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ORIGINAL RESEARCH

Impact of Overnight Fasted State Versus Fed State on Adaptations to Resistance Training: A Randomized Clinical Trial

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The aim was to verify the effects of 12 weeks of resistance training (RT) performed in the fasted state compared with the fed state on body composition and physical performance in young adults. Participants were randomly assigned into fasting RT group (Fast-RT, $n = 15$) and fed RT group (Fed-RT, $n = 13$). Both groups trained two weekly resistance exercise sessions after an overnight fast or between 1 and 2 hr after consumption of a carbohydrate-rich meal, associated with isocaloric nutritional guidance. Assessments of body composition (dual-energy X-ray absorption), quadriceps muscle thickness (ultrasonography), maximum dynamic strength (one repetition maximum test), and muscle power in bench press and knee-extension exercises were performed before and after 12 weeks of intervention. Both Fast-RT and Fed-RT groups showed increases (p time ≤ .01) in quadriceps muscle thickness (1.21 and 1.18 cm, respectively; p group = .371; p Group × Time = .871), maximum dynamic strength (bench press: 10.53 and 4.89 kg, respectively; p group = .251; p Group × Time = .268; knee extension: 28.53 and 29.31 kg, respectively; p group = .919; p Group × Time = .846), and muscle power (knee extension mean power 70% one repetition maximum: 59.28 and 46.21 W, respectively; p group = .833; p Group × Time = .616; knee extension maximal power 70% one repetition maximum: 100.65 and 54.76 W, respectively; p group = .812; p Group × Time = .409). Regardless of food consumption prior to the sessions (fasted state and fed state), RT performed twice weekly across 12 weeks was associated with improvements in muscle hypertrophy and neuromuscular performance in young adults.

***Keywords**:* strength training, fasting, physical performance

Resistance training (RT) provides stimuli for morphological and neural changes resulting in increases in strength, power output, and muscle mass (Folland & Williams, 2007). Besides the stimulus arising from training, energy consumption and adequate distribution of nutrients in the diet are identified as crucial factors to support these gains (Morton et al., 2015). Different nutrition-related methods have been proposed to ensure satisfactory performance during sessions and to enhance adaptations to physical training (Thomas et al., 2016). A strategy that has been investigated in the literature and is widely practiced by the population is performing exercise in an overnight fasted state (Brinkmann et al., 2019; Rothschild et al., 2020; Zouhal et al., 2020), as this practice facilitates daily routines and promotes gastrointestinal comfort in some situations.

Fasting is the absence of ingestion of food and/or drinks that contain energy for a period of several hours (around 12 hr) to a few weeks. Most people fast regularly for 8–12 hr a day, during the night (i.e., overnight fasting; Longo & Mattson, 2014; Maughan et al., 2010). When the body is in the fasted state, nonesterified fatty acids, ketone bodies, and glucose derived from liver glycogen and gluconeogenesis are the predominant sources of energy (Cahill, 2006). Due to the metabolic profile associated with fasting and the energetic demands of physical exercise, abstaining from food consumption before aerobic and resistance exercises appears to enhance fat oxidation (Frawley et al., 2018; Vieira et al., 2016). In this context, the literature suggests that the predominant use of fats during aerobic exercise performed in the fasted state may enhance long-term adaptations related to health and performance (Edinburgh et al., 2022).

Some evidence shows that performing physical training with low carbohydrate availability may attenuate performance during sessions (Aird et al., 2018; Jeukendrup, 2017) due to the positive relationship between glycogen concentrations and physical performance (Knuiman et al., 2015). The scientific literature predominantly recommends consuming meals containing carbohydrates before exercise sessions, maintaining glycogen stores and supporting demands of exercise (Slater & Phillips, 2011; Thomas et al., 2016). King et al. (2022) demonstrated that consuming carbohydrates before resistance exercises generates ergogenic effects compared with performing the session in a fasted state (King et al., 2022). Nevertheless, based on limited available evidence, there is no confirmation that the reduction in acute physical performance associated with fasting translates into smaller magnitudes of adaptations to RT over time, as previous studies did not observe differences between conditions (fasted vs. fed; Brinkmann et al., 2019; Trabelsi et al., 2012, 2013; Triki et al., 2023).

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Indeed, most of interventions involving RT performed in the fasted state were conducted during the Ramadan period (Trabelsi et al., 2012, 2013; Triki et al., 2023), and all protocols did not include personalized dietary prescriptions. It is important to highlight that Ramadan fasting involves other habits associated with religious practices during its execution, whereas overnight fasting is considered a physiological factor, and it is practiced by most people every day. Therefore, although both involve abstinence from energy consumption for periods longer than 8 hr, their effects on physical training may differ. Furthermore, as the amount of energy and nutrient intake throughout the day, especially protein, significantly influences the adaptations resulting from RT (Slater et al., 2019), nutritional control and energy-matched conditions are essential for accurately assessing the chronic effects of RT when exercise sessions are performed in a fasted state compared with a fed state. Thus, there is a lack of data assessing the effects of RT performed after overnight fasting associated with nutritional support aiming at improvements in physical performance.

Therefore, the aim of the present study was to evaluate the effects of 12 weeks of RT performed in the fasted state compared with the fed state on body composition, muscle hypertrophy, and mechanical muscle function in young adults. To assess whether possible chronic adaptation differences between groups would be associated with acute effects of fed or fasted state in acute RT performance, we also assessed the RT total workload across the intervention. Our hypotheses were that smaller magnitudes of changes would be observed in fat-free mass, muscle thickness, maximum dynamic strength, and muscle power following RT performed in the fasted state, whereas similar effects on body fat mass would be found between fasted and fed states.

Methods

This study was a parallel randomized clinical trial registered on clinicaltrials.gov (NCT05482750). It was developed in accordance with the Helsinki Declaration and approved by the local research ethics committee (57332522.1.0000.5347).

Experimental Design

Participants attended the laboratory for the following data collection: body mass, height, anamnesis (identification data, date of birth, age, eating habits, smoking, health condition, use of medications and supplements), dietary record, and questionnaire to assess physical activity level. In addition, analysis of basal metabolic rate (BMR) and a familiarization with neuromuscular performance tests (muscle strength and power) were performed. After that, volunteers were scheduled for a second visit to carry out preintervention procedures. Assessments of outcomes were performed in the following order preintervention and postintervention: body composition, muscle thickness, maximum dynamic strength throughout one repetition maximum (1RM), and muscle power. During this same visit, researchers instructed participants on how to complete the dietary control instrument.

