Timing of resistance training during Ramadan fasting and its effects on muscle strength and hypertrophy

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Running head: Timing and training during Ramadan.

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**Purpose:** During Ramadan month Muslims often continue training to maintain their muscle performance. However, trainers should stress the importance of the time of day chosen for practicing resistance training (RT) during the Ramadan fasting (RF) to avoid health and performance alteration. Thus, this study aimed to investigate the effects of the timing of resistance training (RT) while fasting during Ramadan intermittent fasting (RIF) on muscle strength and hypertrophy in healthy male adults.

**Methods:** Forty healthy Muslim males were randomly allocated to two matched groups: 20 practicing whole-body RT in the late afternoon in a fasted state (FAST) and 20 training in the late evening in a fed state (FED). Both groups performed 4 days/wk of whole-body RT (~75–85% 1RM, 12 repetitions/ 3-4 set) during RIF. Anthropometric measurements, a one-repetition maximum test for the squats (1RM_{SQ}), deadlift (1RM_{DL}), and bench press (1RM_{BP}) were measured. Cross-sectional area (CSA) of the quadriceps and biceps brachii were examined using ultrasound scans. All measurements were taken at four time points: 24 h before the start of Ramadan (T0), on the 15th day of Ramadan (T1), on the 29th day of Ramadan (T2) and 21 days after Ramadan (T3).

**Results:** Post-hoc tests indicated significant pre-to-post improvements in FED at T2 for 1RM_{SQ} (p = 0.02; ES= 0.21) and 1RM_{DL} (p = 0.03; ES=0.24) when compared to T0. No significant changes were observed in the FAST group and for CSA for both groups.

**Conclusions:** Practicing RT during RIF appears not to have adverse effects on muscle hypertrophy and strength no matter whether it is practiced in FED or FAST state. However, RT had greater effects on muscle strength when applied in FED state. Our findings suggest that training sessions should be scheduled after breaking the fast-during Ramadan.

**Keywords:** Fasting, Ramadan, Exercise training, strength, hypertrophy.
Introduction

Ramadan fasting is an Islamic religious obligation requiring healthy pubertal Muslim adolescents and adults to fast from dawn to sunset for approximately 28–30 consecutive days. This fasting involves abstaining from food, fluid intake, engaging in sexual activities and smoking for ~12–20 h/day, depending on the geographic location and season of the year.

Changes in mealtimes and the consumption of food and drink is unrestricted only during the hours of darkness. Caloric restriction during the Ramadan intermittent fasting (RIF) decreases total cholesterol, low-density lipoprotein (LDL), fasting blood glucose levels, and also improves body composition (e.g., lower body fat and higher lean body mass), possibly by mobilizing saturated fatty acids for metabolic processes. However, reductions in total energy and water intake, less daily meals (from 3–4 to 2 meals—a late evening meal and/or an early breakfast) and changes in diet composition can induce acute diurnal dehydration, impair sleep quality, reduce total protein synthesis, and create low energy availability. These changes in terms of food intake and sleep can impact on physiological and psychological functions and may specifically impose major challenges for Muslim athletes who continue training and competitions while fasting.

Abstaining from eating and drinking for many hours before and during exercise can decrease the availability and utilization of energetic substrates and also cause changes in hormonal and metabolic responses in parallel with dehydration. In addition, sleep deprivation and feelings of malaise, increases in fatigue and perceived efforts in response to the same training volume compared to the non-Ramadan period. Most athletes, experience RIF with a limited loss of physical performance during aerobic and anaerobic exercises.

Resistance training (RT) is an exercise modality commonly used to improve muscular fitness (i.e., muscle strength, power, local muscle endurance) as well as motor skill development in various types of sports including soccer and martial arts. It has further become an increasingly popular mode of physical exercise designed to improve body image and self-rated physical attractiveness by stimulating muscular fitness and muscle cross-sectional area (CSA). Studies of the combined effects of RIF and RT on body composition, muscle hypertrophy and physiological adaptation have produced contradictory findings. For example, while muscle strength and power increased significantly in soccer players after resistance training (8-repetitions × 4-sets with 4-min recovery in between) during Ramadan, an absence of changes in body mass and body
composition have been reported for bodybuilders. Moreover, body mass and physical performance declined in male Senegalese runners decreased after RT due to hypoglycemia associated with RIF.

These findings suggest that strength and conditioning specialists should choose an appropriate training period to minimize performance degradation and improve/maintain physical outcomes associated with RIF. Some investigators suggest training would be more beneficial after breaking fast (usually 2–3 h after sunset) to prevent dehydration, hypoglycemia and possible decreases in performance, while other studies suggest that training should take place while fasting to improve sleep quality and prevent hormonal disturbances that can alter performance and muscle growth.

Due to contrasting opinions on the timing of RT during RIF, we investigated the effects of RT on strength and muscle hypertrophy in both fasted (training before breaking fast) and fed states (training after breaking fast). We hypothesized that a) RT can be safely practiced during Ramadan in both fed and fasted states while maintaining muscle strength and hypertrophy, and b) there are larger increases in muscle strength and hypertrophy when training in the fed compared with the fasted state.

