The effects of Ramadan fasting on activity and energy expenditure

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ABSTRACT

Background: Fasting during the month of Ramadan entails abstinence from eating and drinking between dawn and sunset and a major shift in meal times and patterns with associated changes in several hormones and circadian rhythms; whether there are accompanying changes in energy metabolism is unclear.

Objective: We have investigated the impact of Ramadan fasting on resting metabolic rate (RMR), activity, and total energy expenditure (TEE).

Design: Healthy nonobese volunteers (n = 29; 16 women) fasting during Ramadan were recruited. RMR was measured with the use of indirect calorimetry. In subgroups of participants, activity (n = 11; 5 women) and TEE (n = 10; 5 women) in free-living conditions were measured with the use of accelerometers and the doubly labeled water technique, respectively. Body composition was measured with the use of bioelectrical impedance. Measurements were repeated after a wash-out period of between 1 and 2 mo after Ramadan. Nonparametric tests were used for comparative statistics.

Results: Ramadan fasting did not result in any change in RMR (mean ± SD: 1365.7 ± 230.2 compared with 1362.9 ± 273.6 kcal/d for Ramadan and post-Ramadan respectively, P = 0.713, n = 29). However, controlling for the effects of age, sex, and body weight, RMR was higher in the first week of Ramadan than in subsequent weeks. During Ramadan, the total number of steps walked were significantly lower (n = 11, P = 0.001), while overall sleeping time was reduced and different sleeping patterns were seen. TEE did not differ significantly between Ramadan and post-Ramadan (mean ± SD: 2224.1 ± 433.7 compared with 2121.0 ± 718.5 kcal/d for Ramadan and post-Ramadan, P = 0.7695, n = 10).

Conclusions: Ramadan fasting is associated with reduced activity and sleeping time, but no significant change in RMR or TEE. Reported weight changes with Ramadan in other studies are more likely to be due to differences in food intake. This trial is registered at clinicaltrials.gov as NCT02696421. *Am J Clin Nutr* 2018;107:54–61.

Keywords: Energy expenditure, resting metabolic rate, total energy expenditure, activity energy expenditure, Ramadan, fasting, Muslim, doubly labeled water, DLW

INTRODUCTION

The practice of fasting during Ramadan is observed by many of the world's >1.6 billion Muslim population for a full lunar month every year (1). As such, most healthcare professionals, including physicians and dieticians, are likely to see patients needing advice on medical and nutritional aspects of the Ramadan fast. The fast entails abstinence from eating and drinking between dawn and sunset for a whole lunar month (29–30 d). It represents a major shift from established routines and "normality." In particular, timing and composition of meals change (2): an early breakfast is taken just before dawn (suhoor) and lunch is omitted. The fast is broken at sunset when the main meal (iftar) is taken. Sleeping times and patterns also change (3) to allow the morning meal to be consumed before dawn. Missing lunch, and the long gap between major meals, affect appetite (4), hormonal responses to food, and aspects of energy and glucose metabolism. In particular, omitting breakfast has been shown to be associated with a lower exercise-induced thermogenesis (5), and in people with diabetes causes blunting of the insulin and glucagon-like peptide-1 response to food (6).

With the longer gaps between the 2 major meals of the day, reduced physical activity and exercise during the day might be expected. These changes have implications for several biological processes; alterations in hormonal and metabolic processes including circadian rhythms (7), serum cortisol (8), thyroid function (7), plasma leptin (9), adiponectin (10), and neuropeptide

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Supplemental Table 1 and Supplemental Figures 1–3 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

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Abbreviations: DLW, doubly labeled water; k_d, rate at which deuterium is flushed from the body; k_o, rates at which ^{18}O is flushed from the body; N_d, isotope dilution space calculated using deuterium; N_o, isotope dilution space calculated using ^{18}O; RMR, resting metabolic rate; RQ, respiratory quotient; TEE, total energy expenditure.

