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## Timing of Resistance Training During Ramadan Fasting and Its Effects on Muscle Strength and Hypertrophy

Raoua Triki, Hassane Zouhal, Hamdi Chtourou, Iyed Salhi, Nidhal Jebabli, Ayoub Saeidi, Ismail Laher, Anthony C. Hackney, Urs Granacher, Abderraouf Ben Abderrahman

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

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4           **R. Triki**<sup>1</sup>, **H. Zouhal**<sup>2,3</sup>, **H. Chtourou**<sup>4,5</sup>, **I. Salhi**<sup>1</sup>, **N. Jebabli**<sup>1</sup>, **A.**  
5           **Saeidi**<sup>6</sup>, **I. Laher**<sup>7</sup>, **AC. Hackney**<sup>8</sup>, **U. Granacher**<sup>9\*</sup>, and **A. Ben**  
6           **Abderrahman**<sup>1\*</sup>

7           <sup>1</sup> Higher Institute of Sport and Physical Education of Ksar-Said, University of Manouba,  
8           Tunisia.

9           <sup>2</sup> Movement, Sport, Health and Sciences laboratory (M2S). UFR APS, University of  
10           Rennes 2-ENS Cachan, Av. Charles Tillon, 35044 Rennes Cedex, France.

11           <sup>3</sup> Institut International des Sciences du Sport (I2S), 35850 Irodoeur, France.

12           <sup>4</sup> High Institute of Sport and Physical Education of Sfax, University of Sfax, Tunisia

13           <sup>5</sup> Research Unit, Physical Activity, Sport, and Health (UR18JS01), National  
14           Observatory of Sport, Tunis, Tunisia.

15           <sup>6</sup> Department of Physical Education and Sport Sciences, Faculty of Humanities and  
16           Social Sciences, University of Kurdistan, Sanandaj, Kurdistan, Iran.

17           <sup>7</sup> Department of Anesthesiology, Pharmacology, and Therapeutics, Faculty of Medicine,  
18           University of British Columbia, Vancouver, Canada.

19           <sup>8</sup> Department of Exercise & Sport Science, University of North Carolina, Chapel Hill,  
20           NC, USA.

21           <sup>9</sup> Division of Training and Movement Sciences, University of Potsdam, Potsdam,  
22           Germany.

23           **\*: Last authors.**

24           **Corresponding authors:**

25           **R. Triki** [raouatriki1995@gmail.com](mailto:raouatriki1995@gmail.com)

26           **Prof. H. Zouhal**       [hassane.zouhal@univ-rennes2.fr](mailto:hassane.zouhal@univ-rennes2.fr)

27           **Prof. U. Granacher**   [urs.granacher@uni-potsdam.de](mailto:urs.granacher@uni-potsdam.de)

28           <https://orcid.org/0000-0002-7095-813X>

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

42 **Methods:** Forty healthy Muslim males were randomly allocated to two matched  
43 groups: 20 practicing whole-body RT in the late afternoon in a fasted state (FAST) and  
44 20 training in the late evening in a fed state (FED). Both groups performed 4 days/wk  
45 of whole-body RT (~75–85% 1RM, 12 repetitions/ 3-4 set) during RIF.

46 Anthropometric measurements, a one-repetition maximum test for the squats ( $1RM_{SQ}$ ),  
47 deadlift ( $1RM_{DL}$ ), and bench press ( $1RM_{BP}$ ) were measured. Cross-sectional area  
48 (CSA) of the quadriceps and biceps brachii were examined using ultrasound scans. All  
49 measurements were taken at four time points: 24 h before the start of Ramadan (T0),  
50 on the 15th day of Ramadan (T1), on the 29<sup>th</sup> day of Ramadan (T2) and 21 days after  
51 Ramadan (T3).

52 **Results:** Post-hoc tests indicated significant pre-to-post improvements in FED at T2 for  
53  $1RM_{SQ}$  ( $p = 0.02$ ;  $ES = 0.21$ ) and  $1RM_{DL}$  ( $p = 0.03$ ;  $ES = 0.24$ ) when compared to T0. No  
54 significant changes were observed in the FAST group and for CSA for both groups.

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

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

61

## 62 **Introduction**

63 Ramadan fasting is an Islamic religious obligation requiring healthy pubertal  
64 Muslim adolescents and adults to fast from dawn to sunset for approximately 28–30  
65 consecutive days<sup>1</sup>. This fasting involves abstaining from food, fluid intake, engaging in  
66 sexual activities and smoking for ~12–20 h/day, depending on the geographic location  
67 and season of the year<sup>2</sup>.

68 Changes in mealtimes and the consumption of food and drink is unrestricted only  
69 during the hours of darkness<sup>3</sup>. Caloric restriction during the Ramadan intermittent fasting  
70 (RIF) decreases total cholesterol, low-density lipoprotein (LDL), fasting blood glucose  
71 levels<sup>4</sup>, and also improves body composition (e.g., lower body fat and higher lean body  
72 mass)<sup>5</sup>, possibly by mobilizing saturated fatty acids for metabolic processes.<sup>7</sup> However,  
73 reductions in total energy and water intake, less daily meals (from 3–4 to 2 meals--a late  
74 evening meal and/or an early breakfast) and changes in diet composition can induce  
75 acute diurnal dehydration<sup>8</sup>, impair sleep quality<sup>9,10</sup>, reduce total protein synthesis<sup>11</sup>, and  
76 create low energy availability.<sup>12</sup> These changes in terms of food intake and sleep can  
77 impact on physiological and psychological functions and may specifically impose major  
78 challenges for Muslim athletes who continue training and competitions while fasting<sup>3</sup>.

79 Abstaining from eating and drinking for many hours before and during exercise  
80 can decrease the availability and utilization of energetic substrates and also cause  
81 changes in hormonal and metabolic responses in parallel with dehydration.<sup>13,14</sup> In  
82 addition, sleep deprivation and feelings of malaise, increases in fatigue and perceived  
83 efforts in response to the same training volume compared to the non-Ramadan  
84 period.<sup>15,16</sup> Most athletes, experience RIF with a limited loss of physical performance  
85 during aerobic<sup>17,18</sup> and anaerobic exercises.<sup>19,20</sup>

86 Resistance training (RT) is an exercise modality commonly used to improve  
87 muscular fitness (i.e., muscle strength, power, local muscle endurance) as well as motor  
88 skill development in various types of sports including soccer<sup>21</sup> and martial arts.<sup>22</sup> It has  
89 further become an increasingly popular mode of physical exercise designed to improve  
90 body image and self-rated physical attractiveness by stimulating muscular fitness and  
91 muscle cross-sectional area (CSA).<sup>23,25</sup> Studies of the combined effects of RIF and RT  
92 on body composition, muscle hypertrophy and physiological adaptation have produced  
93 contradictory findings.<sup>26,28</sup> For example, while muscle strength and power increased  
94 significantly in soccer players after resistance training (8-repetitions × 4-sets with 4-min  
95 recovery in between) during Ramadan<sup>29</sup>, an absence of changes in body mass and body