In a randomized manner, participants were allocated to one of two different interventions:

- Fasting RT (Fast-RT): Participants were instructed to maintain the nutritional guidance received by the researchers throughout the day and performed two weekly resistance exercise sessions after an overnight fast (10–12 hr) over 12 weeks.
- Fed RT (Fed-RT): Participants were instructed to maintain the nutritional guidance received by the researchers throughout the day and performed two weekly resistance exercise sessions in the fed state (between 1 and 2 hr after consuming a carbohydrate-rich meal) over 12 weeks.

During the intervention (after 8 weeks), adherence to nutritional guidance was verified through 3-day food records. Once the study protocols were completed (after 12 weeks), the volunteers returned to the laboratory for postintervention assessments, following the same steps as the preintervention collections (Figure 1). All procedures were performed at constant temperature and humidity, at the same times of the day, and by the same evaluators in the preintervention and postintervention moments.

Randomization was stratified based on maximum strength values and gender and was performed by a researcher who was not directly involved in the study, using an automatic randomizer (https://www.randomizer.org/). Volunteers were instructed to avoid making reports about the presence or absence of food prior to exercise sessions. In addition, researchers involved in data collection, data analysis, and exercise sessions were also blinded to the intervention groups.

Participants

Sample size calculation was performed based on lower limbs 1RM values in the study by Hamarsland et al. (2022). The calculation was carried out using the G*POWER software (version 3.1) in which $\alpha = .05$ and a power of 95% were adopted, resulting in a need for 28 participants.

The sample consisted of 28 women and men aged between 20 and 40 years old who were not engaged in regular RT. Participants were nonsmokers and did not use medications or supplements, including caffeine and creatine, that could influence the assessed outcomes. In addition, they did not have any chronic illnesses that would prevent them from performing physical exercises. Recruitment took place through advertisements on social media and telephone contact. Volunteers who agreed to all study procedures signed the free and informed consent form before initial assessments.

Procedures

Basal Metabolic Rate

On the day of the BMR test, participants were instructed not to perform physical activities of moderate to high intensity for 24 hr before the test, to have a night's sleep of at least 8 hr, to fast for 12 hr, and not to consume alcohol, caffeine, or any type of medication during this period without prior communication to the research team. All BMR tests were carried out in the early hours of the morning (between 7 and 8.30 a.m.) in an air-conditioned room between 20 °C and 25 °C, with controlled noise and low light. The protocol consisted of 10 min of rest on a stretcher in the supine position, followed by 30 min of exhaled gas collection. To determine the values of VO_2 and VCO_2, a computerized gas analyzer was used (Quark CPET, Cosmed). For data analysis, the first 10 min of gas capture were discarded, and the VO_2 and VCO_2 (l/min) values of the final 20 min of each collection were used to calculate the BMR, averaging the values of the period. To obtain kilocalorie per day values, the equation proposed by Weir (1949) was used.

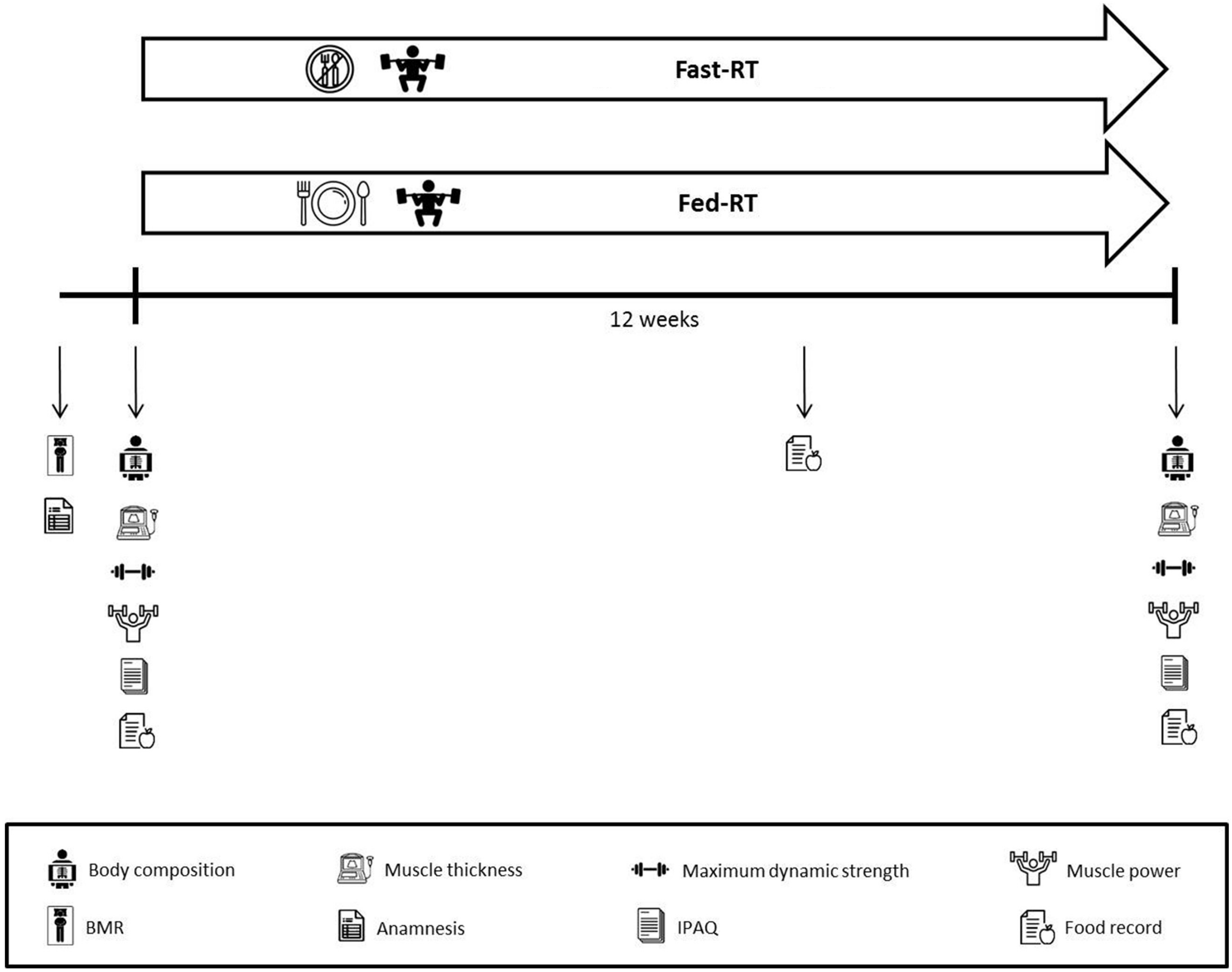

Figure 1 — Experimental design. BMR = basal metabolic rate; IPAQ = International Physical Activity Questionnaire; Fast-RT = fasting resistance training; Fed-RT = fed resistance training.

