Received: 10 July 2022 | Revised: 17 October 2022 | Accepted: 30 October 2022

DOI: 10.1002/oby.23642

Obesity A Research Journal | THE OBESITY SOCIETY | WILEY

ORIGINAL ARTICLE

Time-Restricted Eating

Impact of early time-restricted eating on diet quality, meal frequency, appetite, and eating behaviors: A randomized trial

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Funding information
National Center for Advancing Translational Sciences, Grant/Award Number: UL1 TR001418; National Heart and Lung Institute, Grant/Award Number: T32 HL105349; National Institute of Diabetes and Digestive and Kidney Diseases, Grant/Award Numbers: P30 DK056336, P30 DK072476, P30 DK079626; National Institute of General Medical Sciences, Grant/Award Number: U54 GM104940

Abstract

Objective: Time-restricted eating (TRE) can reduce body weight, but it is unclear how it influences dietary patterns and behavior. Therefore, this study assessed the effects of TRE on diet quality, appetite, and several eating behaviors.

Methods: Adults with obesity were randomized to early TRE plus energy restriction (eTRE + ER; 8-hour eating window from 7:00 AM to 3:00 PM) or a control eating schedule plus energy restriction (CON + ER; ≥12-hour window) for 14 weeks. Food intake was assessed via the Remote Food Photography Method, while eating patterns, appetite, and eating behaviors were assessed via questionnaires.

Results: A total of 59 participants completed the trial, of whom 45 had valid food records. eTRE + ER did not affect eating frequency, eating restraint, emotional eating, or the consistency of mealtimes relative to CON + ER. eTRE + ER also did not affect overall diet quality. The intensity and frequency of hunger and fullness were similar between groups, although the eTRE + ER group was hungrier while fasting.

Conclusions: When combined with a weight-loss program, eTRE does not affect diet quality, meal frequency, eating restraint, emotional eating, or other eating behaviors relative to eating over more than a 12-hour window. Rather, participants implement eTRE as a simple timing rule by condensing their normal eating patterns into a smaller eating window.

INTRODUCTION

Time-restricted eating (TRE) is a form of intermittent fasting that limits eating to a consistent daily window ≤10 hours [1]. Several studies reported that TRE decreases body weight and improves cardiometabolic health [1–5]. Although TRE can, in principle, be practiced with or without reducing calorie intake, several studies suggest that when participants shorten their daily eating window, they spontaneously consume 10% to 25% fewer calories [6–12]. Indeed, one cross-sectional study reported that each 1-hour increase in the daily fasting duration was associated with eating 53 fewer kilocalories, and furthermore, that TRE was associated with eating fewer calories, eating less often, and eating a lower glycemic load diet [13].

In addition to the daily fasting duration, the time of day of eating may also affect calorie intake and eating behavior. Cross-sectional analyses found that eating a greater proportion of calories in the evening and late-night eating are associated with greater energy intake, higher body weight, impaired weight loss, and greater cardiometabolic risk [14, 15]. Shifting a greater proportion of energy intake to the evening also blunts lipid oxidation [4, 16, 17] and impairs insulin sensitivity and hormone expression [18, 19]. By contrast, interventions that shift food intake to the morning and/or earlier in the daytime consistently decrease appetite and/or food intake [20–22] and lead to greater weight loss [21, 23–25] relative to eating later in the day. In addition, diet quality tends to decline later in the day [26], whereas consuming meals early in the day improves diet quality [27, 28]. Late-night eating is also associated with greater energy intake [15], eating more often, and eating at more irregular times [29], which in turn have been linked to increased risk of cardiometabolic diseases [30]. Therefore, practicing TRE by eating earlier in the day (eTRE) could potentially reduce calorie intake, reduce snacking, limit the intake of calorie-dense, nutrient-sparse foods, and encourage more consistent eating times.

Promoting a nutrient-dense, well-balanced diet with good eating habits is very important for health, as higher diet quality is associated with lower risk of cardiovascular disease, cancer, and all-cause mortality [31]. However, little is known about the effects of TRE on diet quality and food intake. To our knowledge, only three trials have assessed the effects of TRE on diet quality via the Healthy Eating Index (HEI), and they found no improvement in HEI scores compared with the control group [2, 32, 33]. One study did find that the HEI score improved within the eTRE group but not the control group [33], whereas another study found that adherence to TRE reduced energy intake by decreasing carbohydrate and alcohol intake [34].

We recently conducted a moderately large weight-loss study comparing eTRE with an extended eating window ≥12 hours. We previously reported that eTRE was superior to eating over a period ≥12 hours for losing body weight, resulting in 2.3-kg greater weight loss over the 14-week intervention [35]. eTRE induced an additional energy deficit of 214 kcal/d as estimated using weight-loss modeling, but self-reported energy intake was not different between groups [35]. eTRE also lowered diastolic blood pressure but it did not affect other fasting cardiometabolic end points in the main intention-to-treat analysis. Herein, as tertiary outcomes of the parent study, we assessed the effects of eTRE on meal timing, eating frequency, diet quality, appetite, and eating behaviors. We hypothesized that eTRE would reduce energy intake relative to eating over a period ≥12 hours, whereas we had no a priori hypotheses on diet quality or eating behaviors.

Study Importance

What is already known?

- By shortening the daily eating window, time-restricted eating (TRE) can spontaneously reduce energy intake and induce modest weight loss.
- The benefits of TRE may depend on the timing of food intake as well as the fasting duration.

What does this study add?

- When combined with a weight-loss program, practicing TRE by eating early in the day (eTRE) did not appreciably affect diet quality, appetite, eating restraint, emotional eating, or other eating behaviors.
- Participants adopted eTRE by slightly shifting a greater proportion of their food intake to the morning snack but did not change the frequency or relative sizes of meals and snacks.

How might these results change the direction of research or the focus of clinical practice?

- Participants implement TRE primarily as a timing rule and do not make significant changes to their meal frequency, diet quality, or eating behaviors.
- Contrary to expectations, TRE does not improve diet quality, eating restraint, or emotional eating or reduce eating at irregular times, at least not in the context of a weight-loss program.