96 composition have been reported for bodybuilders.<sup>30</sup> Moreover, body mass and physical  
97 performance declined in male Senegalese runners decreased after RT due to  
98 hypoglycemia associated with RIF.<sup>31</sup>

99 These findings suggest that strength and conditioning specialists should choose an  
100 appropriate training period to minimize performance degradation and improve / maintain  
101 physical outcomes associated with RIF. Some investigators suggest training would be  
102 more beneficial after breaking fast (usually 2–3 h after sunset) to prevent dehydration,  
103 hypoglycemia and possible decreases in performance<sup>32,33</sup>, while other studies suggest  
104 that training should take place while fasting to improve sleep quality and prevent  
105 hormonal disturbances that can alter performance and muscle growth.<sup>34</sup>

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

## 113 **Materials and methods**

### 114 **Participants**

115 Forty healthy Muslim recreational males weight lifters volunteered to participate  
116 in this study (age= 25.7±5.6 y, mass= 85.1±17.5 kg, height= 175.3±8.9 cm, body-mass-  
117 index [BMI]= 28.3±5.7 kg/m<sup>2</sup>) and were randomly allocated to two groups: 1) Fasted  
118 state group (FAST, n=20) practicing RT in the late afternoon 1 hour before breaking fast  
119 (between 16h and 18h), and 2) a fed state group (FED, n=20) practicing RT in the late  
120 evening after breaking the fast (between 20h and 22h). The study inclusion criteria were  
121 healthy males aged 18 to 35 years, two years of RT experience, free from any injuries  
122 that could impede or hinder the movements performed, no current or history of  
123 cardiometabolic disease, no consumption of supplements other than those provided  
124 during the study (*see below*), and self-reported as not having previously used anabolic  
125 steroids or related-ergogenic aids. The participants were required to refrain from other  
126 non-experimental RT sessions during the study. Participant who did not meet the  
127 inclusion criteria was excluded.

128 All participants were informed of the purpose of the study, the experimental  
129 procedures, possible discomforts, risks, and benefits of the participation and then signed  
130 a written informed consent to participate in the study. The investigation was performed  
131 according to the principles outlined in the Declaration of Helsinki and was approved by  
132 the local University Ethics Committee on Human Research of the University of la  
133 Manouba, Tunisia (Ethics Code: Tn, UM2019-73).

## 134 **Design**

135 Ramadan began on March 3rd and ended on April 3rd, 2021, with an average duration  
136 of the fast being  $\sim 14$  h/d. The study was conducted in Tunisia, where daytime  
137 temperatures were  $23\pm 4^\circ\text{C}$  and relative humidity was  $65\pm 5\%$ . Two weeks before the  
138 start of Ramadan fasting, volunteers visited the laboratory on three days separated by  
139 intervals of 48–72h between visits.

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

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

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

147 After the baseline assessment (T0), all tests (anthropometrics, 1RM, CSAs, PSQI)  
148 were conducted on three separate test occasions: during the 2<sup>nd</sup> week of Ramadan (T1),  
149 during the 4<sup>th</sup> week of Ramadan (T2), and 21 days after the end of Ramadan (T3), with  
150 the same order and the same separated days as the previous pre-test procedures (*Figure*  
151 *1*).

152 **< ADD FIG 1 NEAR HERE >**

## 153 **Training program**

154 All participants trained four days per week (Monday, Tuesday, Thursday, and Friday)  
155 for 8-weeks (one week before Ramadan, 4 weeks during Ramadan and 3 weeks after the  
156 end of Ramadan). Training involved full body RT exercises of 45 to 60 min per session.  
157 The exercise sessions of FAST occurred in the late afternoon during Ramadan (between  
158 16h and 18h) and those for the FED occurred in the evening (between 20h and 22h) a 1–

159 2 hours after breaking the fast. All sessions started with a general warm-up and cool-  
160 down periods of 5–10 min of low-intensity aerobic and dynamic stretching exercises.

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

167 During the first session of each intervention week, 1RM tests were performed for  
168 all exercises to ensure a relative exercise intensity of 75–85% 1RM throughout the eight  
169 weeks of training. The 1RM test and the start of the training session was separated by a  
170 10-minute rest interval.

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

### 179 **Anthropometric measurements**

180 Body composition was assessed following an overnight fast (12 h) and >72 h following  
181 their last exercise bouts at T0, T1, T2 and T3. Body mass was measured to the nearest  
182 10 g using a calibrated electronic scale (MEDISANA®, Neuss, Germany), body height  
183 was measured to the nearest 5 mm using a stadiometer. BMI was then calculated. In  
184 addition, four skinfolds (biceps, triceps, subscapular and suprailium) were measured  
185 with a calibrated Harpenden skinfold (Baty International. England) for the evaluation of  
186 body fat percentage using a previously published algorithm.<sup>35</sup> Lean body mass (LBM)  
187 was calculated as body mass minus body fat mass. All measurements were performed  
188 by a single evaluator who was experienced in each of the procedures.

### 189 **Maximum strength tests**

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

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

202 Pilot data were obtained on two test days from 40 participants to determine the  
203 reproducibility of the test. Our reliability data revealed the following ICCs at 95%: 1-  
204 RM parallel squat (0.929; lower 0.929-upper 0.996), 1-RM bench press (0.779; lower  
205 0.581-upper 0.883), 1-RM deadlift (0.886; lower 0.783-upper 0.940), 1-RM CSA  
206 quadriceps (0.967; lower 0.938-upper 0.983) and 1-RM CSA biceps (0.782; lower 0.587-  
207 upper 0.885).

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

209  
210 Ultrasound images were recorded on four different occasions (before Ramadan (T0), on  
211 the 15<sup>th</sup> day of Ramadan (T1), on the 29<sup>th</sup> day of Ramadan (T2) and 21 days after the end  
212 of Ramadan) to analyze the CSA of the quadriceps and biceps brachii muscle. Ultrasound  
213 scans were performed using a brightness mode (B-mode) imaging device (Esaote,  
214 MyLab<sup>TM</sup>X8, Florence, Italy) with a multifrequency linear-array probe (4-15 MHz, 60-  
215 mm width) using extended-field-of-view mode (EFVO).