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Y (11) in health and disease have been previously reported. Ramadan fasting has been associated with variable weight changes, ranging from modest weight gain (12) to weight neutrality (13) and weight loss (14), with a reported reduction in total calorie intake in some (15), but not all (13), populations. Weight loss observed in some subjects tends to be regained shortly after Ramadan (14).

Investigating energy fluxes in the context of the Ramadan fast could provide a better evidence base for managing patients, particularly those in whom weight management or glycemic control of diabetes is important. The Ramadan fast is also a useful model for investigating the impact of major deviations from meal patterns to physiology and weight changes. While several studies have previously explored dietary changes with Ramadan fasting in various populations, there have been few attempts at quantifying different aspects of energy expenditure during Ramadan. In the current study, we have assessed resting metabolic rate (RMR), physical activity, and 'free-living' total energy expenditure (TEE).

METHODS

Participant screening

Participants were screened clinically, using standard hematologic and biochemical tests, and were excluded if they had conditions that could influence metabolic rate including thyroid dysfunction, anemia, renal and liver dysfunction, and active infection.

Study design

This study was approved by the Medical Research Ethics Committee of the Imperial College London Diabetes Centre and was conducted in 2015–2016. Healthy nonobese participants intending to fast during the month of Ramadan were recruited (**Supplemental Figure 1**). Sample size calculation was based on our pilot study which indicated a standard deviation for resting metabolic rate of 230 kcal/d in the context of Ramadan fasting. The current study was powered to detect a mean change of 100–150 kcal/d between the Ramadan and post-Ramadan periods, with the use of a paired crossover design. With $\alpha = 0.05$ and $\beta = 0.8$, we required 35 participants to detect a change of 100 kcal/d, or 16 to detect a change of 150 kcal/d.

All participants had anthropometric and RMR measurements taken during Ramadan and within 2 mo after Ramadan. In addition, in a subgroup of participants, RMR repeat measurements were performed at week 1, week 2, week 3, and week 4 of Ramadan. TEE and activity were measured in subgroups of subjects in both Ramadan and post-Ramadan periods.

Anthropometric measurements

A trained nurse assessed all participants. Anthropometric measures, including weight, height, and body composition by bioelectrical impedance (BIA-Seca mBCA 515), were assessed and recorded before every RMR measurement (during and after Ramadan). BMI was calculated as weight/height squared (kg/m^2).

RMR measurements

RMR was measured by indirect calorimetry, using the ventilated hood technique (COSMED Quark RMR) and following best-practice recommendations (16). The device used gives values for respiratory quotient (RQ) as well as RMR. Measurements were performed (Ramadan and post-Ramadan) after a minimum of 9 h of fasting from the previous meal including complete abstinence from nicotine and caffeine. In the majority of participants this was between 1400 and 1500 (as suhoor was taken around 0400). Some participants had a late-night meal, rather than a traditional suhoor. In such cases, measurements were taken ≥9 h following the last meal, which might have been around 1000. Participants were also asked to refrain from exercise on the day of RMR measurements. Calibration of the flowmeter and the gas analyzers was performed regularly and according to manufacturers' instructions. Measurements were performed for ≥20 min at room temperature with subjects in light clothing and lying supine, with a ventilated hood over their head and upper body. Data for the first 5 min was discarded and only subsequent measurements that had valid steady-state conditions (≤10% CV in RMR, volume of oxygen, and volume of carbon dioxide) were included.

Activity levels

ActiGraph GT9X (ActiGraph LLC) triaxial accelerometers were used to measure physical activity in a subgroup of participants who were encouraged to maintain their normal daily activities. The participants wore the accelerometer on their nondominant wrist (left). ActiLife 6 software was used for initialization and data upload. A sample rate of 30 Hz was chosen with the accelerometers set to "blind" mode, to avoid the influence of accelerometer data on activity. Participants wore the device for ≥7 d. Individual activity data was considered valid if the accelerometer was worn for ≥7 d, wearing days included ≥2 weekend days, and the accelerometer was worn for ≥10 h/d (17). Wearing time validation was performed using the Choi wear time validation tool (18) in the ActiLife software.