METHODS

Participants

This parallel-arm randomized controlled trial was approved by the Institutional Review Board at the University of Alabama at Birmingham (UAB; IRB number 300001207) and preregistered on ClinicalTrials.gov (NCT03459703). New patients of the UAB Weight Loss Medicine Clinic were enrolled between August 2018 and January 2020. Participants were eligible if they were 25 to 75 years of age, had body mass index (BMI) of 30.0 to 60.0 kg/m^2, weighed less than 450 lb (204.1 kg), and woke up between 4:00 AM and 9:00 AM on most days. Participants were excluded if they had diabetes, were taking glucose-lowering or weight-loss medications, lost or gained more than 5 lb (2.3 kg) of weight in the past month, performed overnight shift work more than 1 d/wk on average, regularly ate over a daily period <10 hours or ate dinner before

6:00 PM, or had a major chronic condition that would affect patient safety or data validity.

Diet protocols

The study design and protocol are available in the primary outcome manuscript [35]. In brief, participants were randomized either to eat within an 8-hour window between 7:00 AM and 3:00 PM (eTRE) or to eat over a self-selected period ≥12 hours (control, CON) for at least 6 d/wk for 14 weeks. All participants followed the standard weight-loss program prescribed by the UAB Weight Loss Medicine Clinic, which included regular weight checks, one-on-one dietary counseling with a registered dietitian to promote energy restriction (ER), recommendations to increase physical activity, and weekly group classes for support and accountability. In total, participants were provided with four one-on-one counseling sessions and instructed to attend at least 10 group classes. During the individual sessions, the dietitian instructed participants to reduce their energy intake by 500 kcal/d below their resting metabolic rate and then provided suggestions and examples customized to each participant's usual diet to both reduce energy intake and eat healthier.

Outcomes

We assessed several eating-related end points, including meal timing, meal frequency, food intake, diet quality, appetite, and eating behaviors. The timing of the eating window was assessed on a daily basis throughout the 14-week intervention. All other end points were assessed at baseline and at week 14. We measured food intake over a 3-day period using the Remote Food Photography Method (RFPM), whereas the remaining eating-related end points were assessed via questionnaires that were administered in the morning following a water-only fast ≥12 hours.

Remote Food Photography Method

To assess food intake, we collected 3-day digital food records using the RFPM [36]. Participants completed food records on two weekdays and one non-weekday. Participants used a smartphone app called SmartIntake to take "before" and "after" pictures of each item of food or beverage. To standardize the images, participants were instructed to take photos at a 45° angle at about an arm's length away from the food and to place a fixed-sized reference card within the field of view. Participants recorded descriptions of what they consumed in the app and then categorized each eating episode as either breakfast, morning snack, lunch, afternoon snack, dinner, or evening snack, which allowed us to assess the distribution of food intake across the day. When food images were not captured or could not be transmitted, participants used a backup method, such as a written food record or a verbal recall conducted over the phone. Using specialized software called the Food Photography Application, trained dietitians identified a match for each food from the Food and Nutrient Database for Dietary Studies (version 6.0; United States Department of Agriculture) and other sources, such as the manufacturer's information and Nutrition Facts labels. The dietitians also estimated the portion sizes using standard portion images and the reference card in the photo. Food and nutrient intakes were calculated as the difference between the selected food and plate waste. We considered 3-day food records to be valid if participants recorded an estimated energy intake within 50% of predicted intake as estimated using the NIH Body Weight Planner, assuming a physical activity level of 1.45. Data from the RFPM were used to estimate changes in eating frequency, the distribution of calorie intake across the day, energy intake, macronutrient composition, and diet quality (described herein).

Diet quality

Data obtained from valid RFPM records were used to quantify diet quality using the HEI-2015 score. The HEI-2015 score [12] assesses conformance to the 2015 Dietary Guidelines for Americans [8], with higher scores indicating greater adherence to the guidelines. The 13 components in the 2015 iteration are the following: adequacy of total fruits, whole fruits, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids and moderation of refined grains, sodium, added sugars, and saturated fats. Each of the components is scored on a density basis out of 1000 calories, except for fatty acids, which is scored using the ratio of unsaturated to saturated fatty acids. As secondary measures of diet quality, we also assessed changes in fiber, cholesterol, fatty acids, the servings of key food groups, micronutrient intake, and alcohol and stimulant intake via the Munich Chronotype Questionnaire.

Adherence and meal timing

Participants self-reported their meal-timing adherence by indicating when they started and stopped eating each day through electronic surveys automatically administered via REDCap software [37, 38]. Participants were classified as adherent if they followed their assigned eating window within a ±30-minute grace period. Days with missing surveys were coded as non-adherent. We also assessed the SD of the eating window as a measure of the regularity or consistency of mealtimes, with lower values indicating more consistent mealtimes.

Appetite

To assess the frequency and intensity of hunger and satiety, we used the Appetite Questionnaire (AQ) and Retrospective Visual Analogue Scales (RVAS), and participants were asked to rate their appetite over

TABLE 1 Baseline characteristics

	Total (n = 59)[a]	CON + ER (n = 30)	eTRE + ER (n = 29)	p value
Demographics				
Age (y)	44 ± 11	43 ± 12	45 ± 10	0.69
Female (%)	80%	80%	79%	1.00
Race (%)				1.00
Black or African American	22%	23%	21%	
Not Black or African American	78%	77%	79%	
Ethnicity (%)				0.25
Not Hispanic or Latino	92%	87%	97%	
Hispanic or Latino	3%	3%	3%	
Unknown or not reported	5%	10%	0%	
BMI (kg/m^2)	39.1 ± 6.6	37.8 ± 5.5	40.5 ± 7.4	0.12
Eating habits				
Eating duration (h/d)	12.8 ± 1.5	13.0 ± 1.7	12.6 ± 1.3	0.64
Eating start time (h:m)	7:28 ± 1:04	7:32 ± 1:10	7:24 ± 0:59	0.16
Eating end time (h:m)	20:15 ± 1:26	20:31 ± 1:42	19:59 ± 1:04	0.33
Eating episodes (number/d)	3.9 ± 0.8	3.8 ± 0.8	3.9 ± 0.7	0.65
Meals	2.7 ± 0.3	2.6 ± 0.3	2.7 ± 0.3	0.31
Snacks	1.2 ± 0.7	1.2 ± 0.8	1.2 ± 0.6	0.97
Diet quality (n = 45)				
Healthy Eating Index score	51 ± 11	52 ± 13	51 ± 8	0.76
Fiber (g/d)	14 ± 4	14 ± 5	13 ± 4	0.44
Added sugar (g/d)	14 ± 8	16 ± 9	12 ± 7	0.15
Cholesterol (mg/d)	360 ± 166	341 ± 193	377 ± 139	0.47
Food groups (n = 45)				
Fruit (servings/d)	0.5 ± 0.7	0.5 ± 0.8	0.5 ± 0.7	0.85
Vegetables (servings/d)	1.5 ± 0.8	1.4 ± 0.6	1.6 ± 0.9	0.23
Legumes (servings/d)	0.5 ± 0.8	0.7 ± 1.0	0.4 ± 0.6	0.25
Grains (servings/d)	5.6 ± 2.0	5.9 ± 2.3	5.3 ± 1.7	0.37
Nuts and seeds (servings/d)	0.7 ± 1.0	0.6 ± 0.9	0.7 ± 1.1	0.72
Eggs (servings/d)	0.8 ± 0.8	0.7 ± 0.9	0.9 ± 0.6	0.63
Dairy (servings/d)	1.4 ± 0.8	1.4 ± 0.8	1.4 ± 0.8	0.85
Fish (servings/d)	0.8 ± 1.3	0.5 ± 1.2	1.1 ± 1.3	0.08
Meat (servings/d)	4.6 ± 2.4	4.6 ± 2.5	4.7 ± 2.3	0.89
Eating behavior				
Restrained eating	14 ± 6	14 ± 5	14 ± 6	0.91
Emotional eating	24 ± 13	26 ± 13	22 ± 12	0.32
External eating	24 ± 6	24 ± 6	23 ± 6	0.30