216 CSA images of the quadriceps were taken using the EFOV mode.<sup>38</sup> Volunteers  
217 remained lying in dorsal decubitus position on a stretcher for 15 minutes to allow fluid  
218 shifts to stabilize before images were obtained.<sup>39</sup> A line from the greater trochanter to  
219 the outer femoral condyle was marked to measure the length of the femur. Four axial  
220 perpendicular lines were then marked, starting from the proximal extremity at intervals  
221 of 20% (proximal), 40% (proximal-middle), 60% (distal-middle) and 80% (distal) of the  
222 femur length using a tape measure and a pachymeter positioned parallel to the thigh



223 *(Figure 2A)*. Lines created with a microporous adhesive tape were then positioned 2 cm  
224 from each of the four axial perpendicular points to delineate the location for positioning  
225 of the ultrasound probe during image acquisition *(Figure 2B)*. It is important to note that  
226 CSA measured at a single point on a muscle's length may not adequately represent the  
227 entire extent of muscle hypertrophy, thus, CSA analysis using several points provide a  
228 more accurate depiction of muscle hypertrophy.<sup>40</sup>

229 <ADD FIGURE 2A NEAR HERE>

230 <ADD FIGURE 2B NEAR HERE>

231

232 The probe was placed transversely on the marked lines across the thigh to allow  
233 for a continuous single view, while the mediolateral angle of the probe was changed  
234 throughout the experiment so that the probe remained perpendicular to the skin *(Figure*  
235 *2C)*.<sup>41</sup> This procedure was performed at constant speed and lasted approximately 4 s in  
236 distal regions to approximately 5 s in proximal regions according to the thigh  
237 circumference of the participants.

238

239 <ADD FIGURE 2C NEAR HERE>

240

241 A water-based gel was applied between the skin and the transducer to achieve  
242 acoustic coupling and avoid any misinterpretation of the images created by the increased  
243 pressure when applying the transducer. Participants were asked to remain relaxed during  
244 the ultrasound procedures. The panoramic images of the four sits that were created by  
245 the moving transducer were digitally stored *(Figure 3)*. Images were analyzed for muscle  
246 thickness, fascicle angle, and fascicle length by using specific software (MyLab™Desk,  
247 Esaote, Italy).

248

249 <ADD FIGURE 3 NEAR HERE>

250

251 The sum of 4 images of the CSAs were taken at 20, 40, 60, and 80% of femur  
252 length on the test day and used to generate a single CSA value per muscle, which was  
253 then used for determining the thickness of the rectus femoris and vastus lateralis muscles.

254 The CSA of the biceps brachii was also measured by the EFOV technique with the  
255 same device and on the same testing day when images of the quadriceps (T0, T1, T2 and  
256 T3) were obtained.<sup>42</sup> Each individual was seated in a comfortable position with arms  
257 resting at 90° shoulder flexion angle, and 0° elbow flexion (i.e., straight arm). A line  
258 from the acromion process of the clavicle to the lateral epicondyle of the humerus was  
259 marked to measure the length of the upper arm. Two axial perpendicular lines were  
260 marked (mid-point of the upper arm: 0 cm, 3 cm below the mid-point: 3 cm) as these  
261 two regions provide the largest biceps brachii CSA that generally lies between the two  
262 perpendicular markings.

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

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

### 273 **Dietary habits**

274 Participants were advised to maintain instructed nutritional regimen by a specialist and  
275 to avoid taking any supplements other than those provided during the study (*see below*).  
276 Dietary adherence was assessed by self-reported food records and analyzed using a  
277 nutritional tracking application (<http://www.myfitnesspal.com>) and the food-  
278 composition tables of the National Institute of Statistics of Tunis (1978). All food and  
279 beverages consumed during the experiment were collected for at least four days a week  
280 to offer a reliable estimate of food intake for the entire week. Total water intake was  
281 defined as the fluid volume of consumed beverages plus the water content of consumed  
282 foods.

283 Individuals were instructed on the correct recording procedures of all food items,  
284 including portion sizes. Each item of food was individually entered into the software  
285 program to determine total energy consumption, and amount of energy derived from  
286 proteins, fats, and carbohydrates for each period analyzed. The mean of nutrient  
287 consumed during the intervention was calculated.<sup>43</sup> Participants consumed a supplement  
288 containing 24 g protein and 1 g carbohydrate before sleeping (Iso100 Hydrolyzed Whey  
289 Protein Isolate; Dymatize Nutrition, Dallas, TX) on training days under the supervision  
290 of the research staff. The nutrients consumed by participants during the study is shown  
291 in *Table 1*, no significant differences between groups and during the experiment were  
292 found.

293

294

< INSERT TABLE 1 NEAR HERE >

295

### 296 **Rating of perceived exertion (RPE)**

297 The Borg scale was used to evaluate the rating of perceived exertion (RPE) during the  
298 exercise sessions at 5 min after the end of the training session at T0, T1, T2 and T3.<sup>44</sup>  
299 Volunteers were advised to look at the scale and respond immediately after the end of  
300 each session to the following prompt: “*Think about your feeling of body effort, how did*  
301 *you feel?*” and entered numbers on a sliding scale, where perceived efforts were rated  
302 between 0 for "extremely easy" and 10 for "extremely difficult."

### 303 **Sleep quality**

304 Sleep quality during and after three weeks of Ramadan was assessed using the full  
305 Pittsburgh Sleep Quality Index (PSQI)<sup>45</sup> before Ramadan (T0), on the 15<sup>th</sup> day of  
306 Ramadan (T1), on the 29<sup>th</sup> day of Ramadan (T2) and 21 days after the end of Ramadan.  
307 We used an Arabic validated version of the PSQI.<sup>46</sup> The global PSQI score is composed  
308 of 7 components: subjective sleep quality (sleep quality perception), sleep latency (time  
309 between lying on bed and start sleeping), sleep duration (period sleeping reported by  
310 subject), habitual sleep efficiency (ratio between time sleeping and time on bed), sleep  
311 disturbance (problems to sleep elected by subjects), sleeping medication (use of  
312 medication to sleep), and daytime dysfunction (intensity of diurnal somnolence).<sup>47</sup> The  
313 7 domains are each scored from 0 (no difficulty for the component of interest) to 3 (very  
314 bad), with a total or global score ranging from 0-21 that reflects sleep quality and

315 disturbances over a 1-month period. A better sleeper would have a lower global PSQI  
316 score, while higher score indicates poor sleep quality.

### 317 **Statistical analyses**

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

325 Effect sizes (ES) were determined from the output of ANOVA by converting  
326 partial eta-squared to Cohen’s d. In addition, within-group ES were computed using the  
327 following equation:  $ES = (\text{mean post} - \text{mean pre}) / SD$ . ES were considered trivial ( $<0.2$ ),  
328 small (0.2-0.6), moderate (0.6-1.2), large (1.2-2, 0) and very large (2.0-4.0).<sup>48</sup> All  
329 statistical analyses were computed at  $p < 0.05$ .

