the Study Population

The average age of the cohort was 33±12 years, and 77% reported being a racial minority and/or having Hispanic ethnicity (Table 1). Overall, 67% reported an education level less than or equivalent to a college degree, and 58% reported having health insurance. The prevalence of overweight or obesity was 49%, and 44% had an at-risk WC (>88 centimeters).

At baseline, the average time of first eating occasion on weekdays versus weekends was 8:54±1:26 versus 10:11±1:49, whereas the average time of the last eating occasion on weekdays versus weekends was similar (20:27±1:32 versus 20:27±1:56). NFD was longer on weekends compared with weekdays (13.7±2.1 hours versus 12.5±1.8 hours). The SD of the time of first and last eating occasion across days was 99±57 minutes and 96±50 minutes, respectively, whereas the SD of NFD was 135±67 minutes. On average, participants consumed close to half of their daily caloric intake after 5 PM (46%) and about 21% after 8 PM. The difference in mean %kcal after 5 PM and 8 PM on weekdays compared with weekends was 14±11% and 16±14%, respectively. However, SD of %kcal consumed after 5 PM and 8 PM was similar (≈18%).

Cross-Sectional Associations of Day-to-Day Eating Pattern Variability Metrics With Cardiometabolic Risk

When day-to-day variability in timing of the first eating occasion was evaluated, every 30-minute increase in eating start time SD was related to 0.56 kg/m² higher BMI (95% CI, 0.07–1.05, P=0.030) (Table 2).

Table 1. Descriptive Characteristics of the Study Population at Baseline (n=115)

Sociodemographic characteristics	Mean (SD) or % (N)
Age, y	33 (12)
Education less than or equivalent to college (%)	67.0% (77)
Health insurance (%)	58.3% (67)
Racial minority and/or Hispanic ethnicity (%)	77.4% (89)
Hispanic ethnicity (%)	45.2% (52)

Eating pattern metrics	Mean (SD)
First eating occasion	
Average time of first eating occasion, HH:MM	9:16 (1:18)
Average time of first eating occasion on weekdays, HH:MM	8:54 (1:26)
Average time of first eating occasion on weekends, HH:MM	10:11 (1:49)
Eating jetlag in time of first eating occasion, h	1.8 (1.4)
Time of first eating occasion, SD, min	99.0 (56.8)
Last eating occasion	
Average time of last eating occasion, HH:MM	20:28 (1:29)
Average time of last eating occasion on weekdays, HH:MM	20:27 (1:32)
Average time of last eating occasion on weekends, HH:MM	20:27 (1:56)
Eating jetlag in time of last eating occasion, h	1.2 (1.2)
Time of last eating occasion SD, min	95.9 (49.5)
Nightly fasting duration	
Average nightly fasting duration, h	12.8 (1.6)
Average NFD on weekdays, h	12.5 (1.8)
Average NFD on weekends, h	13.7 (2.1)
Average weekday-weekend difference in NFD, h	1.9 (1.8)
NFD SD, min	134.8 (66.6)
Timing and extent of evening eating	
% daily calories consumed after 5 PM	46.1 (9.9)
Weekday-weekend difference in % daily calories consumed after 5 PM	13.8 (11.2)
% daily calories consumed after 5 PM SD	17.5 (6.5)
% daily calories consumed after 8 PM	20.7 (15.3)
Weekday-weekend difference in % daily calories consumed after 8 PM	15.7 (14.1)
% daily calories consumed after 8 PM SD	17.6 (8.9)

Cardiometabolic risk factors	Mean (SD) or % (N)
Body mass index, kg/m^2	25.7 (5.4)
Overweight and obesity (%)	48.7% (56)
WC, centimeters	89.9 (12.4)
At-risk WC (>88 cm)	44.3% (51)
Systolic blood pressure, mm Hg	116.0 (12.1)
Diastolic blood pressure, mm Hg	72.6 (10.7)
Fasting glucose, mg/dL	84.7 (21.3)
Hemoglobin A1c (%)	5.5 (0.7)

HH:MM, clock time in hours:minutes; NFD, nightly fasting duration; and WC, waist circumference.

Nonsignificant associations of eating start time SD with higher DBP (β, 1.00; 95% CI, −0.02 to 2.02; P=0.058) and of NFD SD with greater BMI (β, 0.41; 95%CI, −0.02 to 0.84; P=0.066) were noted. No significant associations were observed between variability in %kcal 5 PM and %kcal 8 PM and the cardiometabolic outcomes in cross-sectional analyses (data not shown). However, greater %kcal 5 PM SD was related to 1.42±0.72 mm Hg higher DBP, but this relation failed to reach statistical significance (P=0.052).