Note: All data are presented as mean ± SD, unless otherwise indicated.
Abbreviations: CON + ER, control eating schedule plus energy restriction; eTRE + ER, early time-restricted eating plus energy restriction.
[a]Fifty-nine of ninety participants randomized completed the trial and study questionnaires. Forty-five participants completed the trial and had valid digital food photography records (CON + ER, n = 21; eTRE + ER, n = 24).

the previous week. The AQ measures the frequency of various degrees of hunger and satiety via a 5-point Likert scale, ranging from 1 meaning "Never" to 5 meaning "Always." For the RVAS, participants self-reported their average hunger, hunger during fasting, and fullness while eating on a 0 to 100 scale, with 0 meaning "Not at all" and 100 meaning "Extremely" [39].

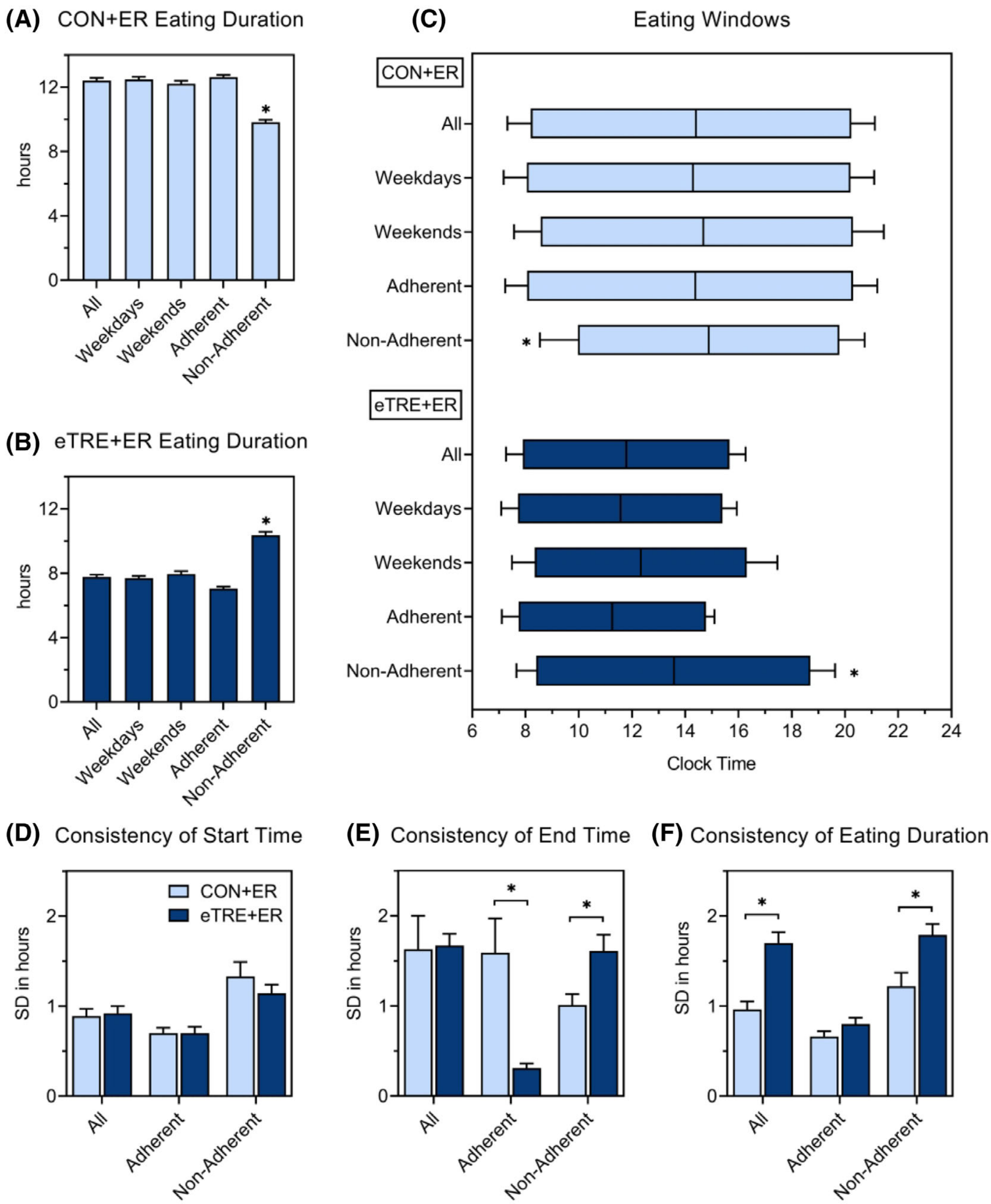

FIGURE 1 Eating windows. (A) The CON + ER group ate over a 12.4-hour period on average but a 9.8-hour window when non-adherent. (B) The eTRE + ER group ate within a 7.8-hour window on average and a 7.0-hour window on adherent days but ate over a 10.4-hour window when not adherent. (C) Participants in both groups started eating at a similar time on average and on weekdays, weekends, and adherent days. When they were not adherent, eTRE + ER participants started eating about 40 minutes later and stopped eating about 4 hours later, whereas CON + ER participants started eating nearly 2 hours later but otherwise stopped eating around their usual time. The eTRE + ER group stopped eating earlier than the CON + ER group in all cases. (D) Both groups were similarly consistent in when they started eating each day, as measured by the SD. (E) However, the eTRE + ER group was more consistent than the CON + ER group in the end time on adherent days but less consistent on non-adherent days. (F) The eTRE + ER group had a more variable eating duration due to non-adherent days. *$p < 0.05$. CON + ER, control eating schedule plus energy restriction; eTRE + ER, early time-restricted eating plus energy restriction [Color figure can be viewed at wileyonlinelibrary.com]

Dutch Eating Behavior Questionnaire

The Dutch Eating Behavior Questionnaire (DEBQ) assesses participants' eating behaviors along three dimensions: emotional, external, and restrained eating [40]. Individual questions are scored on a 5-point Likert scale ranging from "Never" to "Very often," and the composite scores for restrained, emotional, and external eating are tabulated, with higher numbers reflecting more of each trait.