### 330 **Results**

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

338

339 **< INSERT TABLE 2 NEAR HERE >**

340

### 341 **Anthropometric tests**

342 Anthropometric and body composition characteristics of participants are presented in  
343 **Table 2**. There were no significant group  $\times$  time interactions for anthropometric  
344 measures. A significant main effect of time was observed for body mass and body fat

345 percentage. Both FAST and FED groups experienced significant decreases in body mass  
346 ( $p = 0.001$ ;  $ES = 0.44$ ), BMI ( $p = 0.001$ ;  $ES = 0.67$ ) and body fat percentage ( $p = 0.001$ ;  
347  $ES = 0.91$ ) during Ramadan, with no changes in lean body mass in either group ( $p >$   
348  $0.05$ ).

349

350 < INSERT TABLE 2 NEAR HERE >

351

### 352 **Hypertrophy and maximal strength**

353 Group  $\times$  time interactions are reported in Table 3 for measures of CSA and maximal  
354 strength. There were significant group  $\times$  time interactions for  $1RM_{SQ}$  ( $p = 0.001$ ;  $ES =$   
355  $0.21$ ) and  $1RM_{DL}$  ( $p = 0.04$ ;  $ES = 0.10$ ) in favor of the FED group. Post-hoc tests revealed  
356 significant increases in  $1RM_{SQ}$  and  $1RM_{DL}$  at T2 compared to T0 ( $p < 0.05$ ) and at T3  
357 compared to T0 and T1 ( $p < 0.05$ ) for FED. No significant group  $\times$  time effects were  
358 recorded for  $1RM_{BP}$ ,  $CSA_{QC}$ , and  $CSA_{BB}$  ( $p > 0.05$ ).

359 < INSERT TABLE 3 NEAR HERE >

360

### 361 **Rating of perceived exertion (RPE)**

362 The RPE among FAST and FED groups at T0, T1, T2 and T3 is summarized in *Figure*  
363 *4*, significant group  $\times$  time differences between groups for RPE were reported at T1 ( $p =$   
364  $0.02$ ;  $ES = 0.48$ ) and T2 ( $p = 0.03$ ;  $ES = 0.37$ ). A significant main effect of time was  
365 observed among FAST group with increasing at T1 and T2, while RPE remained  
366 unchanged at all time points in the FED state group.

367 < INSERT FIGURE 4 NEAR HERE >

368

### 369 **The Pittsburgh Sleep Quality Index**

370 Data of the Pittsburgh Sleep Quality Index (mean  $\pm$  SD) among FAST and FED groups  
371 at T0, T1, T2 and T3 are reported in (*Table 4*).

372 < INSERT TABLE 4 NEAR HERE >

373

374           There was significant group  $\times$  time interactions for total score of PSQI, a  
375 significant main effect of time was observed among both groups with decreasing of  
376 global PSQI at T1 ( $p < 0.05$ ,  $d = 6.54$ ) and at T2 ( $p < 0.05$ ,  $ES = 6.54$ ) compared to T0;  
377 and increasing of the total score for the PSQI during the two weeks after RIF. No  
378 significant differences between FAST and FED groups were found on any component.

## 379       **Discussion**

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

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

## 400       **Muscle hypertrophy**

401       There were neither adverse or beneficial effects of the combination RT and RIF on biceps  
402 and quadriceps muscle hypertrophy in the two study groups, and as also reported in  
403 previous studies on the effects of RT during other IF protocols. In fact, Moro et al. 2016  
404 studied 34 males who performed RT for 8 weeks (3 resistance sessions/week, 6–8  
405 repetitions at 85–90% of 1 RM) with restrictive feeding (16h fasting/8h fed , 3

406 days/week) and reported no significant changes in CSA for muscles of the arms and  
407 thighs.<sup>49</sup> However, other studies reported increases in muscle hypertrophy in males  
408 following RT in a time restrictive feeding program.<sup>50,52</sup> The discrepancy between our  
409 findings and the latter reports is likely related to conditions of fasting: we studied the  
410 effects of food and water deprivation for the entire month of Ramadan IF while the latter  
411 studies involved only 3 days/week of time restrictive feeding.<sup>50,52</sup> The continuous and  
412 prolonged fasting period during Ramadan decreases daily energy intake due to the  
413 reduction of meal frequency<sup>33</sup> which could hinder gains in muscle mass.

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

## 422 **Muscle strength**

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

433 However, the improvement was observed just for FED group with increases in  
434 (1RM<sub>DL</sub>) and(1RM<sub>sq</sub>). Choosing the optimal training conditions, including timing of  
435 training, during Ramadan is of great interest to Muslim athletes. Several changes in  
436 physiological and psychological parameters during the daytime can impact exercise,  
437 including maximal strength performance. For example, the optimal time of day to

438 conduct an acute high-intensity exercise session during Ramadan is after breaking the  
439 fast, as performance is negatively impacted in a fasting state (morning and evening  
440 sessions).<sup>58</sup>

441 These findings may due to exercise sessions at 21:00 h were performed under  
442 favorable circumstances that were similar to those before Ramadan where athletes were  
443 able to consume food and liquids before exercise sessions, allowing pre-exercise blood  
444 glucose concentration levels and fluid to be within the normal range, whereas training at  
445 18:00 h is not advisable as athletes have not consumed food and fluid for >10 h and  
446 experience higher levels of fatigue ([1]. Another explanation for the improvement only  
447 among FED, that they reached the fatigue sensation more later in comparison with the  
448 FAST group. In fact, in our study, RPE levels, recorded post same exercise, were greater  
449 in fasting participants compared to the subjects in the fed state, indicating that exercising  
450 while fasting may amplify the sensation of physical effort and fatigue independently of  
451 the physiological capacity of the muscles for the same training load.<sup>54</sup>

#### 452 **Study limitations**

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

458 Additionally, this study was conducted only with young males. Therefore, the  
459 observed findings cannot be translated to females. Future studies should examine this  
460 research question in female athletes as more women are now engaging in sports and  
461 exercise training <sup>60</sup>.

#### 462 **Practical applications**

463 Muslim recreational weightlifters try to maintain their physical appearance during  
464 Ramadan despite the physiological and psychological challenges that occur during this  
465 month of daily fasting. Fitness instructors and personal trainers may need to implement  
466 strategies to prevent the negative effects of fasting on muscle hypertrophy and strength.  
467 Our findings suggest that it is feasible to maintain and increase maximal strength but not  
468 muscle circumferences when exercise is performed in the evenings during the fed state.



469 It is possible that the effects we observed may be even more pronounced in geographical  
470 areas where the fasting times are even longer (and conversely, less important in areas  
471 where duration of fasting is shorter). In addition, some non-Muslim weightlifters  
472 followed an intermittent fasting protocol as a nutritional method for muscle toning,  
473 however, trainers practicing RT should stress the importance of adopting an appropriate  
474 nutritional protocol to reach training goals.

## 475 **Conclusion**

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

484

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699 **Table 1.** Estimated daily dietary intake recorded (mean  $\pm$  SD) of the FAST and FED state groups measured during 1 week before the start of  
700 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  
701 group).