Body Composition

Body mass and height were measured using a stadiometer and scale (Urano). Fat-free mass and body fat mass were determined using dual-energy X-ray absorption (Hologic GE). For the procedure, participants were instructed not to perform physical activities of moderate to high intensity 48 hr before the test, to fast for 8 hr, to consume only one glass of water, not to consume alcohol, caffeine, or any type of medication 48 before the test, and to wear light clothing.

Muscle Thickness

Quadriceps femoris muscle thickness was assessed using ultrasonography (Nemio XG, Toshiba). Measurements were taken with participants in the supine position after 15 min of rest and after 72 hr without vigorous physical activity. Muscle thickness was defined as the thickness between the subcutaneous adipose tissue and the bone, which interfaces with muscle tissue were previously defined. The measurement locations were: vastus intermedius and rectus femoris—60% of the distance between the greater trochanter of the femur and the lateral epicondyle of the femur and three centimeters laterally from the midline of the limb; vastus lateralis—midpoint between the greater trochanter and the lateral epicondyle of the femur; and, vastus medialis—30% of the distance between the lateral epicondyle and the greater trochanter of the femur (Cadore et al., 2013). Quadriceps femoris muscle thickness was considered as a sum of all assessed muscles. The same evaluator carried out the measurements at different evaluation moments, taking three measurements for each point. Analyses were carried out using Image-J software (National Institute of Health).

Maximum Dynamic Strength

Maximum dynamic strength was assessed through 1RM test for bench press and knee extension exercises. On the testing day, participants performed a general warm-up on a treadmill for 5 min followed by a specific warm-up in the tested exercises using 30% of the initial load test. Subsequently, each subject's maximum load was determined with a maximum of five attempts. In each attempt, the concentric and eccentric phases lasted 2 s each, and intervals of 3–5 min were taken between them. During the testing procedures, participants were verbally encouraged to produce their maximum force at all times.

Muscle Power Output

After a brief specific warm-up in the bench press and knee extension exercises, maximum power and mean power during concentric phase were evaluated in these exercises at 30% and 70% of 1RM. Individuals performed five repetitions at the maximum intentional velocity in the concentric phase at each intensity and in each exercise. The interval between each execution was 2 min, alternated per exercise. The maximum and mean power values were determined using a linear displacement sensor (ChronoJump) coupled to the equipment. For the analysis, the best repetition of each attempt was used.

Resistance Training

The individuals performed RT twice weekly, on nonconsecutive days, between 7 and 10 a.m., with progressive training intensity and number of sets. Thus, two sets of 13–15 repetitions were performed between the first and fourth weeks, two sets of 10–12 repetitions in the fifth and sixth weeks, three sets of 10–12 repetitions in the seventh and eighth weeks, and three sets of 8–10 repetitions from the ninth week until the end of the intervention. In each change of preestablished number of repetitions, a 5% increase in load was attempted, and adjustments were made according to the participants' feedback. The training load was established so that participants performed sets close to or until concentric failure, according to preestablished ranges of repetitions, throughout the intervention. In addition, in each set, the workload was adjusted when the repetitions performed were either above or below the repetitions established. The execution of repetitions was controlled so that the subjective perception of effort at the end of the series reached values between eight and 10 (subjective perception of effort scale from 0 to 10). The total workload and the workload for the assessed exercises (bench press and knee extension) were monitored by recording the values used by the participants in each session and were analyzed after the intervention. The intervals between sets were 120 s. Each training session consisted of a specific warm-up on equipment for upper and lower limbs, with a set of 15 repetitions being performed with a load not exceeding 30% of the training load, followed by the leg press, bench press, knee extension, seated row, knee flexion, and abdominal and lumbar extension exercises. All training sessions were supervised by experienced strength and conditioning coaches.

Nutritional Guidance

The energy value of the prescribed nutritional guidance was calculated from the result obtained by the BMR of each individual multiplied by the activity factor of 1.7. The macronutrient composition was 3.0–5.0 g/kg of body mass/day of carbohydrates, 2.0 g/kg of body mass/day of proteins, and 20%–35% of the total energy value of the diet of fats (Thomas et al., 2016). The dietary prescription was introduced with the aim of maintaining body mass throughout the study and standardizing the participants' dietary intake, aiming to minimize the influence of the diet on the outcomes analyzed. During the first visit, participants' eating habits and preferences were recorded based on a habitual dietary recall conducted alongside the anamnesis. This information served as the foundation for developing personalized dietary guidelines. At the start of the intervention, participants were provided with daily meal suggestions tailored to the study's nutritional recommendations and their individual routines. In addition, directions regarding preexercise and postexercise meals were provided according to the specificities of each group (prescribed by researchers based on participants' eating habits). Individuals in the Fed-RT group were required to consume a meal composed of carbohydrate-rich foods containing approximately 1.0 g/kg of body mass of this macronutrient between 1 and 2 hr before each session. In the Fast-RT group, this amount of carbohydrates was added at another time of the day, and individuals were instructed to perform the sessions after 10–12 hr of fasting. In addition, volunteers in both groups received the prescription of a personalized postexercise mixed meal (0–2 hr after the session) containing 0.25–0.3 g/kg of body mass of protein (Thomas et al., 2016).

Dietary Control

All participants were instructed not to consume alcoholic beverages and/or drinks containing caffeine for at least 48 hr prior to the main study collection days. In addition, they were instructed to perform the prescribed nutritional guidance throughout the study period and to comply with the instructions determined for the preexercise session period (fasted or fed). Three-day food records were filled out by participants preintervention, after 8 weeks of intervention, and after 12 weeks of intervention to verify possible differences in energy and macronutrient consumption as well as adherence to guidelines. Data regarding energy value and amounts of macronutrients consumed were analyzed using the WebDiet nutrition software.

Physical Activity Level Assessment

Participants were instructed not to perform resistance exercises in addition to the intervention sessions. The level of physical activity was measured using the International Physical Activity Questionnaire short version.

Statistical Analysis

Data were structured and analyzed using the statistical package IBM SPSS statistics (Statistical Package for Social Sciences, version 20.0, IBM). Shapiro–Wilk test was performed to verify data normality, and analysis of homoscedasticity of variances was determined by Levene test and sphericity by Mauchly test. Comparisons between groups were carried out using one-way analysis of variance for data with normal distribution and the Mann–Whitney *U* test for data without normal distribution. For comparisons between the effects of the intervention over time between the different groups, generalized estimating equations analyses were applied, adopting the factors Group (two stratifications) and Time (two stratifications). Pairwise comparisons were performed using post hoc least significant difference test to identify differences. Due to the large number of women in each group, such comparisons were performed both with the total sample and only with the female sample (see Supplementary Tables S1–S3 [available online]). All results were expressed as mean and 95% confidence interval, or median and minimum and maximum values when appropriate, and the accepted significance level was 5%. In addition, effect sizes (ES) were calculated for the preintervention and postintervention means as well as for the mean differences between the groups (Hedges' g; Sullivan & Feinn, 2013).