Table 2. Cross-sectional Associations of Eating Jetlag and Day-to-Day Eating Variability Metrics With Cardiometabolic Risk Factors in Linear Regression Models at Baseline (n=115)*

	Time of first eating occasion SD (per 30 min)			Time of last eating occasion SD (per 30 min)			Nightly fasting duration SD (per 30 min)		
	β (SE)	95% CI	P value	β (SE)	95% CI	P value	β (SE)	95% CI	P value
BMI, kg/m²	0.56 (0.25)	(0.07 to 1.05)	0.030	0.20 (0.29)	(−0.37 to 0.77)	0.501	0.41 (0.22)	(−0.02 to 0.84)	0.066
WC, centimeters	0.89 (0.58)	(−0.25 to 2.03)	0.142	0.08 (0.69)	(−1.27 to 1.42)	0.907	0.43 (0.53)	(−0.61 to 1.47)	0.404
SBP, mm Hg	0.49 (0.60)	(−0.09 to 1.67)	0.414	−0.72 (0.68)	(−2.05 to 0.61)	0.287	−0.19 (0.53)	(−1.23 to 0.85)	0.718
DBP, mm Hg	1.00 (0.52)	(−0.02 to 2.02)	0.058	−0.69 (0.59)	(−1.85 to 0.47)	0.248	0.28 (0.46)	(−0.62 to 1.18)	0.546
Fasting glucose, mg/dL	1.03 (1.12)	(−1.17 to 3.23)	0.361	−0.85 (1.26)	(−3.32 to 0.36)	0.503	0.47 (0.98)	(−1.45 to 2.39)	0.636
HbA1c, %	0.01 (0.04)	(−0.07 to 0.09)	0.852	−0.04 (0.04)	(−0.12 to 0.04)	0.339	−0.01 (0.03)	(−0.07 to 0.05)	0.707

	Eating jetlag in time of first meal (per 30-min weekday versus weekend difference)			Eating jetlag in time of last meal (per 30-min weekday versus weekend difference)			Eating jetlag in nightly fasting duration (per 30-min weekday versus weekend difference)		
	β (SE)	95% CI	P value	β (SE)	95% CI	P value	β (SE)	95% CI	P value
BMI, kg/m²	0.44 (0.17)	(0.11 to 0.77)	0.008	0.33 (0.20)	(−0.06 to 0.72)	0.107	0.31 (0.13)	(0.06 to 0.56)	0.022
WC centimeters	0.91 (0.38)	(0.18 to 1.65)	0.018	0.43 (0.48)	(−0.51 to 1.37)	0.366	0.41 (0.30)	(−0.20 to 1.02)	0.185
SBP, mm Hg	0.71 (0.39)	(−0.05 to 1.47)	0.075	0.17 (0.48)	(−0.77 to 1.11)	0.720	0.54 (0.31)	(−0.07 to 1.15)	0.086
DBP, mm Hg	0.66 (0.34)	(−0.01 to 1.33)	0.058	0.15 (0.42)	(−0.67 to 0.97)	0.717	0.43 (0.27)	(−0.10 to 0.96)	0.115
Fasting glucose, mg/dL	0.72 (0.74)	(−0.73 to 2.17)	0.329	0.21 (0.90)	(−1.55 to 1.97)	0.815	1.10 (0.58)	(−0.04 to 2.24)	0.060
HbA1c, %	0.01 (0.02)	(−0.03 to 0.05)	0.730	0.01 (0.03)	(−0.05 to 0.07)	0.792	0.02 (0.02)	(−0.02 to 0.06)	0.251

BMI indicates body mass index; DBP, diastolic blood pressure; HbA1c, glycated hemoglobin; SBP, systolic blood pressure; and WC, waist circumference.
*Models were adjusted for age, race/ethnicity, health insurance, and sleep duration.

Cross-Sectional Associations of Eating Jetlag Metrics With Cardiometabolic Risk

Every 30-minute increase in weekday versus weekend difference in timing of the first eating occasion was associated with 0.44 kg/m² higher BMI (95% CI, 0.11–0.77; P=0.008) and 0.91 centimeters larger WC (95% CI, 0.18–1.65; P=0.018) in fully adjusted models (Table 2). A 30-minute higher weekday versus weekend difference in NFD related to 0.31 kg/m² higher BMI (95% CI, 0.06–0.56; P=0.022). A greater difference in weekday versus weekend NFD tended to be associated with higher fasting glucose, but this relation did not reach statistical significance (β, 1.10; 95% CI, −0.04 to 2.24; P=0.060). Weekday versus weekend difference in %kcal 5 PM was not associated with any of the cardiometabolic outcomes (data not shown). However, each 10% increase in weekday versus weekend difference in %kcal 8 PM was associated with 0.80 kg/m² higher BMI (P=0.049).