Total energy expenditure measurement

The doubly labeled water (DLW) method was used for measuring free-living energy expenditure over a period of 4–20 d (19, 20). The technique is based on the exponential disappearance of the stable isotopes ^{2}H and ^{18}O from the body after ingestion of a bolus dose of water labeled with both isotopes. These isotopes mix with the hydrogen and oxygen in body water within a few hours. As energy is expended, ^{2}H is lost as water and ^{18}O as both water and CO_2. After correction for isotopic fractionation, the excess disappearance rate of ^{18}O relative to ^{2}H is a measure of CO_2 production rate, which in turn can be used to estimate total energy expenditure by using a modified Weir's formula (21) based on the CO_2 production rate and RQ (measured by indirect calorimetry).

During and 1–2 mo after Ramadan, participants received a dose of DLW based on body size (44–88 g) to match body water enrichment. During Ramadan, the DLW dose could only be administered after iftar and these doses were taken at the patient's own home after careful weighing. After Ramadan, the dose could be taken during the day and under observation. The timings were recorded accurately and taken into account when isotope disappearance calculations were made. The dose enrichment was 10.47 atom percent enrichment ^{18}O and 4.57 atom percent enrichment ^{2}H. A predose urine sample was collected to assess baseline isotope enrichments. The dose was administered between 1900 and 2300 (after iftar) during Ramadan. Post-Ramadan DLW dose was taken during the day; ingestion times and actual dose taken were recorded. Urine samples were then collected daily from day 1 (day of DLW intake) up to day 14. Urine samples were divided into 2-mL cryotubes and stored at –80°C until analysis. The samples were sealed into capillary tubes, which were then vacuum distilled to collect the water, which was then analyzed with the use of an off-axis laser spectroscopy liquid water isotope analyzer (22, 23). Samples were run alongside international laboratory standards of known enrichment (24) for standardization. To derive the isotope dilution spaces (N_o and N_d for O and H, respectively) and the isotope washout constants (k_o and k_d, respectively, for oxygen and hydrogen) we log converted the excess isotope enrichments and then fitted linear relations to the resultant linearized exponentials. The back-extrapolated intercepts were used to evaluate the dilution spaces. Isotope enrichments were converted to daily CO_2 production using the modified 2-pool model equation A6 from Schoeller et al. as recommended for humans (25, 26).

Data analysis

All quantitative data were checked by ≥2 investigators and entered into a spreadsheet. SPSS version 20.0 was used for statistical analyses. Nonparametric tests were used to compare Ramadan and post-Ramadan values for RMR, activity parameters, and TEE. Means are presented as mean ± SD.

RESULTS

Resting metabolic rate and Ramadan fasting

A total of 29 individuals, 13 men and 16 women, aged 19–52 y, completed the study and had fully paired (Ramadan and post-Ramadan) RMR data. All participants were non-obese [15 with BMI (in kg/m^2) 20 to <25 and 14 with BMI 25 to <30, with a mean BMI of 25.8 ± 2.2 and 23.6 ± 3.1 in men and women, respectively, **Table 1**). Hours of fasting from last meal to RMR measurement during Ramadan and post-Ramadan periods were similar (median 10.3 and 10.5 h, respectively). Mean RMR was 1365.7 ± 230.2 kcal/d for Ramadan and 1362.9 ± 273.6 kcal/d for post-Ramadan; the difference was not statistically significant ($P = 0.713$). Furthermore, no significant change in RMR/fat-free mass was found between Ramadan and post-Ramadan periods (30.1 ± 9.2 kcal $\cdot$ d^{-1} $\cdot$ kg^{-1} during Ramadan compared with 30.1 ± 10.0 kcal $\cdot$ d^{-1} $\cdot$ kg^{-1} after Ramadan; $n = 29$; P value = 0.779). However, RQ during and after Ramadan were significantly different ($n = 29$; $P < 0.0001$) with a lower value of 0.80 ± 0.06 during Ramadan compared to 0.88 ± 0.05 after Ramadan.