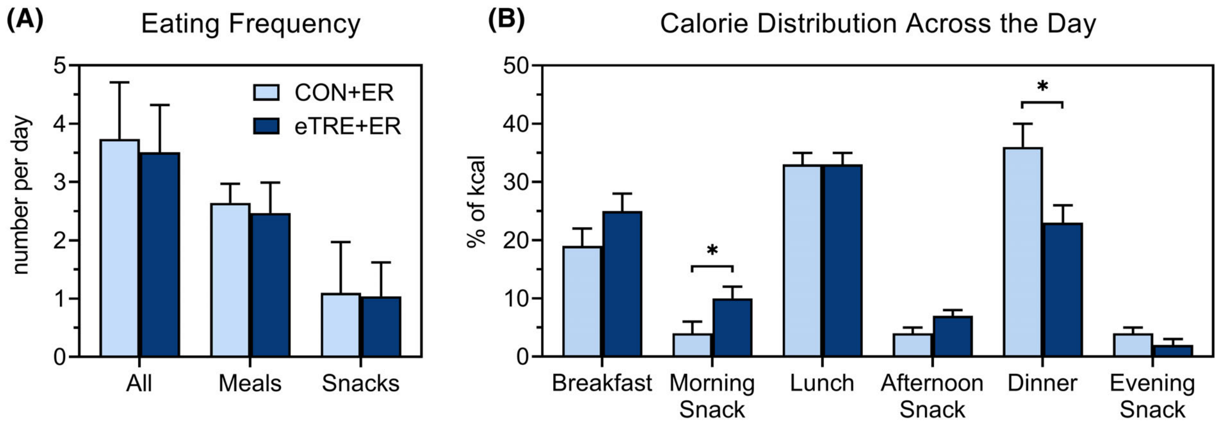

FIGURE 2 Eating frequency and calorie distribution. (A) The frequency of meals and snacks did not change during the intervention and was not different between groups. (B) The distribution of calorie intake across the day at the end of the intervention was similar between groups, except the eTRE + ER participants consumed 6% more of their total calories as a morning snack and 13% fewer of their total daily calories at "dinner" (the last meal of the day) relative to the CON + ER group. The changes in calorie distribution between baseline and week 14 were significant between groups only for the proportion of calories consumed at the morning snack. *$p < 0.05$. CON + ER, control eating schedule plus energy restriction; eTRE + ER, early time-restricted eating plus energy restriction [Color figure can be viewed at wileyonlinelibrary.com]

Statistical analyses

Analyses were performed using two-sided tests with a type I error rate of $\alpha = 0.05$ in the software package R (version 4.0.3). Analyses were performed in completers only. Continuous variables were analyzed using independent *t* tests, whereas categorical data were analyzed using the χ^2 test or Fisher exact test if the assumptions for the χ^2 test did not hold. All results are expressed as mean ± SEM, except where otherwise indicated.

RESULTS

Participants

We screened 656 people and enrolled 90 participants. Because of attrition ($n = 20$) and inability to complete the protocol due to the COVID-19 pandemic ($n = 11$), 59 participants completed all aspects of the intervention. Of the 59 completers, 45 participants had valid food records at both baseline and post-intervention. We included all 59 completers in the analyses of all end points, except for RFPM-derived end points, which were based on the 45 participants with valid food records. Participant characteristics are shown in Table 1. Total weight loss among completers was −4.3 kg (95% confidence interval [CI]: −5.7 to −3.0 kg) in the CON + ER group and −6.6 kg (95% CI: −8.0 to −5.2 kg) in the eTRE + ER group ($p = 0.006$).

Meal timing and consistency

Completers in the CON + ER group adhered to their assigned eating schedule 6.4 ± 0.8 d/wk (mean ± SD), whereas those in the eTRE + ER group adhered 5.8 ± 0.8 d/wk (mean ± SD). The most popular day that both groups chose to be non-adherent was Saturday, followed next by Friday and Sunday (data not shown). Figure 1A,B shows the eating durations for the CON + ER and eTRE + ER groups, respectively. The CON + ER group ate over a 12.4 ± 0.2-hour window overall, whereas the eTRE + ER group ate within a 7.8 ± 0.1-hour window overall and a 7.0 ± 0.1-hour window on adherent days. On non-adherent days, the eTRE + ER group ate over a 10.4 ± 0.2-hour window. Figure 1C illustrates the participants' eating windows. Both groups started eating at a similar time ($p \geq 0.11$) except on non-adherent days ($p < 0.001$). However, the eTRE + ER group always stopped eating earlier than the CON + ER group (all $p < 0.001$), even on non-adherent days, when these participants stopped eating about an hour earlier ($p < 0.001$). We also assessed the consistency of eating times by calculating each individual's SD and then averaging the SD across all participants (Figure 1D–F). As shown in Figure 1D, both groups were similarly consistent in when they started eating ($p \geq 0.29$). However, the eTRE + ER group's eating duration was more variable than the CON + ER group (1.0 ± 0.1 vs. 1.7 ± 0.1 hours; 0.7 ± 0.2 hours; $p < 0.001$). This was due to greater variability in the eTRE + ER group's eating duration on non-adherent days (1.2 ± 0.2 vs. 1.8 ± 0.1 hours; 0.6 ± 0.2 hours; $p = 0.006$), as there was no difference on adherent days (0.7 ± 0.1 vs. 0.8 ± 0.1 hours; 0.1 ± 0.1 hours; $p = 0.12$).

