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Effects of Fed- Versus Fasted-State Aerobic Training During Ramadan on Body Composition and Some Metabolic Parameters in Physically Active Men

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The aim of this study was to evaluate the effects of aerobic training in a fasted versus a fed state during Ramadan on body composition and metabolic parameters in physically active men. Nineteen men were allocated to 2 groups: 10 practicing aerobic training in a fasted state (FAST) and 9 training in an acutely fed state (FED) during Ramadan. All subjects visited the laboratory for a total of 4 sessions on the following occasions: 3 days before Ramadan (Bef-R), the 15th day of Ramadan; the 29th day of Ramadan (End-R), and 21 days after Ramadan. During each session, subjects underwent anthropometric measurement, completed a dietary questionnaire, and provided fasting blood and urine samples. Body weight decreased in FAST and FED by 1.9% ($p < .001$) and 2.6% ($p = .046$), respectively. Body fat percentage decreased only in FAST by 6.2% ($p = .016$). FAST experienced an increase in the following parameters from Bef-R to End-R: urine specific gravity (0.64%, $p = .012$), urea (8.7%, $p < .001$), creatinine (7.5%, $p < .001$), uric acid (12.7%, $p < .001$), sodium (1.9%, $p = .003$), chloride (2.6%, $p < .001$), and high-density lipoprotein cholesterol (27.3%, $p < .001$). Of these parameters, only creatinine increased (5.8%, $p = .004$) in FED. Creatinine clearance values of FAST decreased by 8.9% ($p < .001$) and by 7.6% in FED ($p = .01$) from Bef-R to End-R. The authors conclude that aerobic training in a fasted state lowers body weight and body fat percentage. In contrast, fed aerobic training decreases only body weight. In addition, Ramadan fasting induced change in some metabolic parameters in FAST, but these changes were absent in FED.

Keywords*:* aerobic exercise, dehydration, body fat percentage, Islamic fasting

Ramadan is the holiest month in the Islamic calendar. The uniqueness of Ramadan is that food and fluid intake are concentrated into the hours between sunset and the following sunrise (Wilson, Drust, & Reilly, 2009), so food frequency (BaHammam, 2005) and quantity (Husain, Duncan, Cheah, & Ch'ng, 1987) and fluid intake (Bouhlel et al., 2006) may be affected. Ramadan occurs 11 days earlier every year and thus over time may occur in any of the four seasons. Therefore, the length of the daily fast during Ramadan varies from 11 to 18 hr in tropical countries (Sakr, 1975). As a consequence of the 1 month of repeated periodic food restriction that participation in Ramadan incurs, reductions in caloric intake (Bouhlel et al., 2006) and losses in body weight (Bouhlel et al., 2006; Sweileh, Schnitzler, Hunter, & Davis, 1992) have been observed.

Many participants in Ramadan maintain physical activity during the fasting month. Measurements of the effect of Ramadan fasting on urinary markers of hydration status in athletes are equivocal, showing both an increase (Wilson et al., 2009) and no change in urine osmolarity (Aziz, Slater, Hwa Chia, & The, in press) or specific gravity (Shirreffs & Maughan, 2008) during Ramadan. Several markers of renal function have also been studied during Ramadan to investigate possible effects of periodic fluid restriction. Increases in creatinine and decreases in urea concentration have been observed (Maughan et al., 2008), although others (Ramadan, Telahoun, Al-Zaid, & Barac-Nieto, 1999) report no change in either parameter. Uric acid has been reported to increase in elite judoists (Chaouachi, Chamari, Roky, Wong, Mbazaa, & Bartagi, 2008) but not change in soccer players (Maughan et al., 2008) or physically active men (Ramadan et al., 1999). Several studies have also examined the combined effects of physical activity and Ramadan fasting on serum electrolytes. Ramadan et al. noted an increase in serum bicarbonate and sodium concentrations in sedentary men but no change in either concentration in physically

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active men, and Maughan et al. reported increased serum potassium concentrations but no change in serum sodium concentration. Clearly, the effects of continuing physical activity through Ramadan on hydration status require further investigation.