Results

From 37 participants recruited to participate in the study, 28 individuals (six men and 22 women) completed the interventions (Fast-RT: $n = 15$; Fed-RT: $n = 13$). Losses and exclusions that occurred throughout the study were related to difficulties in reconciling training sessions with work and public transport as well as situations of moving to another city, lack of attendance at training, pregnancy, loss of contact, and personal reasons (Figure 2).

All individuals included in the analysis performed the 24 exercise sessions planned throughout the experiment (100% adherence to training). There were no differences between the groups in the RT total workload throughout interventions (Fast-RT: mean [95% confidence interval] = 8,255.34 [7,015.94, 9,494.74] kg vs. Fed-RT: 7,562.04 [6,337.96, 8,786.11] kg; $p = .440$) as well as workloads in the bench press (Fast-RT: 846.60 [632.23, 1,060.97] kg vs. Fed-RT: 685.11 [566.91, 803.32] kg; $p = .413$) and knee extension (Fast-RT: 1,671.00 [1,431.11, 1,910.89] kg vs. Fed-RT: 1,629.19 [1,338.73, 1,919.66] kg; $p = .811$) exercises. There were no differences between the characteristics of the participants before the intervention (Table 1). Furthermore, throughout the intervention period, individuals did not change physical activity levels and diet composition in relation to the amounts of proteins and lipids consumed. At the end of the study (after 12 weeks), reductions in energy consumption ($p = .011$) and carbohydrates ($p = .006$) were observed in both groups when compared with preintervention and post-8 weeks (see Supplementary Table S4 [available online]). Adverse events were reported by 13 participants, including spinal pain (three individuals) and joint pain (four individuals). Participants in the Fast-RT group reported experiencing dizziness (five individuals), tiredness (three individuals), and nausea (two individuals) in some sessions throughout intervention.

Table 1 Characteristics of Participants

	Fast-RT ($n = 15$)	Fed-RT ($n = 13$)
Age, years	29.27 [25.44, 33.09]	28.54 [25.06, 32.01]
Gender, M/F	4/11	2/11
Body mass, kg	70.40 (53.30 and 91.00)	61.40 (49.00 and 96.10)
Height, cm	167.07 [163.31, 170.82]	165.11 [159.52, 170.71]
BMI, kg/m^2	25.73 [23.87, 27.59]	24.12 [21.03, 27.21]

Note. Data are represented as mean (95% confidence interval) or median (minimum and maximum values). Fast-RT = fasting resistance training; Fed-RT = fed resistance training; BMI = body mass index; M = male; F = female.

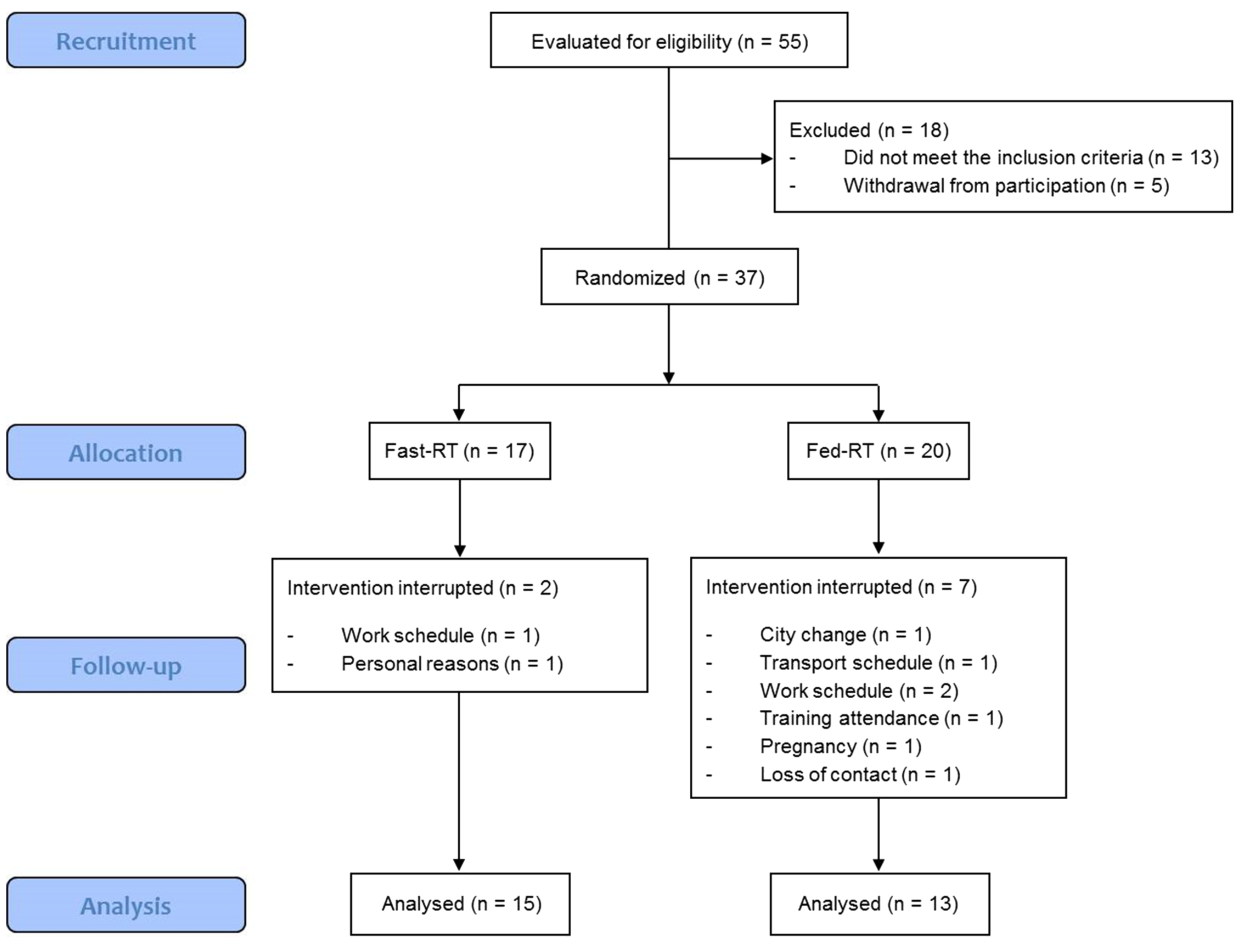

Figure 2 — Study flowchart. Fast-RT = fasting resistance training; Fed-RT = fed resistance training.