Materials and methods

Participants

Forty healthy Muslim recreational males weight lifters volunteered to participate in this study (age = 25.7±5.6 y, mass = 85.1±17.5 kg, height = 175.3±8.9 cm, body-mass-index [BMI]= 28.3±5.7 kg/m²) and were randomly allocated to two groups: 1) Fasted state group (FAST, n=20) practicing RT in the late afternoon 1 hour before breaking fast (between 16h and 18h), and 2) a fed state group (FED, n=20) practicing RT in the late evening after breaking the fast (between 20h and 22h). The study inclusion criteria were healthy males aged 18 to 35 years, two years of RT experience, free from any injuries that could impede or hinder the movements performed, no current or history of cardiometabolic disease, no consumption of supplements other than those provided during the study (see below), and self-reported as not having previously used anabolic steroids or related-ergogenic aids. The participants were required to refrain from other non-experimental RT sessions during the study. Participant who did not meet the inclusion criteria was excluded.
All participants were informed of the purpose of the study, the experimental procedures, possible discomforts, risks, and benefits of the participation and then signed a written informed consent to participate in the study. The investigation was performed according to the principles outlined in the Declaration of Helsinki and was approved by the local University Ethics Committee on Human Research of the University of la Manouba, Tunisia (Ethics Code: Tn, UM2019-73).

**Design**

Ramadan began on March 3rd and ended on April 3rd, 2021, with an average duration of the fast being ~ 14 h/d. The study was conducted in Tunisia, where daytime temperatures were 23±4°C and relative humidity was 65±5%. Two weeks before the start of Ramadan fasting, volunteers visited the laboratory on three days separated by intervals of 48–72h between visits.

**Visit 1:** Participants signed an informed consent form, answered the physical activity readiness questionnaire (PAR-Q) and the Pittsburgh Sleep Quality Index (PSQI), underwent anthropometric measurements and one repetition maximum (1RM) tests.

**Visit 2:** Participants repeated the 1RM tests to determine the loads to be used for the experimental conditions and to assess the reproducibility of the tests.

**Visit 3:** Ultrasound images were recorded to determine the CSAs of the quadriceps muscle and biceps brachii muscle.

After the baseline assessment (T0), all tests (anthropometrics, 1RM, CSAs, PSQI) were conducted on three separate test occasions: during the 2nd week of Ramadan (T1), during the 4th week of Ramadan (T2), and 21 days after the end of Ramadan (T3), with the same order and the same separated days as the previous pre-test procedures (Figure 1).

*<ADD FIG 1 NEAR HERE>*

**Training program**

All participants trained four days per week (Monday, Tuesday, Thursday, and Friday) for 8-weeks (one week before Ramadan, 4 weeks during Ramadan and 3 weeks after the end of Ramadan). Training involved full body RT exercises of 45 to 60 min per session. The exercise sessions of FAST occurred in the late afternoon during Ramadan (between 16h and 18h) and those for the FED occurred in the evening (between 20h and 22h) a 1–
2 hours after breaking the fast. All sessions started with a general warm-up and cool-down periods of 5–10 min of low-intensity aerobic and dynamic stretching exercises.

Five RT exercises were performed in each session, each consisting of four sets. Time under tension was 2 s in concentric mode and 2 s in eccentric mode at an intensity of 75–85% of the 1RM. Two minutes of rest were granted between sets and exercises. Each protocol was repeated twice weekly (Mondays/Thursdays: inclined leg press, parallel squat, deadlifts, calf raise and cable crunches, and Tuesdays/Fridays: bench press, shoulder press, lateral pull-down, barbell curl and obliques raises).

During the first session of each intervention week, 1RM tests were performed for all exercises to ensure a relative exercise intensity of 75–85% 1RM throughout the eight weeks of training. The 1RM test and the start of the training session was separated by a 10-minute rest interval.

Training protocols were started by performing 3 sets of 12 repetitions at 75% of the 1RM during the first week and progressed to 85% of the 1RM during week 6. This progressive overload was monitored by a trained researcher who supervised each workout session to ensure exercises were performed with the correct technique during the concentric and eccentric phases of the movement. The trained researcher also recorded the compliance and individual workout data during each training session so that exercise prescriptions were properly administered (e.g., number of repetitions and sets, rest, velocity of movement, intensity, respiration).

**Anthropometric measurements**

Body composition was assessed following an overnight fast (12 h) and >72 h following their last exercise bouts at T0, T1, T2 and T3. Body mass was measured to the nearest 10 g using a calibrated electronic scale (MEDISANA®, Neuss, Germany), body height was measured to the nearest 5 mm using a stadiometer. BMI was then calculated. In addition, four skinfolds (biceps, triceps, subscapular and suprailium) were measured with a calibrated Harpenden skinfold (Baty International, England) for the evaluation of body fat percentage using a previously published algorithm.\(^{35}\) Lean body mass (LBM) was calculated as body mass minus body fat mass. All measurements were performed by a single evaluator who was experienced in each of the procedures.

**Maximum strength tests**
Maximum strength (1-RM tests for parallel squat, bench press and deadlift) was performed at T0, T1, T2 and T3 and before the first weekly training session to maintain the relative intensity of each exercise. Participants completed 1RM testing using inclined leg press (Hammer Strength, China), Smith machine squat (Hammer Strength, China), standing calf raise machine (Hammer Strength, China), cable crunches (Hammer Strength, China), machine-guided shoulder press (Hammer Strength, China), pulldown machine (Hammer Strength, China), deadlifts, barbell bench press and barbell curl using a 20 kg Olympic barbell with free-weights.