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		T0	T1	T2	T3	Time	Group	Group $\times$ Time
<b>Protein (% kcal)</b>	FAST	18 $\pm$ 8	19 $\pm$ 1	18 $\pm$ 7	18 $\pm$ 7	<b>0.08 (0.37)</b>	<b>0.06 (0.45)</b>	<b>0.1 (0.57)</b>
	FED	18 $\pm$ 6	18 $\pm$ 2	18 $\pm$ 9	18 $\pm$ 6			
<b>Carbohydrate (% kcal)</b>	FAST	47 $\pm$ 5	45 $\pm$ 8	46 $\pm$ 3	47 $\pm$ 1	<b>0.1 (0.46)</b>	<b>0.08 (0.54)</b>	<b>0.07 (0.55)</b>
	FED	47 $\pm$ 3	46 $\pm$ 5	45 $\pm$ 9	46 $\pm$ 7			
<b>Fat (% kcal)</b>	FAST	35 $\pm$ 8	36 $\pm$ 5	36 $\pm$ 4	35 $\pm$ 7	<b>0.09 (0.45)</b>	<b>0.08 (0.38)</b>	<b>0.08 (0.58)</b>
	FED	35 $\pm$ 9	36 $\pm$ 3	37 $\pm$ 2	36 $\pm$ 4			
<b>Energy (kcal/day)</b>	FAST	3472 $\pm$ 245	3436 $\pm$ 249	3425 $\pm$ 283	3482 $\pm$ 275	<b>0.2 (0.37)</b>	<b>0.08 (0.45)</b>	<b>0.09 (0.51)</b>
	FED	3496 $\pm$ 368	3432 $\pm$ 237	3465 $\pm$ 232	3472 $\pm$ 254			
<b>Total water intake (L/day)</b>	FAST	4.3 $\pm$ 0.5	4.1 $\pm$ 0.4	4.2 $\pm$ 0.3	4.1 $\pm$ 0.7	<b>0.06 (0.57)</b>	<b>0.08 (0.35)</b>	<b>0.2 (0.41)</b>
	FED	4.2 $\pm$ 0.4	4.3 $\pm$ 0.6	4.2 $\pm$ 0.3	4.1 $\pm$ 0.4			



718 **Table 2.** Anthropometric and body composition characteristics (means  $\pm$  SD) of the FAST and FED state groups measured during 1 week before  
 719 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)  
 720 (n=20 per group).

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		T0	T1	T2	T3	Time	Group	Group x Time
<b>Body mass (kg)</b>	FAST	79.12 $\pm$ 3.71	76.06 $\pm$ 3.25*	74.19 $\pm$ 3.20*#	77.64 $\pm$ 4.52\$	<b>0.001</b> <b>(0.44)</b>	<b>0.54</b> <b>(0.05)</b>	<b>0.09</b> <b>(0.07)</b>
	FED	80.05 $\pm$ 3.34	79.08 $\pm$ 2.86*	76.23 $\pm$ 3.03*	78.04 $\pm$ 3.52 \$			
<b>BMI (kg/m<sup>2</sup>)</b>	FAST	24.26 $\pm$ 1.72	23.6 $\pm$ 1.45*	22.35 $\pm$ 1.34*#	23.91 $\pm$ 1.19\$	<b>0.001</b> <b>(0.67)</b>	<b>0.27</b> <b>(0.03)</b>	<b>0.13</b> <b>(0.14)</b>
	FED	24.72 $\pm$ 1.03	24.24 $\pm$ 1.26	23.31 $\pm$ 1.50*	24.01 $\pm$ 1.61\$			
<b>Body fat (%)</b>	FAST	16.66 $\pm$ 1.25	15.31 $\pm$ 1.60*	13.53 $\pm$ 1.55*#	14.84 $\pm$ 1.41*\$	<b>0.001</b> <b>(0.91)</b>	<b>0.89</b> <b>(0.00)</b>	<b>0.58</b> <b>(0.05)</b>
	FED	16.20 $\pm$ 0.57	15.31 $\pm$ 1.59*	13.82 $\pm$ 1.65*#	14.93 $\pm$ 1.47*\$			
<b>LBM (kg)</b>	FAST	66.78 $\pm$ 2.94	65.84 $\pm$ 2.92	64.78 $\pm$ 2.86	65.70 $\pm$ 3.39	<b>0.31</b> <b>(0.31)</b>	<b>0.10</b> <b>(0.06)</b>	<b>0.81</b> <b>(0.01)</b>
	FED	67.24 $\pm$ 1.88	66.72 $\pm$ 2.45	66.57 $\pm$ 2.59	66.98 $\pm$ 2.91			

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**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.

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738 **Table 3:** Maximal strength (1RM) and hypertrophy changes (means  $\pm$  SD) of the FAST and FED state groups measured during 1 week before  
 739 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)  
 740 (n=20 per group).