Body Composition

There was a significant Time versus Group interaction for fat-free mass outcome ($p = .025$), with no changes in body mass and fat mass (Table 2). Fast-RT group exhibited a significant increase in fat-free mass after 12 weeks ($p \leq .001$), whereas the Fed-RT group showed no significant difference between 0 and 12 weeks ($p = .352$).

Muscle Thickness

Quadriceps femoris muscle thickness increased over time ($p \leq .001$; ES between groups: 0.07) without showing Group versus Time interaction ($p = .871$) or differences between groups ($p = .371$). Mean quadriceps femoris muscle thickness increase was 1.21 cm (9.60 [9.04, 10.16] cm vs. 10.81 [10.22, 11.39] cm; ES: 0.98) and 1.18 cm (9.24 [8.62, 9.86] cm vs. 10.42 [9.86, 10.99] cm; ES: 0.99) after 12 weeks in the Fast-RT group and Fed-RT group, respectively (Figure 3).

Maximum Dynamic Strength (1RM)

Both Fast-RT and Fed-RT groups significantly increased the 1RM values in bench press ($p = .002$; ES between groups: 0.41) and knee extension ($p \leq .001$; ES between groups: 0.07) exercises after 12 weeks of intervention compared with pretraining values. In the bench press exercise, Fast-RT group showed

Table 2 Effects of Interventions on Body Composition Outcomes in the Total Sample: Fast-RT (*n* = 15) and Fed-RT (*n* = 13)

	Pre	Post 12 weeks	ES pre to post	ES between groups	Delta	*p* Group	*p* Time	*p* Group × Time
Body mass, kg								
Fast-RT	71.87 [66.57, 77.17]	73.15 [68.23, 78.08]	0.12	0.06	1.28	.183	.089	.156
Fed-RT	65.95 [57.54, 74.36]	66.07 [58.21, 73.92]	0.01		0.12			
Fat mass, kg								
Fast-RT	26.06 [22.39, 29.73]	26.06 [22.87, 29.25]	0.00	0.00	0.00	.108	.927	.922
Fed-RT	21.20 [16.15, 26.25]	21.14 [16.40, 25.89]	0.01		-0.06			
Fat-free mass, kg								
Fast-RT	44.01 [40.71, 47.30]	45.16 [41.87, 48.45]*,#	0.16	0.06	1.15	.595	.000	.025
Fed-RT	42.70 [37.09, 48.32]	43.01 [37.71, 48.31]	0.03		0.31			

Note. Mean (95% confidence interval). Fast-RT = fasting resistance training; Fed-RT = fed resistance training; ES = effect size (Hedges' *g*).
*Difference from preintervention. #Time versus Group interaction.

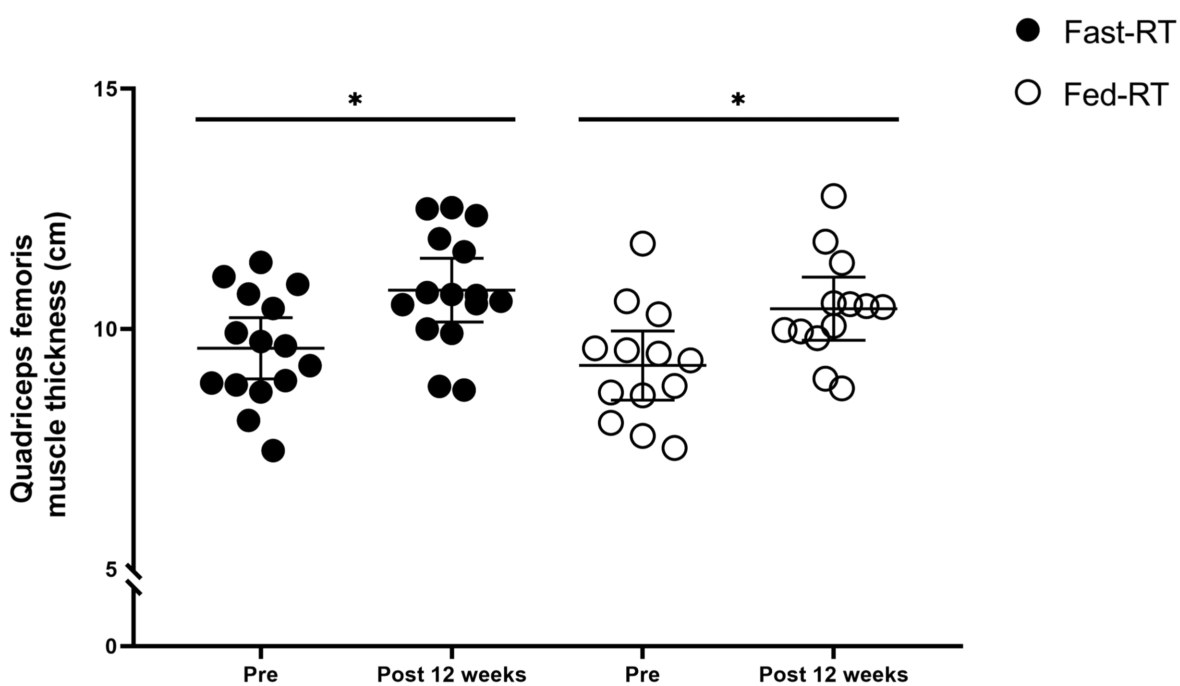

Figure 3 — Mean and 95% confidence interval of quadriceps muscle thickness throughout the intervention. Fast-RT = fasting resistance training; Fed-RT = fed resistance training. *Difference between the preintervention moment and the post 12-week moment considering all groups (time effect).

an increase of 10.53 kg (44.20 [34.40, 53.40] kg vs. 54.73 [44.46, 65.01] kg; ES: 0.49), and Fed-RT group increased by 4.89 kg (38.61 [25.68, 51.55] kg vs. 43.50 [33.88, 53.12] kg; ES: 0.22). Meanwhile, in the knee extension exercise, the increase was 28.53 kg (92.60 [78.79, 106.41] kg vs. 121.13 [107.11, 135.15] kg; ES: 0.96) for Fast-RT group and 29.31 kg (91.15 [76.28, 106.03] kg vs. 120.46 [104.39, 136.53] kg; ES: 0.95) for Fed-RT group (Figure 4).

Muscle Power Output

No significant changes in upper limb muscle power were observed in either the Fast-RT or the Fed-RT groups throughout the intervention. Regarding lower limb muscle power, both groups showed similar increases (time effect) in knee extension mean and maximum power at 30% of 1RM ($p \leq .001$), knee extension mean ($p \leq .001$), and maximal ($p = .005$) power at 70% of 1RM after 12 weeks versus preintervention (Table 3).