Participants performed 10 repetitions without any extra load on the equipment as described by others.\textsuperscript{36,37} Values for 1RM were determined in a concentric mode with a maximum of 6 attempts, with 5-minutes rest periods between each attempt.\textsuperscript{37} In addition, a 3-minute rest period was allowed between tests of each exercise.

Pilot data were obtained on two test days from 40 participants to determine the reproducibility of the test. Our reliability data revealed the following ICCs at 95%: 1-RM parallel squat (0.929; lower 0.929-upper 0.996), 1-RM bench press (0.779; lower 0.581-upper 0.883), 1-RM deadlift (0.886; lower 0.783-upper 0.940), 1-RM CSA quadriceps (0.967; lower 0.938-upper 0.983) and 1-RM CSA biceps (0.782; lower 0.587-upper 0.885).

**Muscle cross-sectional areas (CSAs)**

Ultrasound images were recorded on four different occasions (before Ramadan (T0), on the 15\textsuperscript{th} day of Ramadan (T1), on the 29\textsuperscript{th} day of Ramadan (T2) and 21 days after the end of Ramadan) to analyze the CSA of the quadriceps and biceps brachii muscle. Ultrasound scans were performed using a brightness mode (B-mode) imaging device (Esaote, MyLab\textsuperscript{TM}X8, Florence, Italy) with a multifrequency linear-array probe (4-15 MHz, 60-mm width) using extended-field-of-view mode (EFVO).

CSA images of the quadriceps were taken using the EFOV mode.\textsuperscript{38} Volunteers remained lying in dorsal decubitus position on a stretcher for 15 minutes to allow fluid shifts to stabilize before images were obtained.\textsuperscript{39} A line from the greater trochanter to the outer femoral condyle was marked to measure the length of the femur. Four axial perpendicular lines were then marked, starting from the proximal extremity at intervals of 20\% (proximal), 40\% (proximal-middle), 60\% (distal-middle) and 80\% (distal) of the femur length using a tape measure and a pachymeter positioned parallel to the thigh.
Lines created with a microporous adhesive tape were then positioned 2 cm from each of the four axial perpendicular points to delineate the location for positioning of the ultrasound probe during image acquisition (Figure 2B). It is important to note that CSA measured at a single point on a muscle’s length may not adequately represent the entire extent of muscle hypertrophy, thus, CSA analysis using several points provide a more accurate depiction of muscle hypertrophy.  

The probe was placed transversely on the marked lines across the thigh to allow for a continuous single view, while the mediolateral angle of the probe was changed throughout the experiment so that the probe remained perpendicular to the skin (Figure 2C). This procedure was performed at constant speed and lasted approximately 4 s in distal regions to approximately 5 s in proximal regions according to the thigh circumference of the participants.

A water-based gel was applied between the skin and the transducer to achieve acoustic coupling and avoid any misinterpretation of the images created by the increased pressure when applying the transducer. Participants were asked to remain relaxed during the ultrasound procedures. The panoramic images of the four sites that were created by the moving transducer were digitally stored (Figure 3). Images were analyzed for muscle thickness, fascicle angle, and fascicle length by using specific software (MyLab™Desk, Esaote, Italy).
The sum of 4 images of the CSAs were taken at 20, 40, 60, and 80% of femur length on the test day and used to generate a single CSA value per muscle, which was then used for determining the thickness of the rectus femoris and vastus lateralis muscles.

The CSA of the biceps brachii was also measured by the EFOV technique with the same device and on the same testing day when images of the quadriceps (T0, T1, T2 and T3) were obtained. Each individual was seated in a comfortable position with arms resting at 90° shoulder flexion angle, and 0° elbow flexion (i.e., straight arm). A line from the acromion process of the clavicle to the lateral epicondyle of the humerus was marked to measure the length of the upper arm. Two axial perpendicular lines were marked (mid-point of the upper arm: 0 cm, 3 cm below the mid-point: 3 cm) as these two regions provide the largest biceps brachii CSA that generally lies between the two perpendicular markings.

EFOV scans were obtained by moving the probe along the two marked lines axially from the medial aspect to the lateral aspect of the upper arm in a continuous single view. Pressure was applied minimally but consistently, avoiding compression of the muscle, with transmission gel applied between the skin and the transducer to aid in acoustic coupling. Images of the biceps brachii taken from each region were traced to calculate CSA using a computer software program (MyLab™Desk, Esaote, Italy).

The sum of the two CSAs taken at mid-point of the upper arm was calculated on each testing day at the mid-point of the upper arm: 0 cm, 3 cm below the mid-point: 3 cm to generate a single CSA value per muscle, which was then used for data analysis of the biceps brachii muscle thickness.

**Dietary habits**

Participants were advised to maintain instructed nutritional regimen by a specialist and to avoid taking any supplements other than those provided during the study (see below). Dietary adherence was assessed by self-reported food records and analyzed using a nutritional tracking application ([http://www.myfitnesspal.com](http://www.myfitnesspal.com)) and the food-composition tables of the National Institute of Statistics of Tunis (1978). All food and beverages consumed during the experiment were collected for at least four days a week to offer a reliable estimate of food intake for the entire week. Total water intake was defined as the fluid volume of consumed beverages plus the water content of consumed foods.
Individuals were instructed on the correct recording procedures of all food items, including portion sizes. Each item of food was individually entered into the software program to determine total energy consumption, and amount of energy derived from proteins, fats, and carbohydrates for each period analyzed. The mean of nutrient consumed during the intervention was calculated. Participants consumed a supplement containing 24 g protein and 1 g carbohydrate before sleeping (Iso100 Hydrolyzed Whey Protein Isolate; Dymatize Nutrition, Dallas, TX) on training days under the supervision of the research staff. The nutrients consumed by participants during the study is shown in Table 1, no significant differences between groups and during the experiment were found.