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		T0	T1	T2	T3	Time	Group	Group x Time																																																				
1RM <sub>SQ</sub> (kg)	FAST	168.75 $\pm$ 13.13	169.50 $\pm$ 11.85	168.45 $\pm$ 11.54	172.25 $\pm$ 11.55*#	<b>0.001 (0.60)</b>	<b>0.04 (0.12)</b>	<b>0.001 (0.21)</b>																																																				
	FED	169.65 $\pm$ 12.09	170.78 $\pm$ 11.15	174.23 $\pm$ 12.08*	177.10 $\pm$ 12.69*#				1 RM <sub>BP</sub> (kg)	FAST	106.01 $\pm$ 9.50	110.40 $\pm$ 10.54	109.25 $\pm$ 10.33	120.10 $\pm$ 10.09*	<b>0.001 (0.68)</b>	<b>0.63 (0.006)</b>	<b>0.38 (0.08)</b>	FED	105.50 $\pm$ 10.60	107.35 $\pm$ 10.15	109.50 $\pm$ 10.55	116.75 $\pm$ 10.58*	1RM <sub>DL</sub> (%)	FAST	186.25 $\pm$ 8.13	186.80 $\pm$ 8.88	187.81 $\pm$ 9.38	190.25 $\pm$ 9.88*#	<b>0.001 (0.29)</b>	<b>0.003 (0.12)</b>	<b>0.04 (0.10)</b>	FED	187.50 $\pm$ 8.50	190.85 $\pm$ 8.44	195.40 $\pm$ 9.10*	199.65 $\pm$ 8.39*#	CSA <sub>QC</sub> (cm <sup>2</sup> )	FAST	69.95 $\pm$ 7.14	68.90 $\pm$ 6.98	68.15 $\pm$ 6.58	71.15 $\pm$ 6.27\$	<b>0.94 (0.01)</b>	<b>0.18 (0.12)</b>	<b>0.27 (0.03)</b>	FED	70.60 $\pm$ 6.20	71.90 $\pm$ 6.80	72.80 $\pm$ 6.70	76.45 $\pm$ 6.64*	CSA <sub>BB</sub> (cm <sup>2</sup> )	FAST	20.50 $\pm$ 2.10	21.20 $\pm$ 2.42	20.65 $\pm$ 2.45	22.65 $\pm$ 2.69*\$	<b>0.001 (0.13)</b>	<b>0.88 (0.42)</b>	<b>0.29 (0.32)</b>	FED
1 RM <sub>BP</sub> (kg)	FAST	106.01 $\pm$ 9.50	110.40 $\pm$ 10.54	109.25 $\pm$ 10.33	120.10 $\pm$ 10.09*	<b>0.001 (0.68)</b>	<b>0.63 (0.006)</b>	<b>0.38 (0.08)</b>																																																				
	FED	105.50 $\pm$ 10.60	107.35 $\pm$ 10.15	109.50 $\pm$ 10.55	116.75 $\pm$ 10.58*				1RM <sub>DL</sub> (%)	FAST	186.25 $\pm$ 8.13	186.80 $\pm$ 8.88	187.81 $\pm$ 9.38	190.25 $\pm$ 9.88*#	<b>0.001 (0.29)</b>	<b>0.003 (0.12)</b>	<b>0.04 (0.10)</b>	FED	187.50 $\pm$ 8.50	190.85 $\pm$ 8.44	195.40 $\pm$ 9.10*	199.65 $\pm$ 8.39*#	CSA <sub>QC</sub> (cm <sup>2</sup> )	FAST	69.95 $\pm$ 7.14	68.90 $\pm$ 6.98	68.15 $\pm$ 6.58	71.15 $\pm$ 6.27\$	<b>0.94 (0.01)</b>	<b>0.18 (0.12)</b>	<b>0.27 (0.03)</b>	FED	70.60 $\pm$ 6.20	71.90 $\pm$ 6.80	72.80 $\pm$ 6.70	76.45 $\pm$ 6.64*	CSA <sub>BB</sub> (cm <sup>2</sup> )	FAST	20.50 $\pm$ 2.10	21.20 $\pm$ 2.42	20.65 $\pm$ 2.45	22.65 $\pm$ 2.69*\$	<b>0.001 (0.13)</b>	<b>0.88 (0.42)</b>	<b>0.29 (0.32)</b>	FED	20.90 $\pm$ 2.02	20.45 $\pm$ 2.41	20.91 $\pm$ 2.46	22.15 $\pm$ 2.35#										
1RM <sub>DL</sub> (%)	FAST	186.25 $\pm$ 8.13	186.80 $\pm$ 8.88	187.81 $\pm$ 9.38	190.25 $\pm$ 9.88*#	<b>0.001 (0.29)</b>	<b>0.003 (0.12)</b>	<b>0.04 (0.10)</b>																																																				
	FED	187.50 $\pm$ 8.50	190.85 $\pm$ 8.44	195.40 $\pm$ 9.10*	199.65 $\pm$ 8.39*#				CSA <sub>QC</sub> (cm <sup>2</sup> )	FAST	69.95 $\pm$ 7.14	68.90 $\pm$ 6.98	68.15 $\pm$ 6.58	71.15 $\pm$ 6.27\$	<b>0.94 (0.01)</b>	<b>0.18 (0.12)</b>	<b>0.27 (0.03)</b>	FED	70.60 $\pm$ 6.20	71.90 $\pm$ 6.80	72.80 $\pm$ 6.70	76.45 $\pm$ 6.64*	CSA <sub>BB</sub> (cm <sup>2</sup> )	FAST	20.50 $\pm$ 2.10	21.20 $\pm$ 2.42	20.65 $\pm$ 2.45	22.65 $\pm$ 2.69*\$	<b>0.001 (0.13)</b>	<b>0.88 (0.42)</b>	<b>0.29 (0.32)</b>	FED	20.90 $\pm$ 2.02	20.45 $\pm$ 2.41	20.91 $\pm$ 2.46	22.15 $\pm$ 2.35#																								
CSA <sub>QC</sub> (cm <sup>2</sup> )	FAST	69.95 $\pm$ 7.14	68.90 $\pm$ 6.98	68.15 $\pm$ 6.58	71.15 $\pm$ 6.27\$	<b>0.94 (0.01)</b>	<b>0.18 (0.12)</b>	<b>0.27 (0.03)</b>																																																				
	FED	70.60 $\pm$ 6.20	71.90 $\pm$ 6.80	72.80 $\pm$ 6.70	76.45 $\pm$ 6.64*				CSA <sub>BB</sub> (cm <sup>2</sup> )	FAST	20.50 $\pm$ 2.10	21.20 $\pm$ 2.42	20.65 $\pm$ 2.45	22.65 $\pm$ 2.69*\$	<b>0.001 (0.13)</b>	<b>0.88 (0.42)</b>	<b>0.29 (0.32)</b>	FED	20.90 $\pm$ 2.02	20.45 $\pm$ 2.41	20.91 $\pm$ 2.46	22.15 $\pm$ 2.35#																																						
CSA <sub>BB</sub> (cm <sup>2</sup> )	FAST	20.50 $\pm$ 2.10	21.20 $\pm$ 2.42	20.65 $\pm$ 2.45	22.65 $\pm$ 2.69*\$	<b>0.001 (0.13)</b>	<b>0.88 (0.42)</b>	<b>0.29 (0.32)</b>																																																				
	FED	20.90 $\pm$ 2.02	20.45 $\pm$ 2.41	20.91 $\pm$ 2.46	22.15 $\pm$ 2.35#																																																							

755 **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<  
 756 0.05 compared to T1; \$: p<0.05 compared to T2.