The interaction between participation in Ramadan and exercise and subsequent effects on circulating metabolites are also poorly understood. Although a decrease in resting serum glucose has been noted in moderately trained men (Aziz, Wahid, Png, & Jesuvadian, 2010), soccer players (Aziz et al., in press), and runners (Faye et al., 2005), an absence of change has been reported in elite rugby (Bouhlel et al., 2006) and soccer players (Maughan et al., 2008). Total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) have each been shown to increase in elite judoists (Chaouachi et al., 2008). However, only free-fatty-acid levels have been shown to increase in middle-distance runners (Chennaoui et al., 2009).

During Ramadan, physical training is often scheduled at night to avoid beginning training sessions in a completely fasted state (Wilson et al., 2009), thereby preventing dehydration and hypoglycemia. However, it has been demonstrated that aerobic training in a fasted state can stimulate adaptations in muscle cells to facilitate energy production via fat oxidation (Stannard, Buckley, Edge, & Thompson, 2010; Van Proeyen, Szlufcik, Nielens, Ramaekers, & Hespel, 2011). In fact, aerobic training in a fasted state increases muscle oxidative capacity (Stannard et al., 2010) and at the same time enhances exercise-induced net intramyocellular lipid degradation (Van Proeyen et al., 2011). In addition, aerobic training can prevent the development of an exercise-induced drop in blood glucose concentration (Van Proeyen et al., 2011).

This begs the question as to whether training during the day during Ramadan, although putting the athlete at greater risk of dehydration and hypoglycemia, might accelerate adaptations to training and ultimately result in improved physical performance.

Currently, published studies that have investigated the effects of aerobic exercise during Ramadan on body composition and biochemical parameters of physically active men have not also had a control group that did equivalent exercise in the fed state (Aziz et al., 2010; Ramadan et al., 1999; Stannard & Thompson, 2008). Thus, any specific effects of training while fasted cannot be properly identified. Indeed, this lack of control may explain the varying observations in published studies to date.

The aim of this study was to evaluate the effects of aerobic training during Ramadan fasting on body composition and metabolic parameters of physically active men and to ascertain whether there are differences between the effects of aerobic training during the day (in a fasted state) and aerobic training at night (in a fed state) regarding body composition and selected metabolic parameters.

Methods

Subjects

Nineteen physically active men were recruited into the study and randomly allocated to two groups: Ten participants trained in a fasted state (FAST), and 9 trained in a fed state (FED) during Ramadan. Each subject regularly performed continuous aerobic exercise at least three times/week but did not participate in formal competitive sport. The training sessions consisted of one session of cycling, one session of running, and one session of rowing on a cycle ergometer (Sapilo, Italy) equipped with a heart-rate monitor. One subject in FED also practiced swimming equipped with a heart-rate monitor (Polar, Finland). Each training session lasted 40–60 min. The aerobic-training intensity was equivalent to 60–80% of maximum heart rate and was supervised by the investigators. Subjects were nonsmokers and did not use other substances that would affect the study outcomes. Subjects' descriptive characteristics are provided in Table 1.

Before enrolling in the study, subjects were informed of the experimental procedures and potential risks associated with participation; however, they were not informed of the study purpose. Each subject provided written consent in accordance with the Declaration of Helsinki. The study was approved by the research ethics committee of the Faculty of Medicine of the University of Sfax, Sfax, Tunisia.

Experimental Design

Ramadan began on August 10 and ended on September 9, 2010. The average duration of the fast was approximately 15 hr. The study was conducted in Tunisia, where daytime temperatures were 30–35 °C and relative humidity was 50–65%.