Discussion

The main finding of the present study is that morphological and neuromuscular performance adaptations—specifically those related to muscle hypertrophy, strength, and power output—associated with 12 weeks of RT can occur regardless of food consumption before exercise (fasted state vs. fed state). In addition, overnight fasted state and fed state did not influence the total workload and workload in the target exercises across the RT intervention. Considering that acute physical performance may be impaired by fasting and that carbohydrate consumption before resistance exercise sessions may promote ergogenic effects (King et al., 2022), our initial hypothesis was that RT performed in the fasted state would result in smaller neuromuscular adaptive responses. However, only the hypothesis regarding body fat mass was confirmed, as the effects of fasted physical training on this outcome have been previously documented in the literature (Hackett & Hagstrom, 2017).

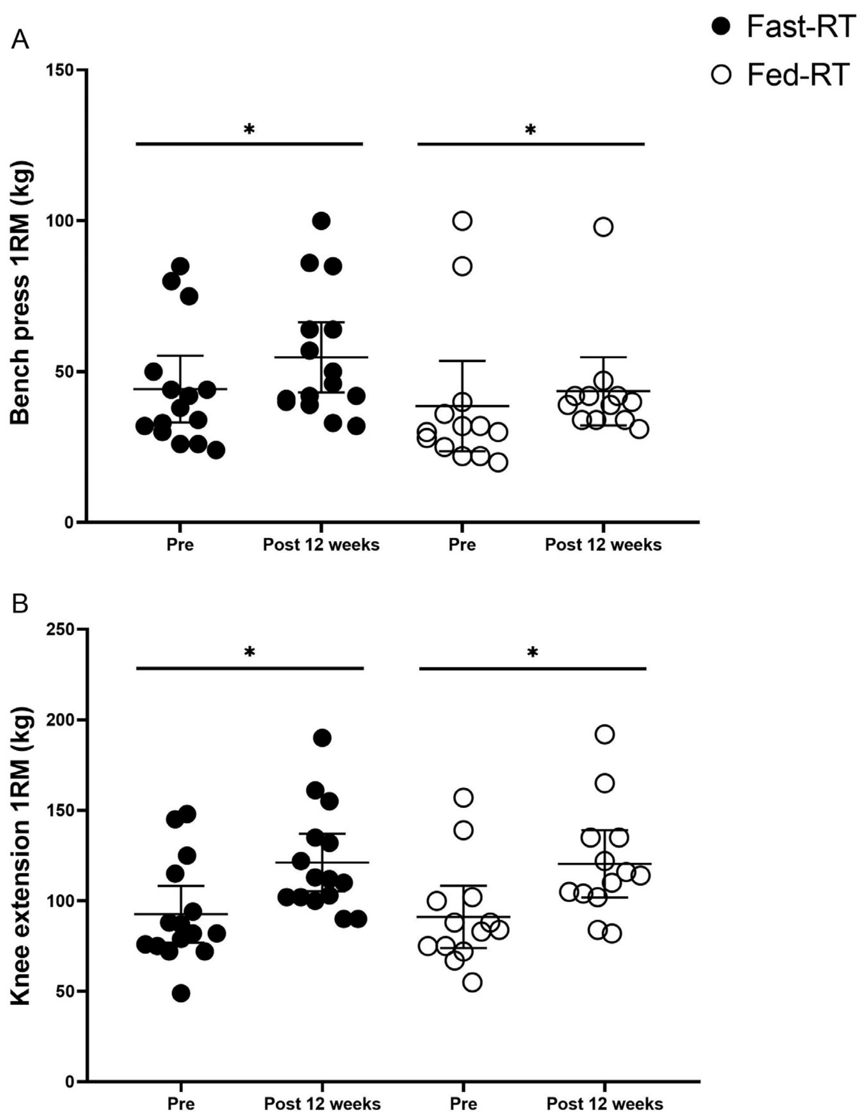

Figure 4 — Mean and 95% confidence interval of maximum muscle strength in the bench press (A) and knee extension (B) exercises throughout the intervention. Fast-RT = fasting resistance training; Fed-RT = fed resistance training; 1RM = one repetition maximum. *Difference between the preintervention moment and the post 12-week moment considering all groups (time effect).

Table 3 Effects of Interventions on Muscle Power in the Total Sample: Fast-RT ($n = 15$) and Fed-RT ($n = 13$)

	Pre	Post 12 weeks	ES Pre to post	ES Between groups	Delta	*p* Group	*p* Time	*p* Group × Time
Bench press mean power 30% 1RM, W								
Fast-RT	216.05 [143.067, 289.03]	252.63 [173.95, 331.30]	0.23	0.25	36.58	.395	.503	.199
Fed-RT	193.22 [95.90, 290.54]	181.72 [110.70, 252.74]	0.07		−11.50			
Bench press maximal power 30% 1RM, W								
Fast-RT	358.95 [237.39, 480.50]	410.36 [283.36, 537.36]	0.19	0.23	51.41	.315	.538	.254
Fed-RT	304.75 [158.04, 451.45]	289.35 [176.97, 401.73]	0.06		-15.40			
Bench press mean power 70% 1RM, W								
Fast-RT	186.93 [130.92, 242.94]	189.07 [129.69, 248.44]	0.01	0.16	2.14	.256	.657	.559
Fed-RT	153.24 [87.49, 218.99]	137.42 [96.23, 178.60]	0.14		-15.82			
Bench press maximal power 70% 1RM, W								
Fast-RT	325.23 [222.33, 428.14]	329.47 [224.81, 434.13]	0.02	0.10	4.24	.367	.789	.678
Fed-RT	273.77 [151.76, 395.78]	254.16 [165.50, 342.82]	0.09		-19.61			
Knee extension mean power 30% 1RM, W								
Fast-RT	203.47 [146.38, 260.55]	233.90 [195.90, 271.90]*	0.29	0.10	30.43	.952	.000	.779
Fed-RT	198.93 [137.47, 260.39]	234.15 [190.06, 278.25]*	0.33		35.22			
Knee extension maximal power 30% 1RM, W								
Fast-RT	443.18 [330.46, 555.90]	544.11 [443.15, 645.07]*	0.44	0.11	100.93	.983	.000	.761
Fed-RT	448.19 [276.50, 619.88]	535.33 [422.36, 648.30]*	0.30		87.14			
Knee extension mean power 70% 1RM, W								
Fast-RT	332.05 [265.49, 398.62]	391.33 [315.71, 466.94]*	0.39	0.18	59.28	.833	.000	.616
Fed-RT	327.26 [232.46, 422.07]	373.47 [308.25, 438.68]*	0.28		46.21			
Knee extension maximal power 70% 1RM, W								
Fast-RT	633.66 [495.39, 771.93]	734.31 [577.75, 890.88]*	0.32	0.29	100.65	.812	.005	.409
Fed-RT	630.07 [426.90, 833.24]	684.83 [555.92, 813.74]*	0.16		54.76			

Note. Mean (95% confidence interval). Fast-RT = fasting resistance training; Fed-RT = fed resistance training; ES = effect size (Hedges' *g*); 1RM = one repetition maximum.
*Difference to preintervention.