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758 **Table 4.** sleep quality recorded (mean  $\pm$  SD) of the FAST and FED state groups measured during 1 week before the start of Ramadan (T0), on  
 759 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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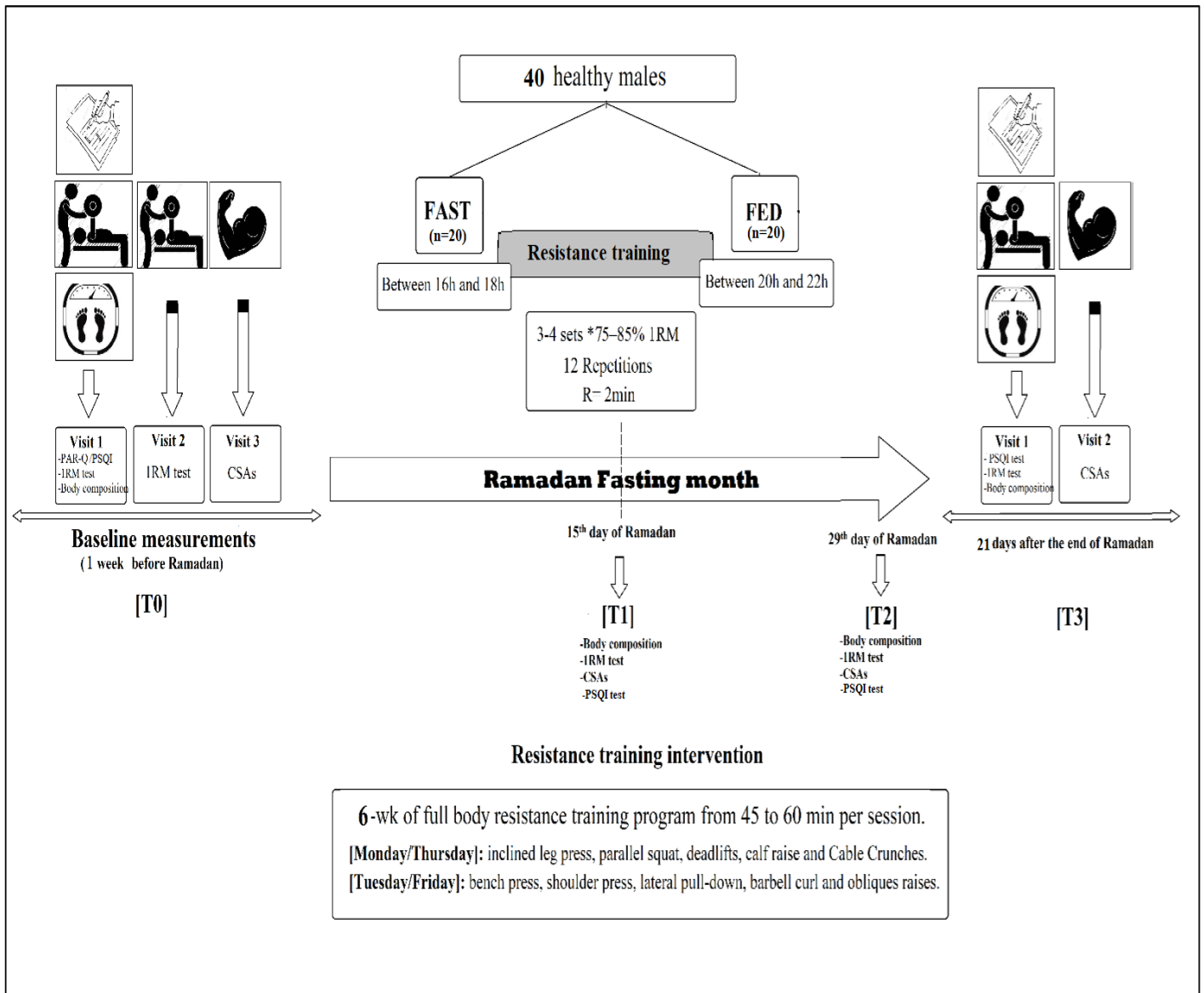
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		T0	T1	T2	T3	Time	Group	Group x Time
sleep quality	FAST	1.2 $\pm$ 0.5	2.4 $\pm$ 0.8*	2.2 $\pm$ 0.7*	1.3 $\pm$ 0.7# $\$$	0.007 (0.48)	0.06 (0.65)	0.1 (0.56)
	FED	1.3 $\pm$ 0.7	2.4 $\pm$ 0.7*	2.3 $\pm$ 0.5*	1.4 $\pm$ 0.6# $\$$			
sleep latency (min)	FAST	17.2 $\pm$ 5.4	17.3 $\pm$ 4.7	16.9 $\pm$ 8.4	16.8 $\pm$ 6.4	0.06 (0.58)	0.07 (0.47)	0.2 (0.56)
	FED	16.9 $\pm$ 6.1	17.5 $\pm$ 6.3	17.1 $\pm$ 7.2	17.1 $\pm$ 5.8			
sleep duration (h)	FAST	7.9 $\pm$ 1.1	6.3 $\pm$ 1.1*	6.7 $\pm$ 1.2*#	7.8 $\pm$ 1.2# $\$$	0.002 (0.69)	0.2 (0.65)	0.06 (0.58)
	FED	8.1 $\pm$ 0.5	6.1 $\pm$ 1.3*	6.6 $\pm$ 1.5*#	7.8 $\pm$ 1.5# $\$$			
sleep efficiency (%)	FAST	98.4 $\pm$ 3.5	95.3 $\pm$ 8.2*	95.2 $\pm$ 7.2*	96.8 $\pm$ 6.5# $\$$	0.005 (0.65)	0.07 (0.37)	0.1 (0.47)
	FED	97.7 $\pm$ 4.1	94.8 $\pm$ 6.7*	95.1 $\pm$ 6.8*	97.1 $\pm$ 7.1# $\$$			
sleep disturbance	FAST	0.7 $\pm$ 0.5	0.7 $\pm$ 0.2	0.6 $\pm$ 0.5	0.6 $\pm$ 0.5	0.07 (0.45)	0.08 (0.45)	0.07 (0.55)
	FED	0.6 $\pm$ 0.3	0.7 $\pm$ 0.5	0.6 $\pm$ 0.4	0.6 $\pm$ 0.4			
daytime dysfunction	FAST	0.4 $\pm$ 0.3	0.4 $\pm$ 0.6	0.4 $\pm$ 0.8	0.5 $\pm$ 0.5	0.07 (0.38)	0.2 (0.38)	0.1 (0.56)
	FED	0.5 $\pm$ 0.6	0.4 $\pm$ 0.7	0.5 $\pm$ 0.6	0.4 $\pm$ 0.3			
Total score of PSQI	FAST	3.4 $\pm$ 2.7	7.2 $\pm$ 2.3*	7.5 $\pm$ 2.1*	3.9 $\pm$ 2.7# $\$$	0.003 (0.47)	0.06 (0.43)	0.08 (0.39)
	FED	3.8 $\pm$ 2.3	7.7 $\pm$ 2.1*	7.3 $\pm$ 2.6*	4.1 $\pm$ 2.1# $\$$			

PSQI: Pittsburgh Sleep Quality Index; \*: p< 0.05 compared to T0; #: p< 0.05 compared to T1; \$: p<0.05 compared to T2.