Resting metabolic rate in early and late Ramadan

The effect of the duration of Ramadan fasting on resting metabolic rate was analyzed by including the week of measurement as categorical variable in multiple linear regression in all individuals in whom a measurement of RMR was performed at least in the first week ($n = 19$) of Ramadan (**Table 2**). The number of subjects who had measurements performed in week 2, 3, 4 and after Ramadan is shown in Table 2. Overall the model fit was good with an adjusted $r^2 = 0.70$. Controlling for the effects of sex, age, weight, and number of hours since suhoor, RMR was significantly lower in weeks 2, 3 and 4 of Ramadan than in week 1 of Ramadan [$\beta = -138.62$ (–255.45, –21.8); $P < 0.05$; $\beta = -155.55$ (–274.83, –36.27); $P < 0.05$; $\beta = -223.84$ (–373.33, –74.35); $P < 0.01$, respectively].

Activity

Paired measurements of activity levels, measured in number of steps, were obtained from 11 individuals, 6 men and 5 women, during Ramadan and 2 mo after Ramadan. The total number of steps per day (converted from activity counts using ActiGraph proprietary software) during Ramadan (9950 ± 1152) was significantly lower ($P = 0.001$) than the total number of steps after Ramadan (11353 ± 2054; Table 1). Activity levels had a unique pattern through timings at other times of the day in Ramadan compared to after Ramadan (**Figure 1**). At night (0000–0600), activity levels were higher in Ramadan compared to post-Ramadan ($P = 0.001$). In contrast, in the morning (0600–1200) and afternoon (1200–1800), activity levels were lower in Ramadan compared to post-Ramadan ($P = 0.001$ and $P = 0.002$ respectively). Unlike other timings of the day, differences in activity levels in the evening (1800–0000) in Ramadan compared to post-Ramadan were not observed ($P = 0.70$). During Ramadan, 3 main patterns of activity could be identified; some subjects stayed awake after iftar and retired to bed after suhoor, waking up later in the morning (**Supplemental Figure 2**A). Some others broke their sleep, retiring to bed before midnight and waking up to eat suhoor, retiring for a second time around 0430 for a brief period of sleep, and waking up for a second time to go to work (Supplemental Figure 2B). We also found some subjects who did not sleep (Supplemental Figure 2C) at all during the night; some participants made up for this with an afternoon nap (not shown). **Figure 2** shows the cumulative median activity curve for all participants.

Total energy expenditure and Ramadan fasting

Ten participants (5 men and 5 women, Table 1) completed doubly labelled water (DLW) experiments. Typical washout curves for an individual during and post-Ramadan are presented in **Supplemental Figure 3**. Linearity in the log-converted curves was excellent, with r^2 averaging 0.995 (SD = 0.007) for the ^{18}O curves and 0.994 (SD = 0.006) for the ^{2}H curves. Individual estimates of N_o, N_d, k_o, and k_d are presented in **Supplemental Table 1**. The dilution space ratio N_d/N_o averaged 1.036 (SD = 0.011) during Ramadan, and 1.027 (SD = 0.008) post-Ramadan. The isotopic washout ratio was 1.226 (SD = 0.060) during Ramadan and 1.213 (SD = 0.060) post-Ramadan.

There was no significant difference in TEE during and post-Ramadan (2224.1 ± 433.7 compared with 2121.0 ± 718.5 kcal/d; $P = 0.7695$, Table 2). ANCOVA showed no significant difference between Ramadan and post-Ramadan regression lines (**Figure 3**) (ANCOVA; $t = 0.35$, $P = 0.727$); the main factor influencing TEE was body weight (ANCOVA; $t = 2.72$, $P = 0.015$).