Subjects visited the laboratory on four separate occasions: 3 days before Ramadan (Bef-R), the 15th

Table 1 Descriptive Characteristics, *M* ± *SD*

	FAST	FED
Age (years)	26.6 ± 3.0	27.6 ± 1.8
Weight (kg)	79.2 ± 3.0	80.5 ± 4.6
Height (cm)	180.0 ± 6.4	176.0 ± 3.2
Body-mass index (kg/m^2)	24.6 ± 1.4	24.5 ± 1.6
Body fat %	19.4 ± 1.3	19.3 ± 1.2
Lean body mass (kg)	63.8 ± 3.0	65.0 ± 3.9
Years aerobic training	1.6 ± 0.7	1.7 ± 0.2
Aerobic training hr/week	3.0 ± 0.6	2.8 ± 0.5
VO_{2max} (ml · min^{-1} · kg^{-1})	44.6 ± 4.2	45.9 ± 2.6

Note. FAST = subjects training in a fasted state; FED = subjects training in a fed state; VO_{2max} = maximal oxygen consumption.

day of Ramadan (Mid-R), the 29th day of Ramadan (End-R), and 21 days after Ramadan (Post-R). In the morning of each visit (approximately 10:30 a.m.), they underwent anthropometric measurements, completed a dietary questionnaire, and provided fasting blood and urine samples. They were instructed to not consume any food or calorie-containing beverage after 11:00 p.m. on the day before each visit. During the 2 weeks before and after the beginning of Ramadan, subjects recorded their exercise sessions along with their rating of perceived exertion (RPE) on the Borg scale (Borg, 1985; Table 2) in a log book. All subjects were familiarized with the use of the RPE scale before the commencement of the study. During Ramadan, exercise sessions of FAST occurred in the late afternoon (between 4:00 and 6:00 p.m.) and those of FED occurred at night (between 9:30 and 10:30 p.m.) after the break of fasting. Neither RPE nor the duration of the exercise sessions changed in either FAST or FED throughout the study. In addition, there were no differences in RPE or the duration of exercise between FAST and FED at any time period.

Body Composition

Body weight was measured to the nearest 100 g using a calibrated electronic scale (Seca Instruments Ltd., Germany), and height was measured to the nearest 5 mm using a stadiometer. Skinfold thickness was measured using calibrated Harpenden calipers (Harpenden, UK) at four standardized sites (biceps, triceps, subscapula, and suprailium). Body fat percentage (BF%) was estimated from skinfold measures using a previously published algorithm (Durnin & Womersley, 1974). Lean body mass was calculated as body weight minus body fat mass.

Dietary Intake Analysis

Subjects were instructed to record all food and beverages consumed during the week before Ramadan and then 3 days/week during Ramadan. Dietary records were analyzed using the Bilnut program (Nutrisoft, Cerelles, France) and the food-composition tables of the National Institute of Statistics of Tunis (1978). Total water intake was defined as the fluid volume of consumed beverages plus the water content of consumed foods.

Urine Specific Gravity

Urine specific gravity was assessed from 30 ml of urine collected from each subject immediately before the anthropometrical measurement. It was measured to the nearest 0.001 unit with a hand refractometer (Atago, Japan).

Serum Biochemistry

During each session, venous blood samples (~5 ml) were taken from an antecubital vein into a plain Vacutainer tube. The blood was allowed to clot and then was centrifuged at 1,500 *g* for 10 min at 4 °C. An aliquot of the serum was used to measure serum glucose immediately after the centrifugation step; the remainder was then stored at –20 °C until subsequent analysis. An automated analyzer (Beckman Coulter Cx9, UK) measured the concentrations of biochemical parameters using the appropriate reactant. Blood glucose, uric acid, TC, and triglycerides were determined using an enzymatic colorimetric method (Biomérieux, France). Urea was determined using an enzymatic method (Biomaghreb, Tunisia). Creatinine concentrations were determined by the Jaffé method. Creatinine clearance was determined using the formula of Cockcroft and Gault (1976). Sodium, potassium, and chloride concentrations were determined by potentiometry. HDL-C concentrations were determined by immunoinhibition (Elitech, France) using an automated analyzer (Flexor Vitalab, Netherlands). LDL-C was calculated using the Friedewald formula (Friedewald, Levy, & Fredrickson, 1972). The ratios TC:HDL-C and LDL-C:HDL-C were derived from the respective concentrations.