Longitudinal Associations of Day-to-Day Eating Pattern Variability Metrics With Cardiometabolic Risk

Every 30-minute increase in eating start time SD and eating end time SD from baseline to 1-year follow-up was associated with an increase of 0.09 (95% CI, 0.03–0.15; P=0.003) and 0.06 (95% CI, 0.001–0.12; P=0.043) in HbA1c percentage, respectively (Table 3). Moreover each 30-minute increase in NFD SD during follow-up was related to a 0.95 mm Hg increase in DBP (95% CI, 0.40–1.50; P=0.001). An increase in eating start time SD over 1-year follow-up tended to be related to increased DBP, but this association did not reach significance (β, 0.73; 95% CI, −0.05 to 1.51; P=0.075). When 1-year change in day-to-day variability in nighttime eating was examined (Table 4), each 10% increase in %kcal after 5 PM SD was associated with a 2.37 mm Hg increase in DBP (95% CI, 0.19–4.55;

Table 3. Longitudinal Associations of 1-Year Change in Eating Jetlag and Day-to-Day Eating Variability Metrics With 1-Year Change in Cardiometabolic Risk Factors in Linear Regression Models (n=99)*

	Time of first eating occasion SD (per 30-min increase)			Time of last eating occasion SD (per 30-min increase)			Nightly fasting duration SD (per 30-min increase)		
	β (SE)	95% CI	P value	β (SE)	95% CI	P value	β (SE)	95% CI	P value
BMI, kg/m²	0.00 (0.08)	(−0.16 to 0.16)	0.995	0.04 (0.08)	(−0.12 to 0.20)	0.642	0.05 (0.06)	(−0.07 to 0.17)	0.353
WC, centimeters	0.15 (0.30)	(−0.46 to 0.76)	0.624	−0.03 (0.30)	(−0.64 to 0.58)	0.909	0.05 (0.23)	(−0.41 to 0.51)	0.804
SBP, mm Hg	0.58 (0.55)	(−0.50 to 1.66)	0.297	−0.29 (0.56)	(−1.39 to 0.81)	0.600	0.47 (0.40)	(−0.31 to 1.25)	0.248
DBP, mm Hg	0.73 (0.40)	(−0.05 to 1.51)	0.075	0.71 (0.41)	(−0.09 to 1.51)	0.088	0.95 (0.28)	(0.40 to 1.50)	0.001
Fasting glucose, mg/dL	0.06 (0.62)	(−1.16 to 1.28)	0.924	−0.52 (0.62)	(−1.74 to 0.70)	0.403	−0.02 (0.45)	(−0.90 to 0.86)	0.967
HbA1c, %	0.09 (0.03)	(0.03 to 0.15)	0.003	0.06 (0.03)	(0.001 to 0.12)	0.043	0.03 (0.02)	(−0.01 to 0.07)	0.196

	Eating jetlag in time of first meal (per 30-min increase in weekday versus weekend differences)			Eating jetlag in time of last meal (per 30-min increase in weekday versus weekend differences)			Eating jetlag in nightly fasting duration (per 30-min increase in weekday versus weekend differences)		
	β (SE)	95% CI	P value	β (SE)	95% CI	P value	β (SE)	95% CI	P value
BMI, kg/m²	0.02 (0.05)	(−0.08 to 0.12)	0.683	0.08 (0.06)	(−0.04 to 0.20)	0.143	0.06 (0.03)	(0.00 to 0.12)	0.072
WC, centimeters	0.03 (0.20)	(−0.38 to 0.43)	0.905	−0.10 (0.23)	(−0.56 to 0.36)	0.639	0.05 (0.13)	(−0.20 to 0.30)	0.776
SBP, mm Hg	0.57 (0.36)	(−0.14 to 1.28)	0.116	0.28 (0.40)	(−0.50 to 1.06)	0.482	0.58 (0.24)	(0.11 to 1.05)	0.017
DBP, mm Hg	0.29 (0.27)	(−0.24 to 0.82)	0.286	0.45 (0.29)	(−0.12 to 1.02)	0.132	0.45 (0.18)	(0.10 to 0.80)	0.012
Fasting glucose, mg/dL	0.46 (0.40)	(−0.32 to 1.24)	0.259	0.11 (0.45)	(−0.77 to 0.99)	0.811	0.31 (0.27)	(−0.22 to 0.84)	0.262
HbA1c, %	0.01 (0.02)	(−0.03 to 0.05)	0.660	0.01 (0.02)	(−0.03 to 0.05)	0.596	−0.02 (0.01)	(−0.04 to 0.00)	0.130

BMI indicates body mass index; DBP, diastolic blood pressure; HbA1c, glycated hemoglobin; SBP, systolic blood pressure; and WC, waist circumference.
*Models were adjusted for age, race/ethnicity, health insurance, and sleep duration.

P=0.036) and a 0.23 increase in HbA1c percentage after follow-up (95% CI, 0.07–0.39; P=0.005); a borderline significant association with increased SBP (β, 2.98; 95% CI, 0.04–5.92; P=0.050) was observed. Adjustment for BMI did not significantly alter these results (Tables S1 and S2). For %kcal after 8 PM, a 10% increase in SD over 1 year was related to a 0.52 kg/m² increase in BMI (95% CI, 0.23–0.81; P=0.001) and a 1.73 centimeter increase in WC (95% CI, 0.58–2.87; P=0.004).