The literature indicates that physical performance during high-intensity aerobic exercise (Aird et al., 2018) and resistance exercise (King et al., 2022) may be harmed by fasting prior to the session. King et al. (2022) demonstrated through a systematic review with meta-analysis that consumption of carbohydrates before resistance exercise sessions (>45 min) can improve the number of sets performed compared with exercises performed in the fasted state (≥8 hr). However, taking together results of the present study and others from interventions involving RT (Brinkmann et al., 2019; Triki et al., 2023), it appears that the possible acute reduction in physical performance associated with the lower availability of carbohydrates during sessions performed in the fasted state did not harm long-term training adaptations. In addition, our results demonstrated similarity between the groups in the total RT workload throughout the interventions. Thus, a reduced training stimulus caused by the absence of carbohydrate intake before resistance exercises was not confirmed, and consequently, no attenuated adaptive responses were observed in the group that performed the sessions in the fasted state. Muscle glycogen is considered the main energy substrate used during resistance exercises. It undergoes a reduction of approximately 24%–40% in its concentration during RT sessions, and it is fully synthesized in a period of approximately 24 hr (Burke et al., 2004; Knuiman et al., 2015). Therefore, it is possible to suggest that glycogen was sufficiently reestablished through the diet consumed throughout the period preceding the exercise session (Thomas et al., 2016). In addition, this reserve was able to meet the demands necessary for adaptations in skeletal muscles.

In general, muscle hypertrophy is achieved when the long-term muscle protein synthesis rate is higher relative to muscle protein degradation. These processes are modulated especially by the overload imposed on the muscles by RT and by the availability of energy and amino acids through the diet (Phillips, 2014). Both Fast-RT and Fed-RT groups performed the same RT volume, lifting similar workloads, and showed no differences in average protein (around 1.4 g/kg of body mass per day) and energy consumption during the intervention. Therefore, it is possible to suggest that RT-induced muscle protein synthesis associated with nutrient consumption in the days across interventions was sufficient to generate muscle hypertrophy of similar magnitude. This mechanism may be speculated on based on data available in the literature, which demonstrate that RT comprising a volume of two to three sets per exercise (around 10 weekly sets per muscle group) and of moderate to high intensity with repetitions performed close to muscle failure (Bernárdez-Vázquez et al., 2022), as well as protein consumption of 1.2–2.0 g/kg of body mass per day (Thomas et al., 2016), is an efficient stimulus in generating hypertrophic gains. Furthermore, these results suggest that preexercise food consumption does not generate a significant impact on the total volume of sessions and, consequently, on the adaptive processes in muscle mass arising from RT when the nutritional intake throughout the day is in accordance with the recommendations (Thomas et al., 2016). Nevertheless, this suggestion can be made considering the RT volume applied in the present study.

To our knowledge, only one study has verified the adaptations induced by RT performed during the fasted state on muscle hypertrophy (Triki et al., 2023). Unlike the results obtained in the present study, Triki et al. (2023) found no differences in the muscle thickness of the biceps brachii and quadriceps femoris throughout the Ramadan period in both the group that performed resistance exercise sessions after fasting for 14 hr and the group that consumed food 1–2 hr before exercise. These discrepancies may be attributed to the Ramadan time course of just 4 weeks and the habits adopted in this religious period, especially regarding the possible reduced consumption of nutrients and fluids, as well as changes in the sleep pattern during its practice (Nachvak et al., 2019; Shephard, 2012; Sunardi et al., 2022). Contrary to the findings on muscle hypertrophy, only the Fast-RT group demonstrated a significant increase in fat-free mass after the 12-week intervention. Despite the Time versus Group interaction observed, it should be highlighted that the ES for increases in this outcome were classified as trivial (<0.20) for both the Fast-RT (0.16) and Fed-RT (0.03) groups. Therefore, due to the minimal clinical effect observed, the results concerning fat-free mass should be interpreted with caution. Other studies evaluating fat-free mass have reported no differences between fasting and fed conditions, which contrasts with the findings of the present study (Brinkmann et al., 2019; Trabelsi et al., 2012; Triki et al., 2023).

Most evidence regarding physical exercise performed in the fasted state compared with the fed state comes from studies using aerobic training. When such interventions aim to evaluate adaptations on body fat mass, no additional effects are observed when sessions are performed in the fasted state (Hackett & Hagstrom, 2017). Thus, despite the fact that fat oxidation is significantly greater during aerobic exercise (Vieira et al., 2016) and during resistance exercise (Frawley et al., 2018) performed in the fasted versus fed state, it appears that the use of lipids as the main energy substrate during sessions does not result in a greater reduction in body fat in the long term, especially when the total energy expenditure during the sessions is equivalent between the conditions (Edinburgh et al., 2020). Therefore, the maintenance of fat mass values without differences between the Fast-RT and Fed-RT groups may be explained by the neutral energy balance prescribed in the nutritional guidance for both groups as the main determining factor for reducing body fat is a negative energy balance (Hall et al., 2012; Strasser et al., 2007). Chronically, few studies have evaluated the effects of RT sessions performed while fasting, and corroborating our results regarding body fat mass, no differences are observed between fasted and fed states (Brinkmann et al., 2019; Trabelsi et al., 2012; Triki et al., 2023).

Increases in maximal strength are especially associated with RT intensity (percentage of 1RM; Schoenfeld et al., 2016). Thus, considering the similar intensities used in the Fast-RT and Fed-RT groups, along with the volume of sets and exercises performed during the intervention, it is plausible to expect similar maximal strength gains in both groups. In contrast, Triki et al. (2023) did not observe differences between fasted and fed states in the bench press 1RM following RT conducted during Ramadan, and only the group performing the protocol in the fed state showed an increase in maximal strength in deadlift and squat exercises (Triki et al., 2023). It can be speculated that the differences between those results and the present findings are related to the different training volumes adopted in the protocols (three to four sets with a weekly frequency of four times in their study vs. two to three sets twice weekly in the present study) as well as the probable importance of carbohydrate consumption prior to higher volume exercise sessions (King et al., 2022).

Performing RT in the fasted or fed state apparently did not influence muscle power output adaptations over the 12 weeks of intervention as both groups showed improvements in most of the muscle power outcomes. The absence of significant changes in the bench press maximum and mean power may be related to the fact that the participants performed traditional RT without being encouraged to perform the concentric phase at maximal intentional velocity of execution, which would characterize a more efficient stimulus for muscle power gains. Although traditional RT may result in gains in rapid force outcomes, as observed in most muscle power results of the present study, it constitutes an inferior stimulus when compared with training with high speed in the concentric phase (Müller et al., 2020; Straight et al., 2016). Thus, future studies comparing fasted versus fed states during power training are needed. To our best knowledge, no previous study has verified the effects of RT performed in the fasted state assessing muscle power output; and therefore, further evidence is needed to confirm our results.