TABLE 1

Patient characteristics at baseline and energy metabolism parameter during and after Ramadan fasting in the study population[1]

			n	Age, y	BMI, kg/m^2	Weight, kg	AFM, kg	FFM, kg	RMR, kcal/d	Total steps/d	TEE, kcal/d
All	Ramadan (baseline)	All	29	33.3 ± 8.7	24.6 ± 2.9	68.5 ± 12.3	—	—	1365.7 ± 230.2	NA	NA
		Men	13	35.8 ± 7.1	25.8 ± 2.2	78.1 ± 7.3	19.7 ± 3.9	58.9 ± 6.8	1538.8 ± 215.2	NA	NA
		Women	16	31.4 ± 10.1	23.6 ± 3.1	60.7 ± 9.8	21.8 ± 7.4	39.5 ± 3.2	1225.0 ± 121.5	NA	NA
	Post-Ramadan	All	29	33.3 ± 8.7	24.6 ± 2.9	68.3 ± 12.5	—	—	1362.9 ± 273.6	NA	NA
		Men	13	35.8 ± 7.1	26.0 ± 2.1	78.1 ± 7.4	19.5 ± 6.4	59.3 ± 17.5	1572.1 ± 267.1	NA	NA
		Female	16	31.4 ± 10.1	23.5 ± 3.1	60.3 ± 9.9	21.1 ± 7.5	39.7 ± 3.3	1192.9 ± 117.9	NA	NA
Activity experiment	Ramadan (baseline)	All	11	34.1 ± 7.3	24.4 ± 3.1	69.6 ± 13.7	—	—	NA	9950 ± 1152	NA
		Men	6	36.3 ± 7.5	25.4 ± 1.4	77.9 ± 7.1	21.0 ± 4.4	57.4 ± 3.8	NA	9710 ± 1135	NA
		Women	5	31.4 ± 6.2	23.3 ± 4.2	59.6 ± 13.6	20.6 ± 11.3	39.5 ± 3.1	NA	10239 ± 1192	NA
	Post-Ramadan	All	11	34.1 ± 7.3	24.9 ± 3.1	71.1 ± 14.4	—	—	NA	11353 ± 2054	NA
		Men	6	36.3 ± 7.5	26.1 ± 1.4	80.4 ± 7.2	22.4 ± 3.6	58.5 ± 4.7	NA	10987 ± 2156	NA
		Women	5	31.4 ± 6.2	23.4 ± 3.9	60.1 ± 13.3	20.2 ± 11.5	40.4 ± 2.6	NA	11792 ± 1864	NA
DLW experiment	Ramadan (baseline)	All	10	32.6 ± 11.3	25.0 ± 3.2	70.5 ± 13.2	—	—	1387.0 ± 249.9	NA	2224.1 ± 433.7
		Men	5	37.6 ± 14.0	26.3 ± 1.8	79.6 ± 5.6	21.0 ± 3.7	59.1 ± 3.9	1597.0 ± 147.3	NA	2538.8 ± 257.7
		Women	5	27.6 ± 5.6	23.8 ± 4.0	61.4 ± 12.3	22.3 ± 9.7	39.6 ± 3.6	1177.0 ± 92.3	NA	1909.4 ± 330.5
	Post-Ramadan	All	10	32.6 ± 11.3	24.8 ± 3.2	69.6 ± 13.1	—	—	1355.2 ± 255.7	NA	2121.0 ± 718.5
		Men	5	37.6 ± 14.0	25.9 ± 1.9	78.4 ± 6.0	20.3 ± 3.6	58.6 ± 3.4	1539.2 ± 214.6	NA	2534.9 ± 716.2
		Women	5	27.6 ± 5.6	23.6 ± 4.0	60.9 ± 12.5	21.4 ± 10.1	40.0 ± 3.4	1171.2 ± 127.9	NA	1707.1 ± 469.6

[1] Values are means ± SDs unless otherwise indicated. Subgroup analysis on participants of total energy expenditure and activity monitoring study are shown. RMR measurements were conducted on all subjects. Activity (using accelerometers; $n = 11$) as steps per day and TEE (using the DLW technique; $n = 10$) were measured on 2 separate subgroups. Apart from activity ($P < 0.001$), no significant differences between Ramadan and post-Ramadan values were seen. AFM, absolute fat mass; DLW, doubly labeled water; FFM, fat-free mass; NA, not applicable; RMR, resting metabolic rate; TEE, total energy expenditure.