Eating frequency and calorie distribution

eTRE + ER did not affect eating frequency. At week 14 (Figure 2A), the eTRE + ER group ate 3.5 ± 0.2 times per day, whereas the CON + ER group ate 3.7 ± 0.2 times per day ($p = 0.44$), and there was no difference in the change scores between groups (−0.3 ± 0.3 times per day; $p = 0.19$). eTRE + ER also did not affect the frequencies or sizes (kilocalories) of meals or snacks as separate categories ($p \geq 0.10$ for change scores; data not shown). However, eTRE + ER modestly affected the

TABLE 2 Changes in food intake and diet quality

Dietary end point	CON + ER, within-group change		eTRE + ER, within-group change		Between-group difference	
	Mean ± SEM	*p*	Mean ± SEM	*p*	Mean ± SEM	*p*
Diet quality ($n = 45$)[a]						
Healthy Eating Index score	7.5 ± 3.6	0.052	4.5 ± 3.5	0.22	−3.0 ± 5.1	0.56
Fiber (g/d)	0 ± 1	0.83	−1 ± 1	0.63	−1 ± 2	0.64
Added sugar (g/d)	−9 ± 2	<0.001*	−6 ± 2	0.008*	3 ± 3	0.27
Solid fat (g/d)	−12 ± 2	<0.001*	−16 ± 3	<0.001*	−4 ± 4	0.30
Cholesterol (mg/d)	−70 ± 40	0.10	−70 ± 39	0.08	0 ± 56	1.00
Oils (g/d)	−12 ± 4	0.008*	−11 ± 3	<0.001*	1 ± 5	0.81
Monounsaturated fat (g/d)	−9 ± 2	<0.001*	−10 ± 2	<0.001*	−1 ± 3	0.71
Polyunsaturated fat (g/d)	−7 ± 2	0.007*	−7 ± 1	<0.001*	0 ± 3	0.92
Omega-3 fatty acids (g/d)	−1 ± 0	0.053	0 ± 0	0.04*	0 ± 0	0.58
Omega-6 fatty acids (g/d)	−6 ± 2	0.01*	-6 ± 1	<0.001*	0 ± 2	0.95
Food groups ($n = 45$)[a]						
Fruit (servings/d)	0.2 ± 0.2	0.28	0.2 ± 0.2	0.18	0.0 ± 0.3	0.97
Vegetables (servings/d)	0.3 ± 0.2	0.29	−0.4 ± 0.3	0.15	−0.7 ± 0.4	0.07
Legumes (servings/d)	−0.3 ± 0.2	0.29	0.0 ± 0.2	0.94	0.3 ± 0.3	0.38
Grains (servings/d)	−2.5 ± 0.5	<0.001*	−1.6 ± 0.6	0.007*	0.8 ± 0.7	0.28
Nuts and seeds (servings/d)	−0.1 ± 0.2	0.71	−0.3 ± 0.3	0.28	−0.2 ± 0.4	0.53
Eggs (servings/d)	−0.1 ± 0.2	0.68	0.0 ± 0.2	0.81	0.0 ± 0.3	0.87
Dairy (servings/d)	−0.2 ± 0.2	0.24	−0.4 ± 0.1	0.01*	−0.2 ± 0.2	0.39
Fish (servings/d)	−0.1 ± 0.3	0.63	−0.6 ± 0.3	0.04*	−0.5 ± 0.4	0.27
Meat (servings/d)	−0.6 ± 0.7	0.43	−0.3 ± 0.4	0.56	0.3 ± 0.8	0.70
Stimulants ($n = 59$ except where otherwise noted)[a]						
Alcohol (g/d) ($n = 45$)	0 ± 0	0.41	−3 ± 1	0.03*	−2 ± 1	0.09
Beer (servings/wk)	−0.1 ± 0.1	0.06	−0.1 ± 0.1	0.41	0.0 ± 0.1	0.81
Wine (servings/wk)	0.0 ± 0.2	0.96	−0.1 ± 0.1	0.46	−0.1 ± 0.2	0.67
Liquor (servings/wk)	0.0 ± 0.1	0.63	0.1 ± 0.1	0.45	0.1 ± 0.1	0.38
Caffeine (mg/d) ($n = 45$)	−57 ± 16	0.002*	−47 ± 17	0.01*	10 ± 24	0.68
Coffee (servings/wk)	−1.7 ± 0.7	0.02*	−3.3 ± 1.7	0.06	−1.6 ± 1.8	0.37
Tea (servings/wk)	−0.9 ± 0.9	0.30	0.0 ± 1.2	0.99	0.9 ± 1.5	0.54
Caffeinated soda (servings/wk)	−0.6 ± 0.7	0.43	−0.3 ± 0.6	0.60	0.2 ± 1.0	0.80

Abbreviations: CON + ER, control eating schedule plus energy restriction; eTRE + ER, early time-restricted eating plus energy restriction.
[a]Fifty-nine of ninety participants randomized completed the trial and study questionnaires. Forty-five participants completed the trial and had valid digital food photography records (CON + ER, $n = 21$; eTRE + ER, $n = 24$).
*$p < 0.05$.

distribution of energy intake across meals and snacks. At week 14 (Figure 2B), the distribution of calorie intake across the day was mostly similar between groups, except the eTRE + ER group consumed a larger morning snack (4% ± 2% vs. 10% ± 2% of total kilocalories; $p = 0.02$) and a smaller "dinner" (the last meal of the day; 36% ± 4% vs. 23% ± 3%; $p = 0.009$) than the CON + ER group. However, the change scores were significantly different only for the midmorning snack (6% ± 3%; $p = 0.045$). On a cumulative basis, the eTRE + ER group ate 13% ± 5% more calories by the end of the morning snack ($p = 0.01$), and these participants' cumulative energy intake remained similarly higher until after dinner (data not shown).

Food intake

Food intake data are shown in Table 2 and Table 3. eTRE + ER did not affect energy intake and macronutrient composition, as previously reported ($p \geq 0.53$) [35]. Neither intervention affected diet quality as assessed by the HEI score, and there were no differences between groups in the HEI score (−3.0 ± 5.1; $p = 0.56$; Figure 3) or in other diet quality indicators, such as fiber, added sugar, cholesterol, saturated fat, other fatty acids, solid fat, or oils ($p \geq 0.27$). eTRE + ER also did not affect the intake of various food groups, including grains, fruit, vegetables, legumes, nuts and seeds,