<INSERT TABLE 1 NEAR HERE>

Rating of perceived exertion (RPE)

The Borg scale was used to evaluate the rating of perceived exertion (RPE) during the exercise sessions at 5 min after the end of the training session at T0, T1, T2 and T3. Volunteers were advised to look at the scale and respond immediately after the end of each session to the following prompt: “Think about your feeling of body effort, how did you feel?” and entered numbers on a sliding scale, where perceived efforts were rated between 0 for "extremely easy" and 10 for "extremely difficult.

Sleep quality

Sleep quality during and after three weeks of Ramadan was assessed using the full Pittsburgh Sleep Quality Index (PSQI) before Ramadan (T0), on the 15th day of Ramadan (T1), on the 29th day of Ramadan (T2) and 21 days after the end of Ramadan. We used an Arabic validated version of the PSQI. The global PSQI score is composed of 7 components: subjective sleep quality (sleep quality perception), sleep latency (time between lying on bed and start sleeping), sleep duration (period sleeping reported by subject), habitual sleep efficiency (ratio between time sleeping and time on bed), sleep disturbance (problems to sleep elected by subjects), sleeping medication (use of medication to sleep), and daytime dysfunction (intensity of diurnal somnolence). The 7 domains are each scored from 0 (no difficulty for the component of interest) to 3 (very bad), with a total or global score ranging from 0-21 that reflects sleep quality and
disturbances over a 1-month period. A better sleeper would have a lower global PSQI score, while higher score indicates poor sleep quality.

**Statistical analyses**

The statistical analyses were conducted using the SPSS program version 16.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics are presented as means ± standard deviations (M ± SD). Normal distribution of data was confirmed using the Shapiro–Wilk test. The effects of training times during Ramadan intermittent fasting were evaluated using a mixed model of ANOVA with 2 (groups: FAST, FED) × 4 (time: T0, T1, T2, T3). If a statistically significant interaction or main effect was found, Bonferroni corrected post-hoc tests were calculated to identify specific differences.

Effect sizes (ES) were determined from the output of ANOVA by converting partial eta-squared to Cohen’s d. In addition, within-group ES were computed using the following equation: ES = (mean post—mean pre)/SD. ES were considered trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0) and very large (2.0-4.0). All statistical analyses were computed at p< 0.05.

**Results**

All participants received treatments as allocated. Adherence to exercise was 100 % for all participants. No training or test-related injuries were recorded. No significant between-group differences were observed for any anthropometric measures, muscle CSA and muscle strength measures at baseline (T0). Dietary intake, RPE values and sleep quality in the FED and FAST groups were recorded at T0, T1, T2, and T3 and are summarized in Table 2. The changes in ES ranged from small-to-moderate for all measurements.

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<INSERT TABLE 2 NEAR HERE>
percentage. Both FAST and FED groups experienced significant decreases in body mass
(p = 0.001; ES = 0.44), BMI (p = 0.001; ES = 0.67) and body fat percentage (p = 0.001;
ES = 0.91) during Ramadan, with no changes in lean body mass in either group (p >
0.05).

Hypertrophy and maximal strength

Group × time interactions are reported in Table 3 for measures of CSA and maximal
strength. There were significant group × time interactions for 1RM_{SQ} (p = 0.001; ES =
0.21) and 1RM_{DL} (p = 0.04; ES = 0.10) in favor of the FED group. Post-hoc tests revealed
significant increases in 1RM_{SQ} and 1RM_{DL} at T2 compared to T0 (p < 0.05) and at T3
compared to T0 and T1 (p < 0.05) for FED. No significant group × time effects were
recorded for 1 RM_{BP}, CSA_{QC}, and CSA_{BB} (p > 0.05).

Rating of perceived exertion (RPE)

The RPE among FAST and FED groups at T0, T1, T2 and T3 is summarized in Figure
4, significant group × time differences between groups for RPE were reported at T1 (p =
0.02; ES = 0.48) and T2 (p = 0.03; ES = 0.37). A significant main effect of time was
observed among FAST group with increasing at T1 and T2, while RPE remained
unchanged at all time points in the FED state group.

The Pittsburgh Sleep Quality Index

Data of the Pittsburgh Sleep Quality Index (mean ± SD) among FAST and FED groups
at T0, T1, T2 and T3 are reported in (Table 4).
There was significant group × time interactions for total score of PSQI, a significant main effect of time was observed among both groups with decreasing of global PSQI at T1 (p < 0.05, d = 6.54) and at T2 (p < 0.05, ES = 6.54) compared to T0; and increasing of the total score for the PSQI during the two weeks after RIF. No significant differences between FAST and FED groups were found on any component.

Discussion

This study evaluated the effects of performing RT during Ramadan month on strength and hypertrophy in male athletes with previous RT experience, and also compared the effects of practicing RT during RIF while still fasting (training before breaking fast) with RT in a non-fasting state (training after breaking fast). Our findings indicate that our first hypothesize was confirmed, practicing RT during RIF has no negative effects on muscular performance in either group. However, our results did not support the second hypothesize. Thus, training in a fed state positively affects only maximal strength with no significant development of muscle circumferences compared to the same total training volume while still fasting. Our findings regarding the lack of muscle hypertrophy in fasted state have to be confirmed in future studies using more sophisticated measuring techniques (e.g., magnetic resonance imaging). Our findings regarding the lack of muscle hypertrophy in fasted state have to be confirmed in future studies using more sophisticated measuring techniques (e.g., magnetic resonance imaging).