Statistical Analyses

All statistical tests were performed using Statistica Software (StatSoft, Paris, France). A 4 (periods) × 2 (FED or FAST) repeated-measures analysis of variance (ANOVA)

Table 2 Rating of Perceived Exertion and Duration of Training Sessions Before and During Ramadan, *M* ± *SD*

	Before Ramadan		Between the Beginning and Mid-R		Between Mid-R and End-R	
	FAST	FED	FAST	FED	FAST	FED
Rating of perceived exertion	12.9 ± 1.5	13.3 ± 2.3	13.3 ± 1.4	13.3 ± 1.6	13.1 ± 1.4	13.9 ± 1.7
Duration of session (min)	47.5 ± 11.6	52.1 ± 10.6	46.3 ± 10.6	51.3 ± 10.7	46.7 ± 10.7	49.3 ± 12.0

Note. Mid-R = middle of Ramadan, 15 days after beginning the fast; End-R = end of Ramadan, 30 days after beginning the fast; FAST = subjects training in a fasted state; FED = subjects training in a fed state.

was applied. A Bonferroni post hoc test was performed where appropriate. Differences between FAST and FED were analyzed using nonpaired Student's *t* test. Statistical significance was set at $p < .05$. All data are expressed as *M* ± *SD*.

Results

Dietary Intake

Estimated mean daily energy intake before Ramadan was similar between FED and FAST. Daily energy intake during Ramadan did not change in both groups compared with Bef-R. However, absolute daily energy intake was significantly higher in FED than in FAST during the period between the beginning and the Mid-R ($p < .001$; see Table 3).

Carbohydrate consumption during Ramadan did not change in either group compared with Bef-R. However, protein consumption in FAST increased by 10.7% ($p = .034$) from Bef-R to Mid-R, and fat consumption of FED increased by 7.7% ($p = .049$) from Bef-R to Mid-R. Expressed as a percentage of daily macronutrient intake, fat and carbohydrate intake did not change during Ramadan in either group. However, protein consumption in FAST was significantly higher during the period between the beginning of Ramadan and Mid-R ($p < .001$) than Bef-R.

Body Weight and Body Composition

Compared with values at Bef-R, body weight of FAST was 1.4% less at Mid-R ($p = .004$), 1.9% less at End-R ($p < .001$). However, body weight of FED was 2.6% less ($p = .046$) at End-R than at Bef-R. There was no difference in body weight between the two groups at any time period in the study (see Table 4).

BF% in FAST decreased by 6.2% ($p = .016$) from Bef-R to End-R. However, BF% of FED remained unchanged during the whole period of the investigation. There was no difference in BF% between the two groups at each time period in the study. Lean body mass did not change during the duration of the study in both groups. Moreover, there were no differences in lean body mass between the two groups at any time period.

Table 3 Dietary Intake Before and During Ramadan, *M* ± *SD*

	Before Ramadan		Between the Beginning and Mid-R		Between Mid-R and End-R	
	FAST	FED	FAST	FED	FAST	FED
Energy intake (kcal/day)	2,803 ± 511	2,795 ± 279	2,466 ± 143	3,056 ± 183###	2,726 ± 346	2,775 ± 312
Protein (g/day)	90.6 ± 18.4	96.3 ± 9.5	100.3 ± 11.2*	98.5 ± 7.0	93.0 ± 13.4	102.6 ± 7.0
Protein (%)	13.2 ± 2.8	13.9 ± 1.9	16.3 ± 2.0***	13.0 ± 0.4###	13.8 ± 2.3	14.9 ± 1.6
Fat (g/day)	102.9 ± 27.4	103.5 ± 16.2	87.4 ± 8.4	111.5 ± 14.4*	103.0 ± 16.3	109.0 ± 8.9
Fat (%)	33.1 ± 6.0	34.1 ± 8.4	32.0 ± 3.1	32.9 ± 4.0###	34.0 ± 3.3	35.5 ± 1.6
Carbohydrate (g/day)	378.5 ± 93.7	369.6 ± 44.9	319.6 ± 44.2	414.8 ± 45.3###	357.1 ± 59.6	346 ± 57.9
Carbohydrate (%)	53.7 ± 6.2	52.9 ± 3.5	51.7 ± 4.9	54.2 ± 4.0	52.2 ± 2.4	49.6 ± 3.1
Total water intake (L/day)	4.0 ± 0.5	4.1 ± 0.5	3.4 ± 0.4*	3.5 ± 0.3	3.3 ± 0.2**	3.9 ± 0.5