TABLE 3 Changes in micronutrient intake

	CON + ER, within-group change		eTRE + ER, within-group change		Between-group difference	
Micronutrient ($n = 45$)[a]	Mean ± SEM	p	Mean ± SEM	p	Mean ± SEM	p
Calcium (mg/d)	−103 ± 50	0.051	−171 ± 78	0.04*	−68 ± 96	0.48
Iron (mg/d)	−2.5 ± 1.0	0.02*	−3.0 ± 1.1	0.01*	−0.5 ± 1.5	0.75
Magnesium (mg/d)	−1 ± 20	0.98	−35 ± 24	0.16	−34 ± 32	0.29
Phosphorus (mg/d)	−190 ± 77	0.02*	−261 ± 76	0.002*	−71 ± 108	0.52
Potassium (mg/d)	−29 ± 175	0.87	−480 ± 148	0.004*	−451 ± 227	0.053
Sodium (mg/d)	−941 ± 208	<0.001*	−733 ± 202	0.001*	208 ± 291	0.48
Zinc (mg/d)	−0.8 ± 0.6	0.22	−2.1 ± 1.0	0.04*	−1.4 ± 1.2	0.26
Copper (μg/d)	0.0 ± 0.1	0.85	−0.3 ± 0.1	0.006*	−0.3 ± 0.1	0.03*
Selenium (μg/d)	−23 ± 9	0.02*	−25 ± 10	0.01*	−3 ± 13	0.85
Vitamin A equivalents (μg/d)	214 ± 93	0.03*	38 ± 132	0.78	−176 ± 166	0.29
Vitamin D (μg/d)	1 ± 1	0.26	−1 ± 1	0.08	−2 ± 1	0.04*
Vitamin C (mg/d)	26 ± 13	0.06	6 ± 19	0.74	−20 ± 24	0.42
Thiamin (mg/d)	−0.3 ± 0.1	0.01*	−0.3 ± 0.1	0.04*	0.1 ± 0.2	0.66
Riboflavin (mg/d)	−0.3 ± 0.1	0.02*	−0.2 ± 0.1	0.14	0.1 ± 0.2	0.52
Niacin (mg/d)	−4.5 ± 2.0	0.03*	−3.5 ± 2.0	0.11	1.1 ± 2.9	0.71
Vitamin B6 (mg/d)	0.1 ± 0.2	0.51	−0.2 ± 0.2	0.47	−0.3 ± 0.3	0.33
Folate (μg/d)	−99 ± 41	0.03*	−34 ± 42	0.42	65 ± 59	0.27
Vitamin B12 (μg/d)	−0.7 ± 0.5	0.13	−1.0 ± 0.5	0.055	−0.3 ± 0.7	0.65
Vitamin K (μg/d)	−12 ± 23	0.59	53 ± 37	0.17	65 ± 45	0.16
Vitamin E (mg/d)	1.1 ± 1.7	0.52	0.5 ± 1.9	0.79	−0.6 ± 2.6	0.82

Abbreviations: CON + ER, control eating schedule plus energy restriction; eTRE + ER, early time-restricted eating plus energy restriction.
[a]Fifty-nine of ninety participants randomized completed the trial and study questionnaires. Forty-five participants completed the trial and had valid digital food photography records (CON + ER, $n = 21$; eTRE + ER, $n = 24$).
*$p < 0.05$.

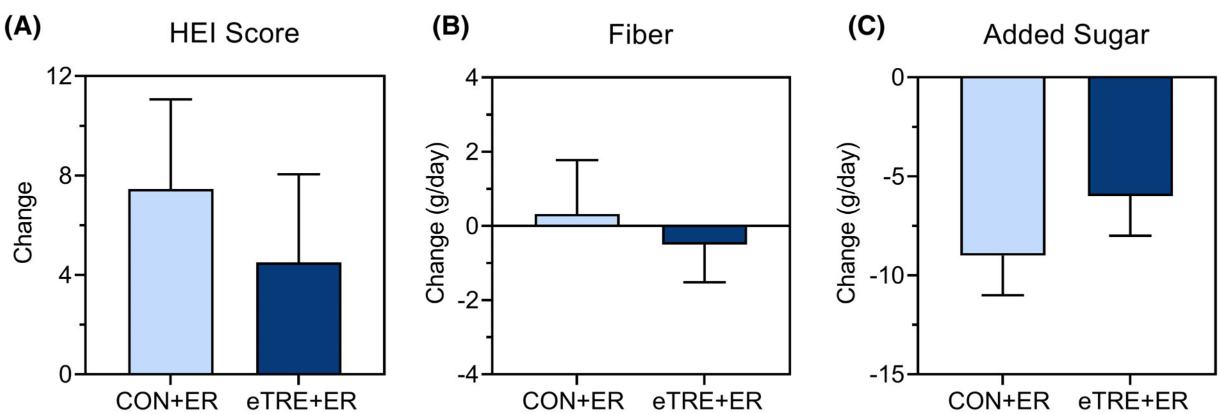

FIGURE 3 Diet quality. (A) Diet quality as assessed by the HEI score did not change in either group during the intervention, nor were there any between-group differences. Similarly, other common indicators of diet quality, such as (B) fiber and (C) added sugar, were similar between groups. CON + ER, control eating schedule plus energy restriction; HEI, Healthy Eating Index; eTRE + ER, early time-restricted eating plus energy restriction [Color figure can be viewed at wileyonlinelibrary.com]

eggs, meat, dairy, fish, and alcohol relative to CON + ER ($p \geq 0.07$). The one exception is that eTRE + ER was less effective at reducing refined grain intake as measured by the HEI component score (-2.5 ± 1.2; $p = 0.03$). There were no differences in any of the other 12 HEI component scores ($p \geq 0.12$), Similarly, there were no differences in the intakes of most micronutrients, except for copper and vitamin D, which decreased in the eTRE + ER group (Table 3).