We studied the effects of RT in two well controlled groups (FAST and FED) that: a) had the same training conditions and total volume training before and during Ramadan; b) consumed no medications anabolic steroids, or ergogenic aids either before or during Ramadan; c) maintained the same nutritional regimen with no significant effects on total energy and nutritional intake; d) had reduced sleep schedule that was delayed only slightly (average ~1 hr) but with no significant differences between groups.

Muscle hypertrophy

There were neither adverse or beneficial effects of the combination RT and RIF on biceps and quadriceps muscle hypertrophy in the two study groups, and as also reported in previous studies on the effects of RT during other IF protocols. In fact, Moro et al. 2016 studied 34 males who performed RT for 8 weeks (3 resistance sessions/week, 6–8 repetitions at 85–90% of 1 RM) with restrictive feeding (16h fasting/8h fed, 3
days/week) and reported no significant changes in CSA for muscles of the arms and thighs.\textsuperscript{49} However, other studies reported increases in muscle hypertrophy in males following RT in a time restrictive feeding program.\textsuperscript{50,52} The discrepancy between our findings and the latter reports is likely related to conditions of fasting: we studied the effects of food and water deprivation for the entire month of Ramadan IF while the latter studies involved only 3 days/week of time restrictive feeding.\textsuperscript{50,52} The continuous and prolonged fasting period during Ramadan decreases daily energy intake due to the reduction of meal frequency\textsuperscript{33} which could hinder gains in muscle mass.

However, in this study, we found no significant differences in total energy and protein intake in the two study groups during the experiment, thus, the lack of muscle mass gain here may possibly be explained due to the changing of protein and glucose oxidation during RIF glycogen depletion in the liver. Muscle proteins (and not glucose) were used for the metabolism to sustain energy used by the other organs (heart, brain..) during starvation\textsuperscript{53,55}. Additionally, cumulative dehydration during fasting can also negatively impact muscle growth, as decreases in fluid consumption can alter serum concentrations of proteins and hormones associated with muscle protein synthesis.\textsuperscript{56}

Muscle strength

An important finding of our study is that there was no significant effect of RIF on (1RM\textsubscript{BP}) in either the FAST or FED study groups. However, there were slight improvements for (1RM\textsubscript{DL}) and (1RM\textsubscript{sq}) in the FED group, with no adverse changes in the FAST group. These findings suggest that practicing RT during Ramadan can sustain or improve strength capacity whether it be practiced before or after breaking the fast, which is consistent with other reports indicating no adverse impacts of RIF on (1RM\textsubscript{BP}).\textsuperscript{57} Furthermore,\textsuperscript{29} observed a slight improvements in muscle strength capacity during RIF. The authors attributed this unchanged performance despite fasting to a constant total training volume and nutrient intake during RIF, as was the case for our study.

However, the improvement was observed just for FED group with increases in (1RM\textsubscript{DL}) and(1RM\textsubscript{sq}). Choosing the optimal training conditions, including timing of training, during Ramadan is of great interest to Muslim athletes. Several changes in physiological and psychological parameters during the daytime can impact exercise, including maximal strength performance. For example, the optimal time of day to
conduc an acute high-intensity exercise session during Ramadan is after breaking the fast, as performance is negatively impacted in a fasting state (morning and evening sessions). 

These findings may due to exercise sessions at 21:00 h were performed under favorable circumstances that were similar to those before Ramadan where athletes were able to consume food and liquids before exercise sessions, allowing pre-exercise blood glucose concentration levels and fluid to be within the normal range, whereas training at 18:00 h is not advisable as athletes have not consumed food and fluid for >10 h and experience higher levels of fatigue ([1]. Another explanation for the improvement only among FED, that they reached the fatigue sensation more later in comparison with the FAST group. In fact, in our study, RPE levels, recorded post same exercise, were greater in fasting participants compared to the subjects in the fed state, indicating that exercising while fasting may amplify the sensation of physical effort and fatigue independently of the physiological capacity of the muscles for the same training load.

**Study limitations**

Our measurements were conducted on two different day-time points (in the late afternoon, just before breaking fast and in the evening, after breaking the fast). Future studies should include additionally time points, such as a third time point in the morning to investigate the effects of training shortly after consuming the pre-dawn meal of *suhur*.

Additionally, this study was conducted only with young males. Therefore, the observed findings cannot be translated to females. Future studies should examine this research question in female athletes as more women are now engaging in sports and exercise training.

**Practical applications**

Muslim recreational weightlifters try to maintain their physical appearance during Ramadan despite the physiological and psychological challenges that occur during this month of daily fasting. Fitness instructors and personal trainers may need to implement strategies to prevent the negative effects of fasting on muscle hypertrophy and strength. Our findings suggest that it is feasible to maintain and increase maximal strength but not muscle circumferences when exercise is performed in the evenings during the fed state.
It is possible that the effects we observed may be even more pronounced in geographical areas where the fasting times are even longer (and conversely, less important in areas where duration of fasting is shorter). In addition, some non-Muslim weightlifters followed an intermittent fasting protocol as a nutritional method for muscle toning, however, trainers practicing RT should stress the importance of adopting an appropriate nutritional protocol to reach training goals.