Some strengths and limitations of the study need to be highlighted. This was the first study to evaluate adaptations to RT performed in a fasted state using dietary prescription and monitoring besides controlling training workloads and the times of day at which exercise sessions were conducted. Although the diet was individually guided, and adherence was monitored throughout the study, participants did not consume their meals in the laboratory nor were the prescribed foods provided to them in a controlled manner by the researchers. In addition, participants were aware of the content of the preexercise meal as blinding was not applied. Despite the dietary recommendations, participants were observed to reduce their energy and carbohydrate intake during the intervention. However, these changes were consistent across both groups, ensuring that no bias was introduced in the comparisons between conditions. Furthermore, most of the sample consisted of female participants, but the number of women was the same in each group, and analyses were carried out consisting only of the female sample to verify possible differences. Most studies in the area are performed with male samples, and results from interventions applied to women are also needed.

In summary, RT is associated with similar adaptations in the overnight fasted and fed states when daily nutritional support is not affected. These findings are probably explained by the similarity between groups in the energy and macronutrient consumption across the day as well as in the total training workload lifted across the intervention. As a practical application, morphological and neuromuscular performance adaptations associated with RT, performed twice a week, with two to three sets per exercise and progressive loads, may be achieved regardless of the food intake adopted before the exercise sessions (fasted state and fed state). Nonetheless, some individuals may experience dizziness, tiredness, and nausea when sessions are performed in the fasted state. Thus, the findings suggest that the need for nutritional support prior to the sessions may be optional and may be dispensed with in situations of logistical difficulties for meals before exercise (e.g., training very early in the morning) or for individuals who experience gastrointestinal discomfort with food consumption before sessions.

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Nontechnical Summary

Resistance training (RT) provides stimuli for morphological and neural changes, resulting in increases in strength, power output, and muscle mass. Besides the stimulus arising from training, energy consumption and adequate distribution of nutrients in the diet are identified as crucial factors to support these gains. Different nutrition-related methods have been proposed to ensure satisfactory performance during sessions and to enhance adaptations to physical training. A strategy that has been investigated in the literature and that is widely practiced by the population is performing exercise in an overnight fasted state as this practice facilitates daily routines and promotes gastrointestinal comfort in some situations. Some evidence shows that performing physical training with low carbohydrate availability may attenuate performance during sessions. Therefore, it is recommended to intake meals containing carbohydrates before exercise sessions. Studies have demonstrated that consuming carbohydrates before resistance exercises generates ergogenic effects compared with performing the session in a fasted state. Nevertheless, based on limited available evidence, there is no confirmation that the reduction in acute physical performance associated with fasting translates into smaller magnitudes of adaptations to resistance training over time. Therefore, the aim of the present study was to evaluate the effects of 12 weeks of resistance training performed in the fasted state compared with the fed state on body composition, muscle hypertrophy, and mechanical muscle function in young adults. The sample consisted of 28 individuals (six men and 22 women) aged between 20 and 40 years old who were not engaged in regular resistance training. Initially, participants underwent data collection, which included measurements of body mass and height as well as anamnesis (identification data, date of birth, age, eating habits, smoking, health condition, use of medications and supplements), dietary record, and a questionnaire to assess physical activity level. In addition, analysis of basal metabolic rate and a familiarization with neuromuscular performance tests (muscle strength and power) were performed. After that, volunteers were scheduled for a second visit to carry out preintervention procedures. Assessments of outcomes were performed in the following order preintervention and postintervention: body composition, muscle thickness, maximum dynamic strength throughout one repetition maximum (1RM), and muscle power. During this same visit, researchers instructed participants on how to complete the dietary control instrument. In a randomized manner, participants were allocated to groups: fasting RT (participants were instructed to maintain the nutritional guidance received from the researchers throughout the day and performed two weekly resistance exercise sessions after 10–12 hr overnight fast over 12 weeks; Fast-RT, $n = 15$) or fed RT (participants were instructed to maintain the nutritional guidance received from the researchers throughout the day and performed two weekly resistance exercise sessions in the fed state, between 1 and 2 hr after consuming a carbohydrate-rich meal, over 12 weeks; Fed-RT, $n = 13$). Both groups performed the same resistance training, which was conducted on nonconsecutive days between 7 and 10 a.m., with a linear progression in intensity and consisting of seven exercises. This training intervention was combined with individualized nutritional guidance wherein daily energy intake was calculated based on basal metabolic rate multiplied by an activity factor of 1.7. The macronutrient composition included 3.0–5.0 g/kg of body mass per day of carbohydrates, 2.0 g/kg of body mass per day of protein, and fats accounting for 20%–35% of the total energy intake. All individuals included in the analysis performed the 24 exercise sessions planned throughout the experiment (100% adherence to training). There were no differences between the characteristics of the participants before the intervention. Furthermore, throughout the intervention period, individuals did not change physical activity levels and diet composition in relation to the amounts of proteins and lipids consumed. At the end of the study (after 12 weeks), reductions in energy consumption and carbohydrates were observed in both groups. Adverse events were reported by 13 participants, including spinal pain (three individuals) and joint pain (four individuals). Participants in the Fast-RT group reported experiencing dizziness (five individuals), tiredness (three individuals), and nausea (two individuals) in some sessions throughout intervention. Regarding body composition, there was a significant Time versus Group interaction for fat-free mass outcome, with no changes in body mass and fat mass. Fast-RT group exhibited a significant increase in fat-free mass after 12 weeks, whereas the Fed-RT group showed no significant difference between 0 versus 12 weeks. In addition, quadriceps femoris muscle thickness and 1RM values in bench press and knee extension exercises significantly increased over time. No significant changes in upper limb muscle power were observed in either the Fast-RT or Fed-RT groups throughout the intervention. Regarding lower limb muscle power, both groups showed similar increases after 12 weeks versus preintervention. In summary, resistance training induces similar adaptations in the overnight fasted and fed states when daily nutritional support is not affected. As a practical application, morphological and neuromuscular performance adaptations associated with resistance training, performed twice a week, with two to three sets per exercise and progressive loads, may be achieved regardless of the food intake adopted before the exercise sessions. Thus, the findings suggest that the need for nutritional support prior to the sessions may be optional and may be dispensed with in situations of logistical difficulties for meals before exercise (e.g., training very early in the morning) or for individuals who experience gastrointestinal discomfort with food consumption before sessions.