Longitudinal Associations of Eating Jetlag Metrics With Cardiometabolic Risk

Null results were observed for eating start and end time jetlag metrics (Table 3). In contrast, every 30-minute increase in NFD weekday versus weekend differences from baseline to 1 year was associated with a 0.58 mm Hg (95% CI, 0.11–1.05; P=0.017) and 0.45 mm Hg (95% CI, 0.10–0.80; P=0.012) increase in SBP and DBP, respectively. Adjustment for BMI in the models did not appreciably change these associations (Tables S1 and S2). With respect to evening caloric intake jetlag metrics (Table 4), each 10% increase in weekday versus weekend differences in %kcal after 5 PM over 1 year was associated with a 1.83 mm Hg increase in SBP (95% CI, 0.30–3.36; P=0.022); however, this association was attenuated after adjustment for BMI (β, 1.52; 95% CI, 0.01–3.03; P=0.052). Further, greater eating jetlag in %kcal after 5 PM was nonsignificantly associated with increased DBP (β, 1.15; 95% CI, −0.01 to 2.31; P=0.053). Every 10% increase in %kcal after 8 PM weekday versus weekend differences after 1-year follow-up was associated with a 0.25 kg/m² increase in BMI over time (95% CI, 0.07–0.43; P=0.008).

Table 4. Longitudinal Associations of 1-Year Change in Evening Eating Variability Metrics With 1-Year Change in Cardiometabolic Risk Factors in Linear Regression Models (n=99)*

	%kcal after 5 PM SD (per 10% increase)			%kcal after 8 PM SD (per 10% increase)		
	β (SE)	95% CI	*P* value	β (SE)	95% CI	*P* value
BMI, kg/m²	0.19 (0.22)	(−0.24 to 0.62)	0.376	0.52 (0.15)	(0.23 to 0.81)	0.001
WC, centimeters	0.64 (0.84)	(−1.02 to 2.29)	0.457	1.73 (0.58)	(0.58 to 2.87)	0.004
SBP, mm Hg	2.98 (1.50)	(0.04 to 5.92)	0.050	0.39 (1.11)	(−1.79 to 2.57)	0.728
DBP, mm Hg	2.37 (1.11)	(0.19 to 4.55)	0.036	0.71 (0.83)	(−0.92 to 2.34)	0.392
Fasting glucose, mg/dL	−0.36 (1.71)	(−3.71 to 2.99)	0.835	0.51 (1.24)	(−1.92 to 2.94)	0.681
HbA1c, %	0.23 (0.08)	(0.07 to 0.39)	0.005	0.01 (0.06)	(−0.11 to 0.13)	0.819

	Eating jetlag in %kcal after 5 PM (per 10% increase in weekday versus weekend differences)			Eating jetlag in %kcal after 8 PM (per 10% increase in weekday versus weekend differences)		
	β (SE)	95% CI	*P* value	β (SE)	95% CI	*P* value
BMI, kg/m²	0.09 (0.11)	(−0.13 to 0.31)	0.445	0.25 (0.09)	(0.07 to 0.43)	0.008
WC, centimeters	0.41 (0.43)	(−0.43 to 1.24)	0.350	0.61 (0.36)	(−0.08 to 1.30)	0.103
SBP, mm Hg	1.83 (0.78)	(0.30 to 3.36)	0.022	0.50 (0.68)	(−0.83 to 1.83)	0.464
DBP, mm Hg	1.15 (0.59)	(−0.01 to 2.31)	0.053	0.25 (0.50)	(−0.73 to 1.23)	0.627
Fasting glucose, mg/dL	1.00 (0.89)	(−0.74 to 2.74)	0.266	0.99 (0.75)	(−0.48 to 2.46)	0.188
HbA1c, %	0.01 (0.04)	(−0.07 to 0.09)	0.897	0.02 (0.04)	(−0.06 to 0.10)	0.551