Note. Mid-R = middle of Ramadan, 15 days after beginning the fast; End-R = end of Ramadan, 30 days after beginning the fast; FAST = subjects training in a fasted state; FED = subjects training in a fed state.

Significantly different from before Ramadan: *$p < .05$; **$p < .01$; ***$p < .001$. Significantly different from FAST: ###$p < .001$.

Table 4 Body Weight and Body Composition During the Four Phases of the Study, *M* ± *SD*

	Group	Bef-R	Mid-R	End-R	Post-R
Weight (kg)	FAST	79.2 ± 3.0	78.1 ± 3.0*	77.7 ± 3.0***	78.7 ± 2.7
	FED	80.5 ± 4.6	79.1 ± 4.4	78.4 ± 4.6*	79.4 ± 4.8
Body fat %	FAST	19.4 ± 1.3	18.6 ± 1.5	18.2 ± 0.7*	18.9 ± 1.5
	FED	19.3 ± 1.2	18.8 ± 1.0	18.5 ± 0.9	18.9 ± 1.1
Lean body mass (kg)	FAST	63.8 ± 3.0	63.6 ± 2.7	63.6 ± 2.7	63.9 ± 3.1
	FED	65.0 ± 3.9	64.2 ± 3.6	63.9 ± 4.0	64.4 ± 4.1

Note. Bef-R = before Ramadan, 4 days before beginning the fast; Mid-R = middle of Ramadan, 15 days after beginning the fast; End-R = end of Ramadan, 30 days after beginning the fast; Post-R = after Ramadan, 21 days after the conclusion of the fast; FAST = subjects training in a fasted state; FED = subjects training in a fed state.

Significantly different from Bef-R: *$p < .05$; ***$p < .001$.

Urine Specific Gravity

Compared with values at Bef-R, urine specific gravity in FAST was 0.81% higher at Mid-R ($p < .001$) and 0.64% higher at End-R ($p = .012$). However, urine specific gravity in FED did not change throughout the study. Urine specific gravity of FAST was significantly higher than that of FED both at Mid-R ($p = .007$) and at End-R ($p = .038$; see Table 5).

Renal-Function Markers

Urea, uric acid, and creatinine concentrations measured at Bef-R were the same in FAST and FED. Urea values in FAST were 8.7% higher at End-R than at Bef-R ($p < .001$), whereas urea values of FED did not change throughout the study. Compared with values at Bef-R, creatinine values at End-R increased by 7.5% in FAST ($p < .001$) and by 5.8% in FED ($p = .004$). Creatinine clearance values of FAST decreased by 8.9% ($p < .001$) and by 7.6% in FED ($p = .01$) from Bef-R to End-R. Compared with values at Bef-R, uric acid values in FAST were 10.4% higher at Mid-R ($p = .011$) and 12.7% larger at End-R ($p < .001$). However, uric acid values in FED remained unchanged over the whole period of the investigation. There were no differences in urea, creatinine, creatinine clearance, and uric acid values between FED and FAST at each time period (see Table 6).

Serum Electrolytes

There were no differences between FED and FAST in serum sodium and chloride concentrations at Bef-R. At Bef-R, serum potassium values in FED were higher than those in FAST ($p = .039$). Compared with values at Bef-R, serum sodium concentrations in FAST were 1.7% higher at Mid-R ($p = .008$) and 1.9% higher at End-R ($p = .003$). However, serum sodium concentrations in FED did not change throughout the study. Compared with values at Bef-R, serum chloride values in FAST were 2.6% larger at End-R ($p < .001$). However, serum chloride values in FED did not change throughout the study. Serum potassium concentrations did not change throughout the study in either group. No differences were found in sodium and chloride values between FAST and FED at any time period of the investigation.