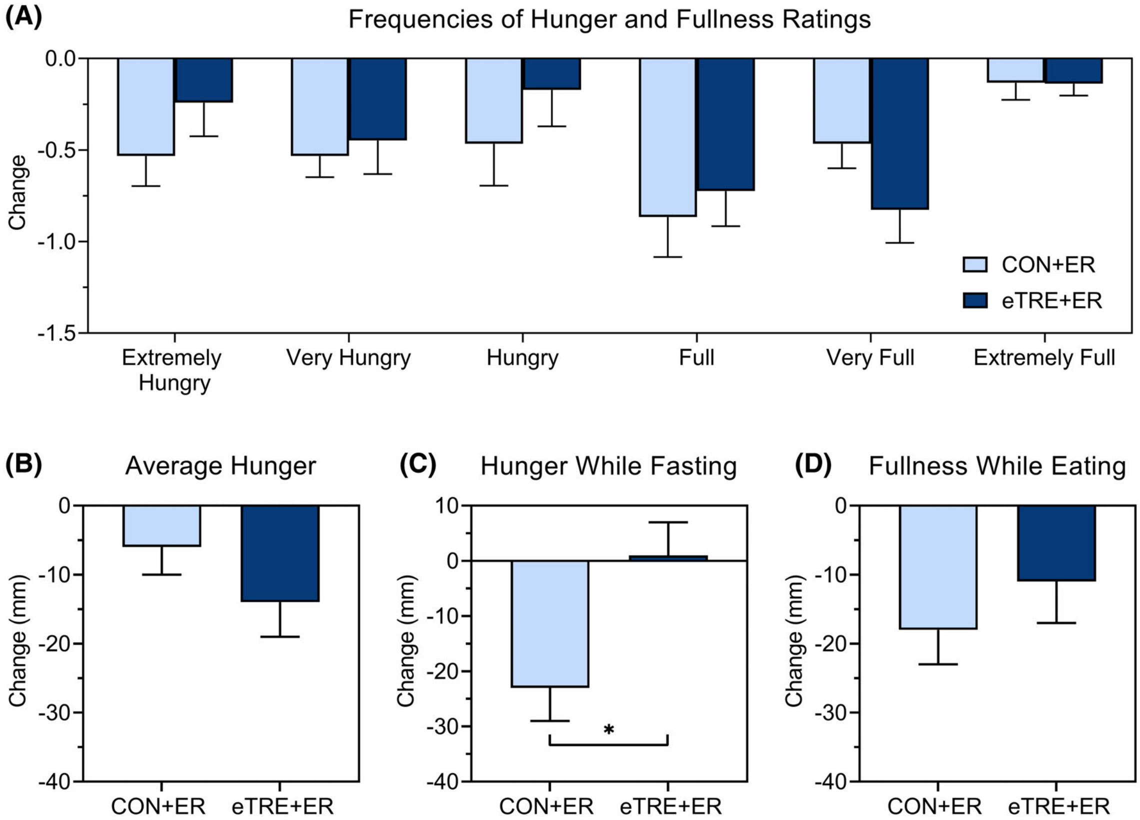

FIGURE 4 Hunger and fullness. (A) There were no differences in the frequencies of various degrees of hunger and fullness between groups, as assessed by the Appetite Questionnaire. Ratings of hunger assessed by retrospective visual analog scales indicated that (B) average hunger and (D) fullness while eating were similar between groups. However, (C) eTRE + ER was less effective at suppressing hunger during the fasting period than CON + ER. *$p < 0.05$. CON + ER, control eating schedule plus energy restriction; eTRE + ER, early time-restricted eating plus energy restriction [Color figure can be viewed at wileyonlinelibrary.com]

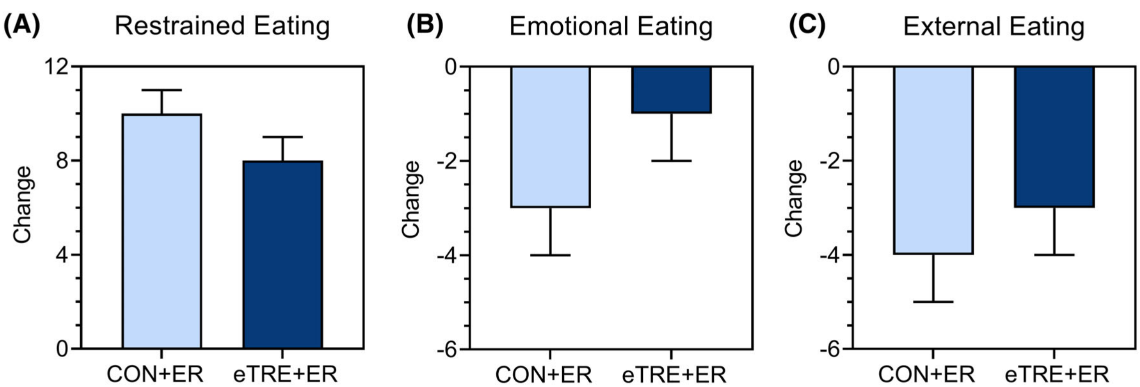

FIGURE 5 Eating behavior. There were no between-group differences in (A) restrained eating, (B) emotional eating, or (C) external eating, as assessed by the Dutch Eating Behavior Questionnaire. CON + ER, control eating schedule plus energy restriction; eTRE + ER, early time-restricted eating plus energy restriction [Color figure can be viewed at wileyonlinelibrary.com]

Hunger and fullness

Appetite data are shown in Figure 4. eTRE + ER did not affect the frequencies of various degrees of hunger and fullness as measured by the AQ (all $p \geq 0.11$; Figure 4A) or average hunger as measured by the RVAS (-7 ± 6 mm; $p = 0.24$; Figure 4B). CON + ER was more effective at suppressing hunger while fasting (24 ± 9 mm; $p = 0.008$; Figure 4C), whereas the two interventions led to similar fullness or satiation while eating (7 ± 8 mm, $p = 0.38$; Figure 4D).

Eating behavior

Data from the DEBQ are shown in Figure 5. eTRE + ER did not affect restrained eating (−1 ± 2; $p = 0.42$), emotional eating (1 ± 2; $p = 0.49$), or external eating (1 ± 1; $p = 0.47$).

DISCUSSION

We recently conducted one of the first relatively large weight-loss studies to compare TRE versus eating over a period ≥12 hours and found that eTRE was superior for losing weight [35]. Here, we investigated the effects of eTRE on several dietary outcomes, including meal timing, eating frequency, diet quality, appetite, and eating behaviors.

We thoroughly investigated how participants adopted their assigned eating windows in the real world. The eTRE + ER participants ate over a 7.0-hour window ending a few minutes before 3:00 PM when they adhered but ate over a 10.4-hour window when they were non-adherent. Contrary to our expectations, the eTRE + ER participants did not eat over a period ≥12 hours period on non-adherent days and they still ate over a shorter eating window than at baseline. The most popular day both groups chose to be non-adherent was Saturday, followed next by Friday and Sunday. We also examined how consistent participants were with the timing and duration of their eating windows. On adherent days, the eTRE + ER group was very consistent at stopping eating around 3:00 PM. However, on non-adherent days, these participants were less consistent, resulting in the eTRE + ER group having a more variable eating duration overall than the CON + ER group. Surprisingly, we found that eTRE did not improve the consistency of the eating window and that it may instead increase the variability of the eating window because of participants being non-adherent and/or having break days.