BMI indicates body mass index; DBP, diastolic blood pressure; HbA1c, glycated hemoglobin; SBP, systolic blood pressure; and WC, waist circumference.
*Models were adjusted for age, race/ethnicity, health insurance, and sleep duration.
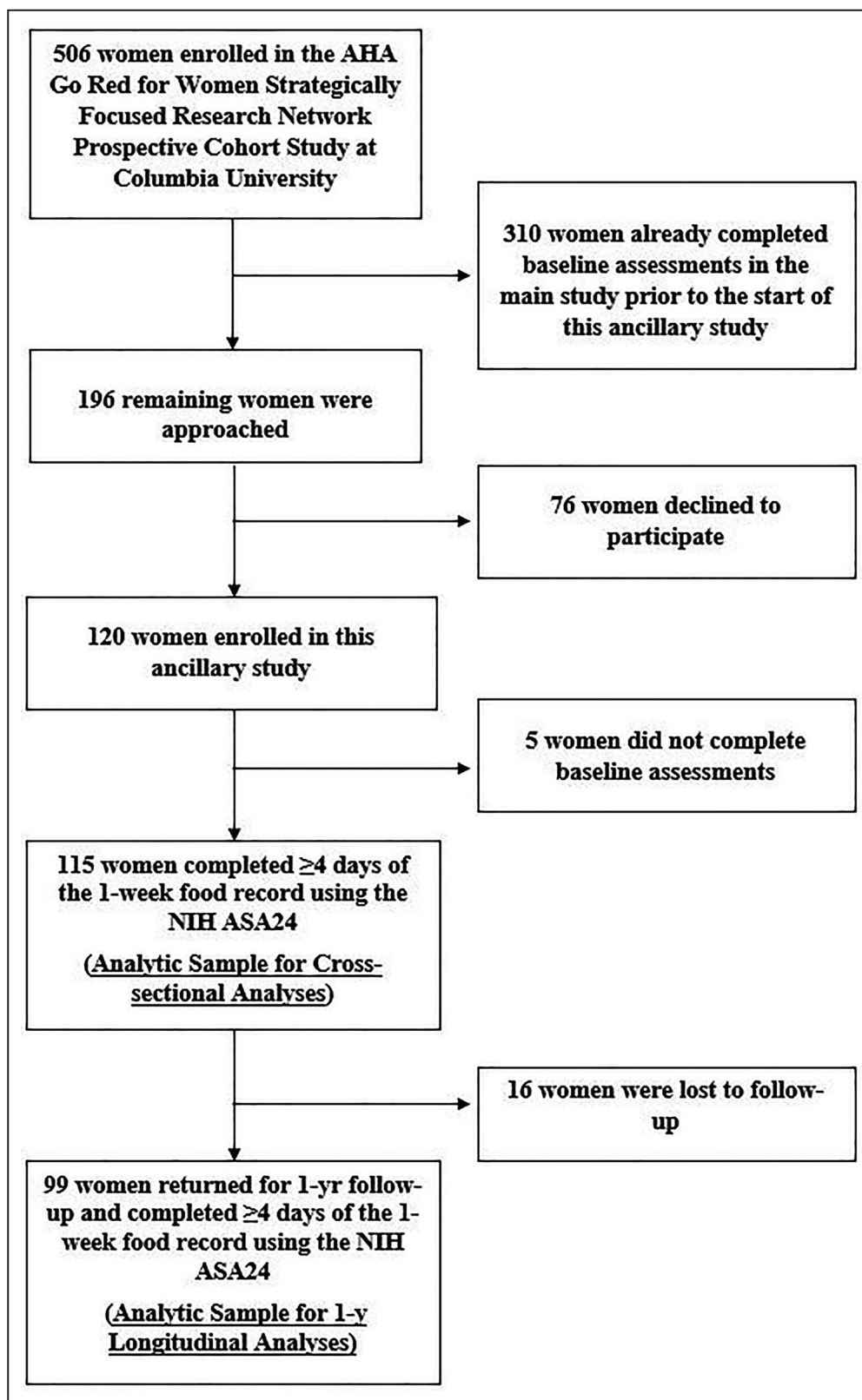
DISCUSSION

We provide evidence that day-to-day variability in timing of energy intake, duration of the eating period, and evening eating, including weekday versus weekend differences in these metrics (ie, eating jetlag), is associated with worse cardiometabolic risk profiles in a community-based sample of racially and ethnically diverse US women. Greater day-to-day variability in timing of the first and last eating occasion and NFD was associated with higher body weight status and BP and with poorer long-term glycemic control. Similarly, eating jetlag in timing of the first eating occasion and NFD was associated with markers of adiposity and BP. Finally, increased day-to-day variability and eating jetlag in timing and extent of evening eating were related to reduced glycemic control and increased BP, body weight status, and central adiposity, with the greatest detrimental effects associated with variability in eating after 8 PM. If confirmed in larger population-based cohorts and controlled intervention studies, these findings could have a significant impact on lowering the cardiometabolic disease burden at the population level.

Our results are consistent with studies in European populations.[6,17-20] In a Spanish study of 260 young adults, aged 20 to 30 years, circadian pattern of energy intake was related to adiposity, as intradaily variability of the daily rhythm of energy intake was associated with greater BMI.[6] In a cross-sectional study of ≈3600 Swedish men and women, those who identified as being "always or usually regular eaters" versus "sometimes or never regular eaters" had 37% lower odds of having the metabolic syndrome.[17] In cross-sectional and prospective analyses of the 1946 British birth cohort that included >1700 men and women, irregular energy intake (% daily calories), mostly at breakfast, lunch, and between meals, was related to increased odds of metabolic syndrome, though associations were attenuated after restricting the sample to plausible reporters.[19,20] Irregularity in energy intake at lunch, the evening meal, and daily total consumption was associated with greater odds of having overweight and higher WC. Further, most significant associations of irregular energy intake with metabolic syndrome were observed in individuals with overweight, supporting the hypothesis that the effects of meal irregularity on

Figure. Participant recruitment and retention flow chart.
The American Heart Association (AHA) Go Red for Women Strategically Focused Research Network is a community-based 1-year prospective cohort study of 506 racially and ethnically diverse women encompassing different life stages (aged 20–76 years). A subset of 196 women were approached to participate in this ancillary study, designed to investigate fasting/eating cycles and meal timing patterns in relation cardiometabolic risk. Of the 120 women who consented to participate, 115 women met criteria for inclusion in this analysis by providing ≥4 days of complete diet data using the National Institutes of Health's (NIH) Automated Self-Administered 24-Hour Recall (ASA24) dietary assessment tool at baseline, and 99 of these women returned for the 1-year follow-up visit.