Serum Lipid and Glucose

TC, triglycerides, HDL-C, and LDL-C values were not different between the two groups at Bef-R. TC and triglycerides did not change throughout the study in FAST and FED. Compared with values at Bef-R, HDL-C of FAST was 18.2% larger at Mid-R ($p = .023$) and 27.3% larger at End-R ($p < .001$) and at Post-R ($p = .012$). However, HDL-C values of FED did not change over the whole period of the investigation. LDL-C values did not change throughout the study in either group, and there were no differences between the groups at any time period. TC:HDL-C and LDL-C:HDL-C ratios were not different between the two groups at Bef-R. Compared with values at Bef-R, the TC:HDL-C ratio of FAST was 11.1% larger at Mid-R ($p = .017$) and 13.9% larger at End-R ($p = .003$) and Post-R ($p = .002$). The TC:HDL-C ratio of FED increased by 27.7% ($p = .016$) at End-R compared with Bef-R. Compared with values at Bef-R, the LDL-C:HDL-C ratio of FAST was 17.4% less at Mid-R ($p = .01$) and 21.7% less at End-R ($p = .001$) and Post-R ($p = .001$). The LDL-C:HDL-C ratio of FED decreased by 25.3% at Mid-R ($p = .05$) and 30.4% ($p = .02$) at End-R compared with Bef-R.

Serum glucose measured at Bef-R was the same in FAST and FED. These did not change throughout the study in either group.

Discussion

Our results show that aerobic training undertaken in the latter part of the daily fast of Ramadan (FAST) lowers body weight and BF% in physically active men. In contrast, an equivalent amount of aerobic training undertaken after the break of fast (FED) decreases only body weight. In addition, Ramadan fasting induced some changes in urinary and biochemical parameters in FAST that were absent in FED.

With a cross-sectional training study design such as employed in the current study, we cannot be sure that each training group experienced exactly the same training load and thus that the differences in the dependent variables between training groups are entirely a result of Ramadan. However, several published studies indicate that Ramadan fasting had no effect on the training load

Table 5 Urine Specific Gravity During the Four Phases of the Study, *M* ± *SD*

Group	Bef-R	Mid-R	End-R	Post-R
FAST	1.022 ± 0.006	1.030 ± 0.003*	1.028 ± 0.004*	1.017 ± 0.003
FED	1.021 ± 0.006	1.020 ± 0.005##	1.022 ± 0.004#	1.022 ± 0.007

Note. Bef-R = before Ramadan, 4 days before beginning the fast; Mid-R = middle of Ramadan, 15 days after beginning the fast; End-R = end of Ramadan, 30 days after beginning the fast; Post-R = after Ramadan, 21 days after the conclusion of the fast; FAST = subjects training in a fasted state; FED = subjects training in a fed state.

Significantly different from Bef-R: *$p < .05$. Significantly different from FAST: #$p < .05$; ##$p < .01$.

Table 6 Serum Biochemical Parameters During the Four Phases of the Study, *M* ± *SD*