TABLE 2
Resting metabolic rate in early and late Ramadan[1]

Covariate	*n*	Estimate (95% CI)	SE	Sig.
Intercept	—	741.91 (372.05, 1111.78)	183.40	<0.001
Week 2	9	–138.62 (–255.45, –21.8)	57.93	0.021
Week 3	9	–155.55 (–274.83, –36.27)	59.15	0.012
Week 4	5	–223.84 (–373.33, –74.35)	74.13	0.004
Post-Ramadan	16	–46.30 (–140.6, 47.99)	46.76	0.328
Time since suhoor, h	—	–4.85 (–24.46, 14.77)	9.72	0.621
Male sex	—	203.89 (95.02, 312.77)	53.99	<0.001
Age, y	—	–0.73 (–5.7, 4.24)	2.46	0.768
Weight, kg	—	10.10 (6.22, 13.97)	1.92	<0.001

[1]The effect of the duration of Ramadan fasting on resting metabolic rate was analyzed by including the week of measurement as categorical variable in multiple linear regression. Resting metabolic rate is significantly lower in weeks 2, 3, and 4 of Ramadan than during the first week, when controlling for time since suhoor, sex, age, and weight. Sig., significance.

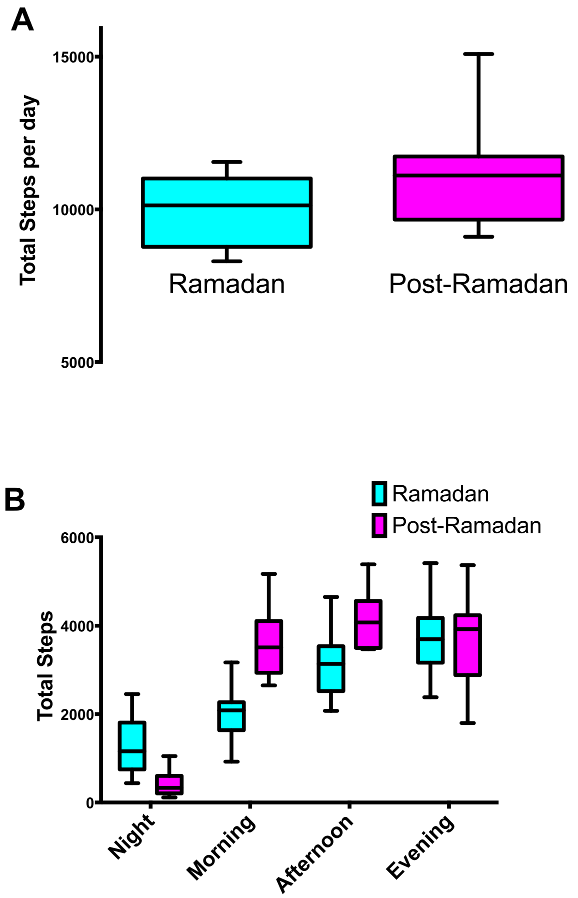

FIGURE 1 The effect of Ramadan fasting on activity: box plot of total number of steps per day in 11 participants during and after Ramadan (A); box plot of total number of steps per night, morning, afternoon, and evening in Ramadan and after Ramadan in 11 participants (B). Comparisons have been made with the use of the Wilcoxon signed-rank test. Total mean ± SD number of steps per day (9950 ± 1152 compared with 11353 ± 2053, $P = 0.001$), activity in the morning (1974 ± 583 compared with 3606 ± 715, $P = 0.001$) and afternoon (3193 ± 783 compared with 4164 ± 670, $P = 0.002$) were significantly lower during Ramadan compared with after Ramadan, whereas nocturnal activity was higher during Ramadan (1261 ± 629 compared with 416 ± 279, $P = 0.001$). There was no significant difference in activity level in the evenings between Ramadan and post-Ramadan periods.