In our study, we also found that eTRE did not reduce the number of meals or snacks, which is in contrast to at least one previous study [41]. This null finding may stem from the weight-loss programming in our trial. In addition to providing counseling to restrict energy intake, a registered dietitian encouraged participants in the eTRE + ER group to eat their usual number of meals and snacks within a shorter eating window so that they would ingest a sufficient amount of food before the end of their eating window. Therefore, our findings may not generalize to people who follow eTRE without the support of a dietitian or other interventionist. We also found that the eTRE + ER group did not majorly change the sizes of various meals and snacks relative to the CON + ER group. The only significant difference is that the eTRE + ER participants ate a modestly larger midmorning snack than the CON + ER group and also modestly increased the cumulative proportion of calories they ate for breakfast and the midmorning snack combined. Taken together, this suggests that our participants practiced eTRE primarily by condensing the same number of meals and snacks into a shorter eating window, rather than by eating less often or markedly changing the sizes of their meals or snacks.

Eating earlier in the day has also been linked to better diet quality [26]. However, in our trial, eTRE + ER did not affect diet quality as assessed by the HEI score either relative to baseline or the CON + ER group. Our findings are consistent with previous research suggesting that TRE does not influence diet quality [2, 32, 33]. Interestingly, eTRE + ER did not affect alcohol consumption and it was less effective in reducing refined grains, which could stem from the eTRE + ER group relying more on processed breakfast foods such as cereal, bread, and baked goods and/or the need to have readily available snack foods. Maleab et al. [7] did find that TRE reduces snacking and specifically reduces the intake of high-quality snacks. We did not explore whether eTRE affected food choices at different times of the day. Overall, there were no major or overarching thematic differences in food or nutrient intake either relative to baseline or between groups. This may be due to our limited sample of completers with valid diet records. Our largely null results could also be because participants in both groups received the same dietary counseling promoting healthier food options, which may have masked the effects of eTRE alone. Therefore, our results may not generalize to people who follow TRE outside the context of a weight management program. Nonetheless, our data suggest that eTRE does not meaningfully affect food intake, beyond potentially decreasing energy intake.

We also investigated the effects of eTRE on self-reported appetite. eTRE did not affect the frequency or intensity of hunger or satiety, although it did increase feelings of hunger during the fasting period. This conflicts with other studies that have reported that TRE reduces appetite and improves appetite and satiety hormones [1, 4, 10, 42]. Because some of these studies matched calorie intake across groups and/or were conducted in energy balance, one possible way to reconcile these findings is that TRE could enable people to sustain a larger calorie deficit at the same level of hunger; this deserves further exploration. It has also been suggested that intermittent fasting interventions, such as TRE, induce weight loss by increasing restraint and decreasing emotional eating, thereby curbing snacking. However, eTRE did not affect dietary restraint, emotional eating, or external eating as assessed by the DEBQ, nor did it affect snacking in our study. One criticism of intermittent fasting is that TRE may perpetuate emotional eating and promote negative eating behaviors such as binge eating. However, similar to Gabel et al. [43], we did not observe detrimental effects of TRE on eating behavior. However, this area warrants further investigation as individuals with disordered eating tendencies are often excluded from weight-loss trials.

Our study has both strengths and limitations. Strengths include that we have conducted one of the largest and most detailed investigations into eating behaviors and diet quality, with a variety of assessments. Limitations include a reduced sample size due to attrition and the COVID-19 pandemic and that we excluded some food records because of severe underreporting. As a result, we were only powered to detect rather large effects in eating behaviors. In addition, all eating-related end points were analyzed only in completers and were collected via self-report, which may be impacted by response bias. This includes the retrospective appetite assessments, which can also be subject to recall bias. Appetite is more accurately assessed using standardized meal tests. Furthermore, we did not collect dietary data at multiple time points and collected dietary data only at baseline and during the last week of the intervention, which may not adequately represent how participants ate during the course of the study. We also primarily tracked meal timing adherence and not adherence to the ER recommendation, a decision we made to limit participant burden. Lastly, we cannot rule out sampling bias, namely, that individuals who were more interested in or could more readily adopt eTRE enrolled in our trial.

We conclude that, at least when combined with a weight-loss program, eTRE does not appreciably affect eating frequency, meal and snack sizes, overall diet quality, eating restraint, emotional eating, and other eating behaviors relative to eating over a period ≥12 hours. eTRE slightly changed the distribution of energy intake across meals and snacks. Contrary to popular claims, eTRE also did not improve the consistency of the eating window, because of the large increase in the eating duration on non-adherent "break" days, although participants did eat at more consistent times on adherent days. The consequence of this increased variability in the eating window due to break days and whether it has any negative metabolic or circadian consequences merits further investigation. Importantly, eTRE did not increase overall hunger despite producing greater weight loss, although hunger was higher while fasting. Rather, we conclude that individuals following eTRE incorporate it primarily as a timing rule and condense their habitual eating habits into a smaller window, rather than changing the number, size, or food content of meals and snacks. Therefore, TRE is a simple, low-structure dietary intervention that allows increased flexibility in eating choices by focusing solely on meal timing.O

ACKNOWLEDGMENTS

We thank our study participants for their time and the University of Alabama at Birmingham Weight Loss Medicine clinic staff, especially Karin Crowell. We also thank Karissa Neubig and Tulsi Patel for their help in measuring dietary intake and tracking adherence. Study data can be obtained by emailing the corresponding author. Sharing of deidentified study data will be governed by a data transfer agreement.

FUNDING INFORMATION

This study was supported by grants UL1 TR001418 from the National Center for Advancing Translational Sciences and P30 DK056336 from the National Institute of Diabetes and Digestive and Kidney Diseases of the NIH. Resources and support were also provided by two Nutrition Obesity Research Center grants (P30 DK056336; P30 DK072476), a Diabetes Research Center grant (P30 DK079626), an NIH Predoctoral T32 Obesity Fellowship to Cody J. Hanick (T32 HL105349), and the Louisiana Clinical and Translational Science Center (U54 GM104940). The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.

CONFLICT OF INTEREST

Pennington Biomedical Research Center/Louisiana State University has an interest in the intellectual property surrounding the Remote Food Photography Method and SmartIntake app, which were used to measure food intake, and coauthor Corby K. Martin is an inventor of the technology. All other authors declared no conflict of interest.

CLINICAL TRIAL REGISTRATION

ClinicalTrials.gov identifier NCT03459703.

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How to cite this article: Steger FL, Jamshed H, Martin CK, et al. Impact of early time-restricted eating on diet quality, meal frequency, appetite, and eating behaviors: A randomized trial. *Obesity (Silver Spring)*. 2023;31(Suppl. 1):127-138. doi:10.1002/oby.23642