**Conclusion**

Ramadan fasting and maintaining RT induces favorable changes in body composition (loss of fat, maintain lean tissue) without disturbing total energy and fluid intake. Furthermore, maintaining RT volume during RIF have no negative effect on strength and hypertrophy. Additionally, practicing after breaking fast leads to significant improvement on maximal strength. Thus, choosing the adequate time of training, practicing nutritional strategies and maintaining the same training volume during Ramadan, allows fasting recreational athletes to sustain and improve muscle performance.

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Table 1. Estimated daily dietary intake recorded (mean ± SD) of the FAST and FED state groups measured during 1 week before the start of Ramadan (T0), on the 15th day of Ramadan (T1), the day after the end of Ramadan (T2) and 21 days after the end of Ramadan (T3) (n=20 per group).

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<tr>
<td>FAST</td>
<td>18 ± 8</td>
<td>19 ± 1</td>
<td>18 ± 7</td>
<td>18 ± 7</td>
<td>0.08 (0.37)</td>
<td>0.06 (0.45)</td>
<td>0.1 (0.57)</td>
</tr>
<tr>
<td>FED</td>
<td>18 ± 6</td>
<td>18 ± 2</td>
<td>18 ± 9</td>
<td>18 ± 6</td>
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<tr>
<td><strong>Carbohydrate (%) kcal</strong></td>
<td></td>
<td></td>
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<td></td>
<td>0.1 (0.46)</td>
<td>0.08 (0.54)</td>
<td>0.07 (0.55)</td>
</tr>
<tr>
<td>FAST</td>
<td>47 ± 5</td>
<td>45 ± 8</td>
<td>46 ± 3</td>
<td>47 ± 1</td>
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<tr>
<td>FED</td>
<td>47 ± 3</td>
<td>46 ± 5</td>
<td>45 ± 9</td>
<td>46 ± 7</td>
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<tr>
<td><strong>Fat (%) kcal</strong></td>
<td></td>
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<td></td>
<td></td>
<td>0.09 (0.45)</td>
<td>0.08 (0.38)</td>
<td>0.08 (0.58)</td>
</tr>
<tr>
<td>FAST</td>
<td>35 ± 8</td>
<td>36 ± 5</td>
<td>36 ± 4</td>
<td>35 ± 7</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>FED</td>
<td>35 ± 9</td>
<td>36 ± 3</td>
<td>37 ± 2</td>
<td>36 ± 4</td>
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<tr>
<td><strong>Energy (kcal/day)</strong></td>
<td></td>
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<td></td>
<td>0.2 (0.37)</td>
<td>0.08 (0.45)</td>
<td>0.09 (0.51)</td>
</tr>
<tr>
<td>FAST</td>
<td>3472 ± 245</td>
<td>3436 ± 249</td>
<td>3425 ± 283</td>
<td>3482 ± 275</td>
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<td></td>
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<tr>
<td>FED</td>
<td>3496 ± 368</td>
<td>3432 ± 237</td>
<td>3465 ± 232</td>
<td>3472 ± 254</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Total water intake (L/day)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.06 (0.57)</td>
<td>0.08 (0.35)</td>
<td>0.2 (0.41)</td>
</tr>
<tr>
<td>FAST</td>
<td>4.3 ± 0.5</td>
<td>4.1 ± 0.4</td>
<td>4.2 ± 0.3</td>
<td>4.1 ± 0.7</td>
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</tr>
<tr>
<td>FED</td>
<td>4.2 ± 0.4</td>
<td>4.3 ± 0.6</td>
<td>4.2 ± 0.3</td>
<td>4.1 ± 0.4</td>
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</tbody>
</table>
Table 2. Anthropometric and body composition characteristics (means ± SD) of the FAST and FED state groups measured during 1 week before the start of Ramadan (T0), on the 15th day of Ramadan (T1), the day after the end of Ramadan (T2) and 21 days after the end of Ramadan (T3) (n=20 per group).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group</th>
<th>Phases</th>
<th>T0</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>Time</th>
<th>Group</th>
<th>Group x Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>fast</td>
<td>fast</td>
<td>fast</td>
<td>fast</td>
<td>0.001</td>
<td>0.54</td>
<td>0.09</td>
</tr>
<tr>
<td>Body mass</td>
<td></td>
<td>kg</td>
<td>79.12±3.71</td>
<td>76.06±3.25*</td>
<td>74.19±3.20*#</td>
<td>77.64±4.52$</td>
<td>0.44</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>fed</td>
<td>kg</td>
<td>80.05±3.34</td>
<td>79.08±2.86*</td>
<td>76.23±3.03*</td>
<td>78.04±3.52 $</td>
<td>0.67</td>
<td>0.03</td>
<td>0.14</td>
</tr>
<tr>
<td>BMI</td>
<td></td>
<td>kg/m²</td>
<td>24.26±1.72</td>
<td>23.6±1.45*</td>
<td>22.35±1.34#</td>
<td>23.91±1.19$</td>
<td>0.89</td>
<td>0.58</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>fed</td>
<td>kg/m²</td>
<td>24.72±1.03</td>
<td>24.24±1.26</td>
<td>23.31±1.50*</td>
<td>24.01±1.61$</td>
<td>0.91</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td>Body fat</td>
<td></td>
<td>%</td>
<td>16.66±1.25</td>
<td>15.31±1.60*</td>
<td>13.53±1.55#</td>
<td>14.84±1.41$</td>
<td>0.31</td>
<td>0.10</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>fed</td>
<td>%</td>
<td>16.20±0.57</td>
<td>15.31±1.59*</td>
<td>13.82±1.65#</td>
<td>14.93±1.47$</td>
<td>0.31</td>
<td>0.06</td>
<td>0.01</td>
</tr>
<tr>
<td>LBM</td>
<td></td>
<td>kg</td>
<td>66.78±2.94</td>
<td>65.84±2.92</td>
<td>64.78±2.86</td>
<td>65.70±3.39</td>
<td>0.31</td>
<td>0.10</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>fed</td>
<td>kg</td>
<td>67.24±1.88</td>
<td>66.72±2.45</td>
<td>66.57±2.59</td>
<td>66.98±2.91</td>
<td>0.31</td>
<td>0.06</td>
<td>0.01</td>
</tr>
</tbody>
</table>