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┌─────────────────────────────────┐
│ 506 women enrolled in the AHA   │
│ Go Red for Women Strategically  │
│ Focused Research Network        │
│ Prospective Cohort Study at     │
│ Columbia University             │
└─────────────────────────────────┘
              │         ┌─────────────────────────────────┐
              │────────▶│ 310 women already completed     │
              │         │ baseline assessments in the     │
              ▼         │ main study prior to the start of│
┌─────────────────────────────────┐ │ this ancillary study            │
│ 196 remaining women were        │ └─────────────────────────────────┘
│ approached                      │
└─────────────────────────────────┘
              │         ┌─────────────────────────────────┐
              │────────▶│ 76 women declined to            │
              │         │ participate                     │
              ▼         └─────────────────────────────────┘
┌─────────────────────────────────┐
│ 120 women enrolled in this      │
│ ancillary study                 │
└─────────────────────────────────┘
              │         ┌─────────────────────────────────┐
              │────────▶│ 5 women did not complete        │
              │         │ baseline assessments            │
              ▼         └─────────────────────────────────┘
┌─────────────────────────────────┐
│ 115 women completed ≥4 days of  │
│ the 1-week food record using the│
│ NIH ASA24                       │
│ (Analytic Sample for Cross-     │
│ sectional Analyses)             │
└─────────────────────────────────┘
              │         ┌─────────────────────────────────┐
              │────────▶│ 16 women were lost to follow-   │
              │         │ up                              │
              ▼         └─────────────────────────────────┘
┌─────────────────────────────────┐
│ 99 women returned for 1-yr      │
│ follow-up and completed ≥4 days │
│ of the 1-week food record using │
│ the NIH ASA24                   │
│ (Analytic Sample for 1-y        │
│ Longitudinal Analyses)          │
└─────────────────────────────────┘
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cardiometabolic disease could be mediated by mechanisms related to excess adiposity.[19,20]

Our finding that eating jetlag metrics are related to higher BMI and WC is consistent with the only published study on this topic.[8] In that study, a greater difference in the midpoint of the eating period on weekdays versus weekends was associated with higher BMI in young Spanish adults. Our results

are also consistent with the literature demonstrating that social jetlag is related to higher risk for obesity.[2] Notably, weekday versus weekend differences in timing of the first compared with last eating occasion were more consistently associated with outcomes. This is best explained by our observation that the variability in eating timing and duration between weekends versus weekdays was driven primarily by a difference in eating start time, which was later on weekends, whereas timing of the last eating occasion was similar. This finding is consistent with the Spanish study of eating jetlag and BMI, where participants delayed the timing of breakfast, and thus the eating midpoint on weekends, whereas the timing of dinner was mostly maintained.[8] Similarly, in healthy free-living US adults, data from a smartphone app demonstrated significant variation in breakfast time between weekdays and weekends leading to "metabolic jetlag" whereas the time of last caloric intake did not significantly change in any of the days.[21] Thus, timing of the first eating occasion may be a particularly important target for reducing eating jetlag. This is likely because timing of the first eating occasion is influenced by wake time, which varies more between weekdays and weekends owing to work schedules and social constraints.[22]

Although eating jetlag was driven primarily by variability in eating start time in this study, variability in the amount and timing of energy consumed in the evening was also associated with cardiometabolic risk. Higher percentage of daily calories consumed in the evening or at the largest evening meal has been linked to obesity risk.[23–25] However, to our knowledge, the current study is the first to report that day-to-day and weekday versus weekend variability in nighttime eating is related to higher adiposity, BP, and HbA1c. Given previous data indicating that US adults may have a bias toward eating late, with eating patterns occurring erratically across the wake period,[21] regularity in timing and level of nighttime eating may also represent a novel aspect of diet to consider for preserving cardiometabolic health.

Notably, greater day-to-day and weekday-weekend differences in span of the daily eating period and nighttime eating emerged as significant predictors of higher BP. To our knowledge, no previous study has evaluated eating pattern variability and eating jetlag metrics in relation to BP. However, circadian timing of food intake has previously been linked to hypertension risk in women. In the Australian National Nutrition and Physical Activity Survey, a temporal eating pattern characterized by a later lunch was associated with higher SBP and DBP and 49% higher odds for hypertension among women only.[26] In our cohort of women, we have previously shown every 30-minute delay in eating start time and 1-hour reduction in span of the daily eating period was related to >1 mm Hg

higher SBP and DBP.[12] Additionally in this cohort, a higher %kcal consumed at the evening meal was related to 1.69 mm Hg higher DBP. Overall, these data indicate that eating timing and duration and nighttime eating patterns are associated with BP, but additional research is warranted to confirm our results on day-to-day variability and weekday-weekend differences in these metrics.