DISCUSSION

Ramadan is unique and differs from both prolonged and short-term starvation. The former decreases RMR (27–29), whereas short-term starvation (≤4 d) may increase RMR, and this has been attributed to a rise in norepinephrine concentrations (30). We have investigated Ramadan as a separate entity that may be of relevance to the growing trend to prescribe 'intermittent fasting' for therapeutic weight loss. There are very few studies of energy expenditure in this context (31, 32). El Ati et al. (33) investigated the effect of Ramadan fasting on anthropometric and metabolic variables in healthy Tunisian Muslim women; despite marked changes in food intake during Ramadan, there were no significant changes in body weight, body composition, or resting energy expenditure. More recently, McNeil et al. (34) conducted a study to examine the effect of Ramadan fasting on variations in eating behavior, appetite ratings, satiety efficiency, and energy expenditure in 20 Muslim participants. They reported no significant differences in anthropometric measures before Ramadan compared to during Ramadan and after Ramadan, and no significant difference in RMR, thermic effect of food, and TEE before and after Ramadan. Notably however, in this study, RMR, thermic effect of food, and TEE were not measured during Ramadan. Similarly, Harder-Lauridsen et al. (35) found only minor differences in BMI, and no significant change in body composition in fasting men before and Ramadan. In spite of the lack of significant change in RMR with Ramadan fasting, our study has shown a lower RQ during Ramadan compared to post-Ramadan period, a finding similar to that reported by El Ati et al. (33) and suggestive of a shift towards fat rather than carbohydrate as source of fuel during Ramadan.

We used the DLW technique to measure free-living 24-h energy expenditure in the context of Ramadan fasting. DLW is a well-validated technique to measure free-living 24-h energy expenditure (36–39). We have also explored the other important aspects of energy expenditure, namely RMR and physical activity. RMR was significantly lower in mid- and late-Ramadan fasting compared to the first week of Ramadan. It has previously been demonstrated that acute starvation causes an increase in RMR in association with increasing serum norepinephrine (39), raising the possibility that the same phenomenon may also occur in the context of intermittent fasting. Our results suggest,

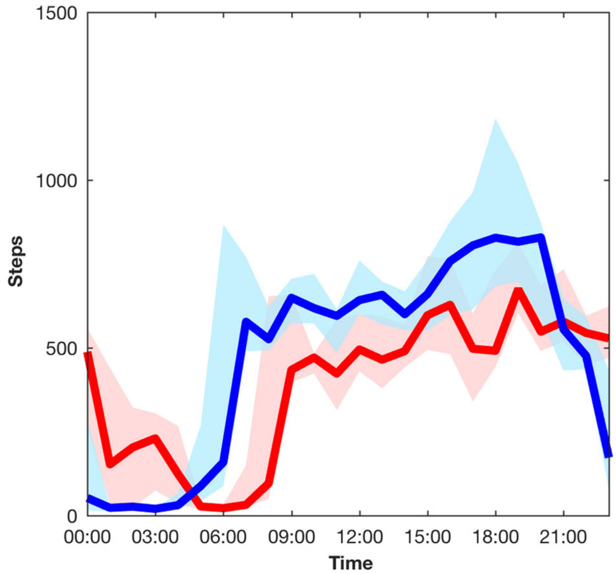

FIGURE 2 Twenty-four-hour activity profiles (number of steps per hour) during (gray) and after Ramadan (black) represented as overall median 24-h profile for all study participants ($n = 11$). Solid lines represent median; highlighted areas represent the 25th and 75th percentiles of all measurement days. Cumulative pattern for all participants indicates a dominant tendency to stay awake during the night and sleep after suhoor, retiring to bed around midnight and waking up very early in the morning. There is more activity at night during Ramadan; after Ramadan, there is more activity during the day.