BMI: body mass index; LBM: lean body mass; *: p<0.05 compared to T0; #: p<0.05 compared to T1; $: p<0.05 compared to T2.
Table 3: Maximal strength (1RM) and hypertrophy changes (means ± SD) of the FAST and FED state groups measured during 1 week before the start of Ramadan (T0), on the 15th day of Ramadan (T1), the day after the end of Ramadan (T2) and 21 days after the end of Ramadan (T3) (n=20 per group).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group</th>
<th>Phases</th>
<th>T0</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>Time</th>
<th>Group</th>
<th>Group x Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM SQ</td>
<td>FAST</td>
<td>168.75±13.13</td>
<td>169.50±11.85</td>
<td>168.45±11.54</td>
<td>172.25±11.55*#</td>
<td>0.001 (0.60)</td>
<td>0.04 (0.12)</td>
<td>0.001 (0.21)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FED</td>
<td>169.65±12.09</td>
<td>170.78±11.15</td>
<td>174.23±12.08*</td>
<td>177.10±12.69*#</td>
<td></td>
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</tr>
<tr>
<td>1RM BP</td>
<td>FAST</td>
<td>106.01±9.50</td>
<td>110.40±10.54</td>
<td>109.25±10.33</td>
<td>120.10±10.09*</td>
<td>0.001 (0.68)</td>
<td>0.63 (0.006)</td>
<td>0.38 (0.08)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FED</td>
<td>105.50±10.60</td>
<td>107.35±10.15</td>
<td>109.50±10.55</td>
<td>116.75±10.58*</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1RM DL (%)</td>
<td>FAST</td>
<td>186.25±8.13</td>
<td>186.80±8.88</td>
<td>187.81±9.38</td>
<td>190.25±9.88*#</td>
<td>0.001 (0.29)</td>
<td>0.003 (0.12)</td>
<td>0.04 (0.10)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FED</td>
<td>187.50±8.50</td>
<td>190.85±8.44</td>
<td>195.40±9.10*</td>
<td>199.65±8.39*#</td>
<td></td>
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</tr>
<tr>
<td>CSA QC (cm²)</td>
<td>FAST</td>
<td>69.95±7.14</td>
<td>68.90±6.98</td>
<td>68.15±6.58</td>
<td>71.15±6.27$</td>
<td>0.94 (0.01)</td>
<td>0.18 (0.12)</td>
<td>0.27 (0.03)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FED</td>
<td>70.60±6.20</td>
<td>71.90±6.80</td>
<td>72.80±6.70</td>
<td>76.45±6.64*</td>
<td></td>
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</tr>
<tr>
<td>CSA BB (cm²)</td>
<td>FAST</td>
<td>20.50±2.10</td>
<td>21.20±2.42</td>
<td>20.65±2.45</td>
<td>22.65±2.69*$#</td>
<td>0.001 (0.13)</td>
<td>0.88 (0.42)</td>
<td>0.29 (0.32)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FED</td>
<td>20.90±2.02</td>
<td>20.45±2.41</td>
<td>20.91±2.46</td>
<td>22.15±2.35#</td>
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</tr>
</tbody>
</table>

1RM: one-repetition maximum; CSA: cross section area; SQ: squat; BP: bench press; DL: deadlift; QC: quadriceps; BB: biceps brachii; *: p< 0.05 compared to T0; #: p<0.05 compared to T1; $: p<0.05 compared to T2.
Table 4. Sleep quality recorded (mean ± SD) of the FAST and FED state groups measured during 1 week before the start of Ramadan (T0), on the 15th day of Ramadan (T1), the day after the end of Ramadan (T2) and 21 days after the end of Ramadan (T3) (n=20 per group).