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**Figure 1. Study design**

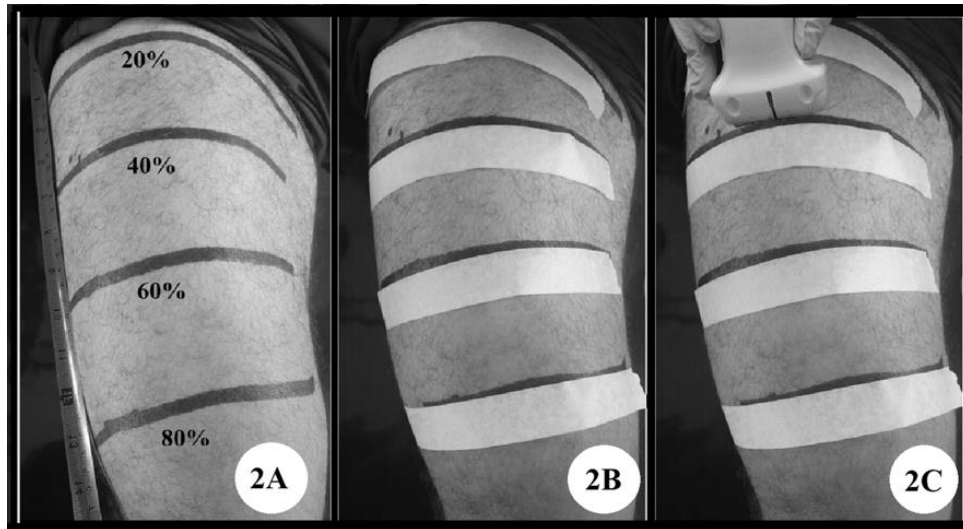
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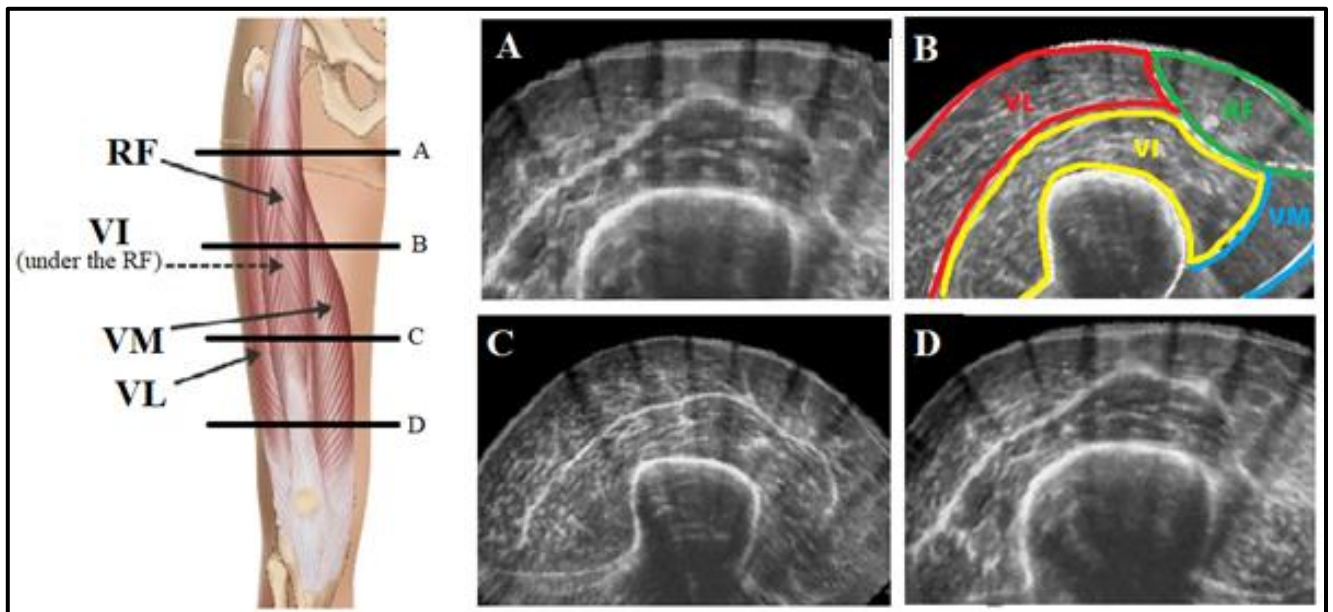


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785 **Figure 2.** Thigh marking procedures (A and B) and ultrasound images acquisition  
786 (C).

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790 **Figure 3.** Ultrasound images and cross-sectional areas (CSAs) of quadriceps at 20%  
791 proximal (A), 40% (B), 60% (C), and 80% (D) of femur length. RF: rectus femoris;  
792 VI: vastus intermedius; VL: vastus lateralis; VM: vastus medialis.

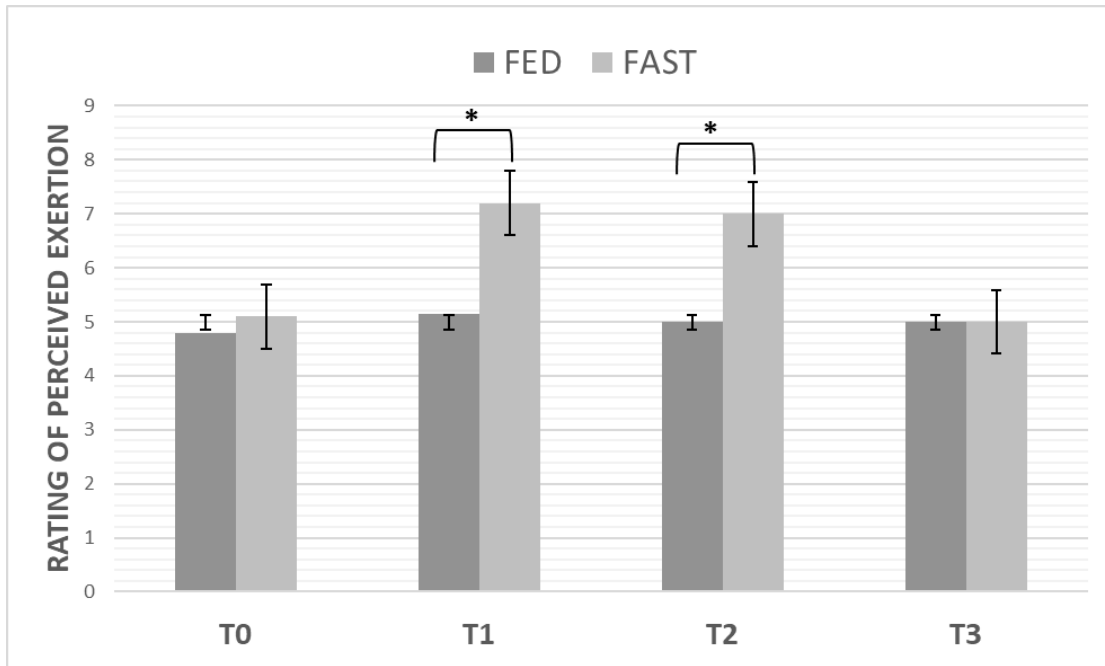
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801 **Figure 4.** Rating of perceived effort (RPE) among FAST and FED state group.

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\*: P < 0.05 significant differences between groups.

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