The variability of eating patterns may influence cardiometabolic health via mechanisms related to circadian disruption and energy balance regulation. The timing and regularity of food intake play an important role in maintaining robust circadian rhythms.[4,5] Although the master clock in the brain that regulates body processes is regulated by light, food intake is also a dominant cue that entrains peripheral clocks in organ systems including those involved in metabolic processes.[4,5] In addition to circadian misalignment, irregular eating patterns could dampen diurnal circadian rhythms, including those involved in the anticipatory response to feeding, possibly leading to impaired glucose and BP homeostasis as well as energy expenditure and gastrointestinal alterations.[4,27,28] Finally, irregular eating patterns have been linked to lower energy expenditure, greater hunger, and lower fullness ratings, which leads to a positive energy balance, thereby increasing the risk for obesity and its cardiometabolic sequela, such as impaired glycemic control and elevated BP.[29]

Strengths of our study include the prospective design, which enabled the investigation of cross-sectional and longitudinal associations. The use of an electronic food record to collect 7 consecutive days of diet data, where women could enter information about their eating habits in real time with visual aids for increased accuracy, enabled the investigation of weekday versus weekday differences in eating patterns and allowed for the most accurate estimation of the daily eating period by accounting for eating occasions after midnight. The use of timing of the first and last eating occasion and eating span to evaluate eating jetlag is an important methodological strength of this study, because these metrics may provide a more adequate representation of eating patterns than conventional meal categories (eg, breakfast, lunch, and dinner), which tend to differ across cultures.[21] The assessment of several cardiometabolic risk factors, representing a multisystem biological risk profile for cardiovascular disease, as outcomes is also an important contribution of this study, as most prior studies have focused on obesity risk as an outcome.

Some limitations that warrant acknowledgement include the short follow-up duration and modest sample size. Although we observed significant associations over the 1-year follow-up period, longer follow-up is necessary to better understand how changes in eating pattern regularity influence

cardiometabolic risk across adulthood. Furthermore, because of the modest sample size, our findings may be due to chance, and we were unable to investigate potential differences in the observed relations by life stage or race/ethnicity. Although we recruited a racially and ethnically diverse sample, this was a community-based cohort of relatively young, healthy women living in New York City. Thus, results may not be generalizable to other populations with varying age and racial/ethnic distributions and metabolic health profiles. Finally, the possibility of residual confounding by unknown or unmeasured risk factors cannot be ruled out. For instance, aspects of diet quality may confound these associations or alternatively diet quality may be a partial mediator of the relations between eating pattern variability and cardiometabolic outcomes; the complex role of diet quality in these associations warrants further investigation.

CONCLUSIONS

Irregular eating patterns are prevalent in the United States[21]; herein, we show that an eating pattern characterized by greater eating jetlag and day-to-day variability in timing of energy intake, eating span, and extent of evening eating may contribute to the cardiometabolic disease burden. Because of limited epidemiologic data, current dietary recommendations lack explicit guidance on food intake timing and stability.[30,31] Population-based cohort studies should collect time-stamped diet data to investigate the complex interplay of diet quantity, quality, and eating pattern timing and regularity in cardiometabolic risk profiles and inform evidence-based dietary guidelines. Deciphering potential differences in these relations by sex, race, ethnicity, life stage, and social and biological factors that influence when people eat including work schedules, sleep patterns, socioeconomic status, and genetic predisposition is essential, as a "one-size-fits-all" eating plan may not be realistic given the broad spectrum of people affected by cardiometabolic diseases.[32,33] Such advances in the field of chrono-nutrition will be critical in shaping our understanding of the implications of eating pattern regularity on public health and the development of effective personalized cardiometabolic disease prevention diet strategies.[33]

ARTICLE INFORMATION

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Acknowledgments

Sources of Funding

Disclosures

Supplementary Material

Tables S1–S2

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SUPPLEMENTAL MATERIAL

Table S1. Longitudinal Associations of 1-Yr Change in Eating Jetlag and Day-to-Day Eating Variability Metrics with 1-Yr Change in Cardiometabolic Risk Factors in Linear Regression Models (n=99) [*, †]