<table>
<thead>
<tr>
<th></th>
<th>T0</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>Time</th>
<th>Group</th>
<th>Group x Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sleep Quality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAST</td>
<td>1.2 ± 0.5</td>
<td>2.4 ± 0.8*</td>
<td>2.2 ± 0.7*</td>
<td>1.3 ± 0.7#$</td>
<td>0.007 (0.48)</td>
<td>0.06 (0.65)</td>
<td>0.1 (0.56)</td>
</tr>
<tr>
<td>FED</td>
<td>1.3 ± 0.7</td>
<td>2.4 ± 0.7*</td>
<td>2.3 ± 0.5*</td>
<td>1.4 ± 0.6#$</td>
<td></td>
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<tr>
<td><strong>Sleep Latency (min)</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>FAST</td>
<td>17.2 ± 5.4</td>
<td>17.3 ± 4.7</td>
<td>16.9 ± 8.4</td>
<td>16.8 ± 6.4</td>
<td>0.06 (0.58)</td>
<td>0.07 (0.47)</td>
<td>0.2 (0.56)</td>
</tr>
<tr>
<td>FED</td>
<td>16.9 ± 6.1</td>
<td>17.5 ± 6.3</td>
<td>17.1 ± 7.2</td>
<td>17.1 ± 5.8</td>
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<tr>
<td><strong>Sleep Duration (h)</strong></td>
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</tr>
<tr>
<td>FAST</td>
<td>7.9 ± 1.1</td>
<td>6.3 ± 1.1*</td>
<td>6.7 ± 1.2#</td>
<td>7.8 ± 1.2#$</td>
<td>0.002 (0.69)</td>
<td>0.2 (0.65)</td>
<td>0.06 (0.58)</td>
</tr>
<tr>
<td>FED</td>
<td>8.1 ± 0.5</td>
<td>6.1 ± 1.3*</td>
<td>6.6 ± 1.5#</td>
<td>7.8 ± 1.5#$</td>
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<tr>
<td><strong>Sleep Efficiency (%)</strong></td>
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</tr>
<tr>
<td>FAST</td>
<td>98.4 ± 3.5</td>
<td>95.3 ± 8.2*</td>
<td>95.2 ± 7.2*</td>
<td>96.8 ± 6.5#$</td>
<td>0.005 (0.65)</td>
<td>0.07 (0.37)</td>
<td>0.1 (0.47)</td>
</tr>
<tr>
<td>FED</td>
<td>97.7 ± 4.1</td>
<td>94.8 ± 6.7*</td>
<td>95.1 ± 6.8*</td>
<td>97.1 ± 7.1#$</td>
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<tr>
<td><strong>Sleep Disturbance</strong></td>
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</tr>
<tr>
<td>FAST</td>
<td>0.7 ± 0.5</td>
<td>0.7 ± 0.2</td>
<td>0.6 ± 0.5</td>
<td>0.6 ± 0.5</td>
<td>0.07 (0.45)</td>
<td>0.08 (0.45)</td>
<td>0.07 (0.55)</td>
</tr>
<tr>
<td>FED</td>
<td>0.6 ± 0.3</td>
<td>0.7 ± 0.5</td>
<td>0.6 ± 0.4</td>
<td>0.6 ± 0.4</td>
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<tr>
<td><strong>Daytime Dysfunction</strong></td>
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<tr>
<td>FAST</td>
<td>0.4 ± 0.3</td>
<td>0.4 ± 0.6</td>
<td>0.4 ± 0.8</td>
<td>0.5 ± 0.5</td>
<td>0.07 (0.38)</td>
<td>0.2 (0.38)</td>
<td>0.1 (0.56)</td>
</tr>
<tr>
<td>FED</td>
<td>0.5 ± 0.6</td>
<td>0.4 ± 0.7</td>
<td>0.5 ± 0.6</td>
<td>0.4 ± 0.3</td>
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<tr>
<td><strong>Total Score of PSQI</strong></td>
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<tr>
<td>FAST</td>
<td>3.4 ± 2.7</td>
<td>7.2 ± 2.3*</td>
<td>7.5 ± 2.1*</td>
<td>3.9 ± 2.7#$</td>
<td>0.003 (0.47)</td>
<td>0.06 (0.43)</td>
<td>0.08 (0.39)</td>
</tr>
<tr>
<td>FED</td>
<td>3.8 ± 2.3</td>
<td>7.7 ± 2.1*</td>
<td>7.3 ± 2.6*</td>
<td>4.1 ± 2.1#$</td>
<td></td>
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</tr>
</tbody>
</table>

PSQI: Pittsburgh Sleep Quality Index; *: p< 0.05 compared to T0; #: p< 0.05 compared to T1; $: p<0.05 compared to T2.
Figure 1. Study design

-FAST (n=20)
  - Resistance training
    - Between 16th and 18th
    - 3-4 sets *75-85% 1RM
    - 12 Repetitions
    - R=2min

-FED (n=20)
  - Resistance training
    - Between 20th and 22th

Ramadan Fasting month

Baseline measurements
  - (1 week before Ramadan)
[T0]

Visit 1
  - T1: VO2max, DEXA scan
  - T2: VO2max, CSA
  - T3: VO2max, CSA

Visit 2
  - CSA

Visit 3
  - CSA

Resistance training intervention

6-wk of full body resistance training program from 45 to 60 min per session.
- [Monday/Thursday]: inclined leg press, parallel squat, deadlifts, calf raise and Cable Crunches.
- [Tuesday/Friday]: bench press, shoulder press, lateral pull-down, barbell curl and obliques raises.
**Figure 2.** Thigh marking procedures (A and B) and ultrasound images acquisition (C).

**Figure 3.** Ultrasound images and cross-sectional areas (CSAs) of quadriceps at 20% proximal (A), 40% (B), 60% (C), and 80% (D) of femur length. RF: rectus femoris; VI: vastus intermedius; VL: vastus lateralis; VM: vastus medialis.
Figure 4. Rating of perceived effort (RPE) among FAST and FED state group. 
*: P< 0.05 significant differences between groups.