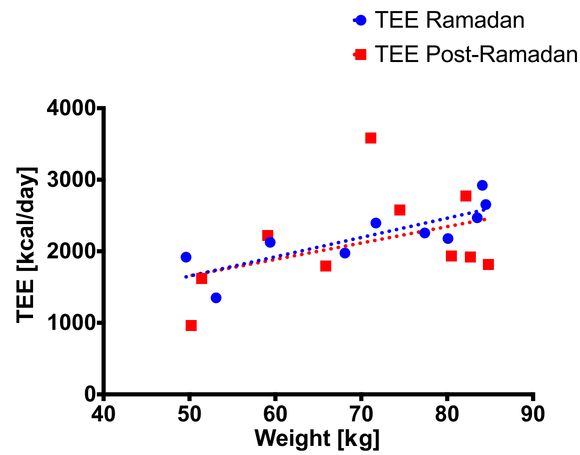

FIGURE 3 The correlation between TEE and weight during and after Ramadan in 10 participants. There was no significant difference between Ramadan and post-Ramadan regression lines (ANCOVA; $t = 0.35$, $P = 0.727$); the main factor influencing TEE was body weight ($t = 2.72$, $P = 0.015$). TEE, total energy expenditure.

however, that this may not be the case and that after a few days of intermittent fasting there is some metabolic adaptation with a reduction in RMR. This may be of importance in some diets that promote skipping and spacing meals and may be an explanation for difficulties in weight loss and weight loss maintenance after the first few days of such dietary practices. Ramadan is often seen as a period of relative inactivity and as such we had hypothesized that activity energy expenditure and thus 24-h energy expenditure should also be reduced with Ramadan fasting. We used accelerometers to measure activity in a smaller group of individuals and showed a trend to support the hypothesis that people are less physically active during Ramadan fasting. Our study did not show a significant difference in TEE in Ramadan and post-Ramadan periods (2224 compared with 2121 kcal/d). Our data have also indicated interindividual variability in activity patterns and how they change during Ramadan. In most participants, we have shown a shift in the timing of activity from mainly daytime before Ramadan to mainly nighttime during Ramadan. Many of our participants seemed to have much reduced sleeping times during Ramadan. In our group of subjects, we were also able to demonstrate different patterns of activity during Ramadan, confirming a reduction in sleeping time and broken sleep in the majority of subjects. This reduction in sleep time may offset any reductions in expenditure produced by lower activity and lower RMR leading to the nonsignificant effects on TEE.

In common with other Ramadan studies, we faced reluctance from potential participants who did not wish to deviate from their normal Ramadan routines. Many of our initial potential volunteers found wearing accelerometer wristbands and/or providing multiple urine specimens during Ramadan unacceptable. Other limitations of our study include inherent methodological issues. We have used ActiGraph wristbands to monitor activity. These accelerometers are very useful in monitoring steps, but other activities such as cycling or prayers may not be captured so may underestimate activity. We observed considerable variability in minute-to-minute RMR records during indirect calorimetry; as a result, and to maximize accuracy, we had to repeat the procedure in some subjects.

We made no attempts at investigating 2 specific aspects of energy balance in the context of Ramadan: food intake and the thermic effect of food. The former has been the subject of several previous studies (15, 40, 41), with most but not all finding an overall reduction in food intake; a change in composition of food with an increase in carbohydrate intake has also been shown, although these are in part determined by local culture and food preference.

Our findings may be of relevance to weight and weight loss with Ramadan. Several studies have investigated the impact of Ramadan on body weight and metabolic health. Results have been inconsistent, largely due to differences in dietary habits, gender, age, and ethnicity. A recent systematic meta-analysis of 30 self-controlled cohort studies (42) has reported the beneficial effects of Ramadan on metabolic status, including lower blood glucose concentrations, improved lipid profiles, and reduced body weight. Our results indicate that the reduction in activity in Ramadan is not universal and that some people were actually more physically active during this period. It is therefore possible to be as active in Ramadan as other months of the year, and this should be emphasized and encouraged. Ramadan has been associated with increased insulin resistance and this would make continued physical activity even more important.

In conclusion, our results suggest that Ramadan is associated with reduced physical activity, and reduced RMR after the first week of fasting. These reductions in components of the energy expenditure did not, however, translate into an overall reduction in TEE. This was possibly because there was also a large reduction in time spent sleeping which might offset the energy savings from reduced activity and RMR. Ramadan results in profound disruptions of daily activity patterns but overall energy balance does not appear greatly affected. Our results are of relevance to millions of Muslims who observe Ramadan fasting and may have implications to dietary restriction programs that promote skipping and spacing meals.

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