	Group	Bef-R	Mid-R	End-R	Post-R
Urea (mmol/L), CV = 5.9%	FAST	4.59 ± 0.36	4.68 ± 0.46	5.02 ± 0.28***	4.54 ± 0.39
	FED	4.62 ± 0.21	4.71 ± 0.47	4.88 ± 0.49	4.57 ± 0.28
Creatinine (μmol/L), CV = 3%	FAST	87.80 ± 5.92	90.62 ± 3.20	94.42 ± 3.98***	85.80 ± 4.82
	FED	86.55 ± 4.16	89.22 ± 3.56	91.55 ± 3.39*	88.04 ± 2.29
Uric acid (μmol/L), CV = 2.9%	FAST	298.50 ± 53.05	329.50 ± 47.22**	336.50 ± 39.49***	302.10 ± 40.43
	FED	283.67 ± 44.73	307.78 ± 39.42	309.67 ± 24.21	296.89 ± 29.63
Creatinine clearance (ml/min)	FAST	128.48 ± 11.85	122.39 ± 8.24	116.99 ± 9.94***	130.39 ± 7.80
	FED	130.98 ± 8.51	124.68 ± 6.71	121.03 ± 6.24**	126.73 ± 5.45
Sodium (mmol/L), CV = 2.7%	FAST	142.10 ± 2.13	144.50 ± 2.22**	144.80 ± 1.81*	142.90 ± 0.99
	FED	141.67 ± 1.87	143.00 ± 1.50	143.89 ± 1.54	142.00 ± 1.66
Potassium (mmol/L), CV = 2.9%	FAST	4.38 ± 0.36#	4.41 ± 0.35	4.45 ± 0.32	4.41 ± 0.32
	FED	4.69 ± 0.21	4.57 ± 0.25	4.49 ± 0.39	4.50 ± 0.23
Chloride (mmol/L), CV = 2.8%	FAST	102.70 ± 1.64	103.00 ± 1.33	105.40 ± 1.26***	103.10 ± 1.79
	FED	103.11 ± 1.96	103.67 ± 1.58	104.33 ± 1.22	103.78 ± 1.30
TG (mmol/L), CV = 2.9%	FAST	0.69 ± 0.16	0.76 ± 0.17	0.77 ± 0.13	0.72 ± 0.13
	FED	0.74 ± 0.13	0.77 ± 0.07	0.77 ± 0.11	0.76 ± 0.1
TC (mmol/L), CV = 3.1%	FAST	3.92 ± 0.37	4.06 ± 0.30	4.08 ± 0.28	3.89 ± 0.34
	FED	3.86 ± 0.38	3.91 ± 0.46	3.88 ± 0.31	3.81 ± 0.30
HDL-C (mmol/L), CV = 3%	FAST	1.11 ± 0.24	1.30 ± 0.18*	1.38 ± 0.27***	1.32 ± 0.24*
	FED	1.09 ± 0.21	1.31 ± 0.11	1.36 ± 0.16	1.28 ± 0.18
LDL-C (mmol/L)	FAST	2.46 ± 0.29	2.37 ± 0.28	2.31 ± 0.43	2.22 ± 0.38
	FED	2.40 ± 0.42	2.22 ± 0.46	2.14 ± 0.37	2.15 ± 0.36
TC:HDL-C	FAST	3.64 ± 0.68	3.16 ± 0.45*	3.07 ± 0.73**	3.06 ± 0.70**
	FED	3.64 ± 0.67	3.01 ± 0.43	2.90 ± 0.50*	3.05 ± 0.58
LDL-C:HDL-C	FAST	2.30 ± 0.56	1.86 ± 0.39**	1.77 ± 0.64**	1.77 ± 0.62**
	FED	2.29 ± 0.61	1.71 ± 0.41*	1.61 ± 0.48*	1.74 ± 0.51
Glucose (mmol/L), CV = 2.3%	FAST	4.89 ± 0.44	4.84 ± 0.55	4.81 ± 0.48	4.95 ± 0.50
	FED	4.61 ± 0.52	4.68 ± 0.39	4.62 ± 0.31	4.81 ± 0.45

Note. Bef-R = before Ramadan, 4 days before beginning the fast; Mid-R = middle of Ramadan, 15 days after beginning the fast; End-R = end of Ramadan, 30 days after beginning the fast; Post-R = after Ramadan, 21 days after the conclusion of the fast; CV = assay coefficient of variance; FAST = subjects training in a fasted state; FED = subjects training in a fed state; TG = triglycerides; TC = total cholesterol; HDL-C = high-density lipoprotein cholesterol; LDL-C = low-density lipoprotein cholesterol.