	Time of First Eating Occasion SD (per 30-min increase)			Time of Last Eating Occasion SD (per 30-min increase)			Nightly Fasting Duration SD (per 30-min increase)		
	β (SE)	95% CI	p-value	β (SE)	95% CI	p-value	β (SE)	95% CI	p-value
WC (centimeters)	0.05 (0.12)	(-0.19, 0.29)	0.661	-0.01 (0.12)	(-0.25, 0.23)	0.949	0.02 (0.08)	(-0.14, 0.18)	0.839
SBP (mmHg)	0.54 (0.53)	(-0.50, 1.58)	0.316	-0.25 (0.54)	(-1.31, 0.81)	0.637	0.44 (0.39)	(-0.32, 1.20)	0.258
DBP (mmHg)	0.76 (0.40)	(-0.02, 1.54)	0.064	0.78 (0.41)	(-0.02, 1.58)	0.056	0.98 (0.28)	(0.43, 1.53)	0.001
Fasting glucose (mg/dl)	0.01 (0.61)	(-1.19, 1.21)	0.991	-0.54 (0.61)	(-1.74, 0.66)	0.380	-0.06 (0.45)	(-0.94, 0.82)	0.897
HbA1c (%)	0.09 (0.03)	(0.03, 0.15)	0.002	0.06 (0.03)	(0.001, 0.12)	0.040	0.03 (0.02)	(-0.01, 0.07)	0.180
	Eating Jetlag in Time of First Meal (per 30-min increase in weekday vs. weekend differences)			Eating Jetlag in Time of Last Meal (per 30-min increase in weekday vs. weekend differences)			Eating Jetlag in Nightly Fasting Duration (per 30-min increase in weekday vs. weekend differences)		
	β (SE)	95% CI	p-value	β (SE)	95% CI	p-value	β (SE)	95% CI	p-value
WC (centimeters)	0.00 (0.08)	(-0.16, 0.15)	0.979	-0.08 (0.09)	(-0.26, 0.10)	0.380	0.01 (0.05)	(-0.09, 0.11)	0.901
SBP (mmHg)	0.49 (0.34)	(-0.18, 1.16)	0.152	0.12 (0.40)	(-0.66, 0.90)	0.754	0.53 (0.23)	(0.08, 0.98)	0.024
DBP (mmHg)	0.33 (0.26)	(-0.18, 0.84)	0.209	0.40 (0.30)	(-0.19, 0.99)	0.189	0.47 (0.17)	(0.14, 0.80)	0.009
Fasting glucose (mg/dl)	0.36 (0.39)	(-0.40, 1.12)	0.364	0.00 (0.45)	(-0.88, 0.88)	0.997	0.25 (0.27)	(-0.28, 0.78)	0.361
HbA1c (%)	0.01 (0.02)	(-0.03, 0.05)	0.575	0.01 (0.02)	(-0.03, 0.05)	0.516	-0.02 (0.01)	(-0.04, 0.00)	0.169

[*]BMI: Body Mass Index; CI: Confidence Interval; DBP: Diastolic Blood Pressure; HbA1c: Glycated Hemoglobin; SBP: Systolic Blood Pressure; WC: Waist Circumference
[†]Models were adjusted for age, race/ethnicity, health insurance, sleep duration, and BMI

Table S2. Longitudinal Associations of 1-Year Change in Evening Eating Variability Metrics with 1-Year Change in Cardiometabolic Risk Factors in Linear Regression Models (n=99)[*, †]

	%kcal after 5PM SD (per 10% increase)			%kcal after 8PM SD (per 10% increase)		
	β (SE)	95% CI	p-value	β (SE)	95% CI	p-value
WC (centimeters)	0.21 (0.32)	(-0.42, 0.84)	0.516	0.57 (0.23)	(0.12, 1.02)	0.016
SBP (mmHg)	2.77 (1.45)	(-0.07, 5.61)	0.059	-0.30 (1.11)	(-2.48, 1.88)	0.786
DBP (mmHg)	2.49 (1.10)	(0.33, 4.65)	0.026	0.34 (0.86)	(-1.35, 2.03)	0.692
Fasting glucose (mg/dl)	-0.60 (1.68)	(-3.89, 2.69)	0.724	0.15 (1.27)	(-2.34, 2.64)	0.908
HbA1c (%)	0.23 (0.08)	(0.07, 0.39)	0.004	0.02 (0.06)	(-0.10, 0.14)	0.725
	Eating Jetlag in %kcal after 5PM (per 10% increase in weekday vs. weekend differences)			Eating Jetlag in %kcal after 8PM (per 10% increase in weekday vs. weekend differences)		
	β (SE)	95% CI	p-value	β (SE)	95% CI	p-value
WC (centimeters)	0.10 (0.17)	(-0.23, 0.43)	0.563	0.17 (0.14)	(-0.10, 0.44)	0.228
SBP (mmHg)	1.52 (0.77)	(0.01, 3.03)	0.052	0.16 (0.67)	(-1.15, 1.47)	0.815
DBP (mmHg)	0.95 (0.60)	(-0.23, 2.13)	0.117	0.03 (0.51)	(-0.97, 1.03)	0.959
Fasting glucose (mg/dl)	0.85 (0.89)	(-0.89, 2.59)	0.347	0.84 (0.76)	(-0.65, 2.33)	0.269
HbA1c (%)	0.01 (0.04)	(-0.07, 0.09)	0.845	0.03 (0.04)	(-0.05, 0.11)	0.491

[*]BMI: Body Mass Index; CI: Confidence Interval; DBP: Diastolic Blood Pressure; HbA1c: Glycated Hemoglobin; SBP: Systolic Blood Pressure; WC: Waist Circumference

[†]Models were adjusted for age, race/ethnicity, health insurance, sleep duration, and BMI