Significantly different from Bef-R: *$p < .05$; **$p < .01$; ***$p < .001$. Significantly different from FAST: #$p < .05$.

of runners (Chennaoui et al., 2009), judoists (Chaouachi et al., 2008), rugby players (Bouhlel et al., 2006), and soccer players (Aziz, Chia, Singh & Faizul Wahid, 2011), showing that sportsmen maintain training volume during Ramadan. In this context, it is worth remembering that all participants have participated in Ramadan since childhood, so they are very familiar with any associated physical stresses. In addition, training was prescribed and closely supervised, so we are confident that this indeed was the case. Furthermore, although the variation (*SD*) for training duration in each group is high (Table 2), the mean training duration is similar.

The significant decrease in BF% in FAST may be a result—at least in part—of the increased utilization of stored body fat. This has been previously reported (el Ati, Beji, & Danguir, 1995; Ramadan et al., 1999) and may be related to an increased ability to use lipids during exercise (Bouhlel et al., 2006; Stannard & Thompson, 2008). However, the lack of change in BF% in FED might simply reflect a Type 2 error, so use of a noninvasive method to measure changes in body fatness (e.g., DEXA) in future studies of Ramadan is warranted. Dehydration, as suggested by Bouhlel et al., could also be implicated in the decreased body weight of both groups.

Urine specific gravity of FAST increased during Ramadan, likely because of dehydration attributable to reduced fluid intake. In contrast, urine specific gravity in FED did not change, nor did total water intake. Our findings are dissonant with those of Shirreffs and Maughan (2008), which may be a result of differences in exercise regimen, climate, and fluid intake.

The increases in markers of renal function in FAST during Ramadan are most likely also caused by dehydration. Moreover, increased urea concentrations in FAST may be explained by increased protein breakdown after exercise sessions or decreased renal blood flow. Some investigators have also suggested that increased urea concentrations may be caused by exercise-induced energy expenditure and reduced energy intake (Degoutte et al., 2006). However, this suggestion can be excluded because energy intake remained unchanged during Ramadan compared with pre-Ramadan.

For FAST, dehydration likely led to the elevations of creatinine and creatinine clearance values during Ramadan, indicating that renal function was impaired during Ramadan. Similarly, uric acid increased in FAST during Ramadan. Our results are consistent with those of Chaouachi et al. (2008), who attributed increased uric acid levels to dehydration and increased protein breakdown.

Our finding that serum sodium concentrations increased in response to Ramadan fasting in FAST is contrary to the lack of change reported by other investigations (Maughan et al. 2008; Ramadan et al. 1999). Similarly, serum chloride concentrations increased only in FAST during Ramadan, which was likely a consequence of both dehydration and elevations in serum sodium (Anagnostopoulos, Edelman, Planelles, Teulon, & Thomas, 1984). Because of the dehydration and the elevations in serum sodium that occurred in FAST, one might expect that increases in serum potassium concentrations would also be observed, but this was not the case.

During this study, we used a combination of markers, and in addition to body mass to indicate hydration status, we used urinary and blood-based markers. The state of dehydration noted in FAST was absent in FED. This finding can be attributed to adequate fluid intake after break of fast and during training sessions.

HDL-C increased during Ramadan in both groups, a finding that was also observed in the study conducted by Chaouachi et al. (2008). However, mechanism(s) by which fasting increases HDL-C are not clear, although loss of weight may increase HDL-C (Al Hourani, Atoum, Akel, Hijjawi, & Awawdeh, 2009). LDL-C remained unchanged during Ramadan in FAST and FED. Our results do not agree with those of Chaouachi et al., which indicate an increase in LDL-C in elite judoists. We suggested an absence of change in the dietary saturated fat intake to explain our findings (Mattson & Grundy, 1985).

In conclusion, Ramadan fasting and aerobic exercise practiced in a fasted state can be combined effectively to reduce body weight and body fat, as well as improving lipid profiles. Body composition and hydration status, however, may be influenced by the timing of that training during Ramadan. Individuals engaging in aerobic exercise during Ramadan should drink plentiful amounts of fluid during the nighttime to compensate for the dehydration that occurs during daylight hours.

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