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Full-body resistance training promotes greater fat mass loss than a split-body routine in well-trained males: A randomized trial

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Abstract

While significant progress has been made in understanding the resistance training (RT) strategy for muscle hypertrophy increase, there remains limited knowledge about its impact on fat mass loss. This study aimed to investigate whether full-body is superior to split-body routine in promoting fat mass loss among well-trained males. Twenty-three participants were randomly assigned to 1 of 2 groups: full-body (n = 11, training muscle groups 5 days per week) and split-body (n = 12, training muscle groups 1 day per week). Both groups performed a weekly set volume-matched condition (75 sets/week, 8–12 repetition maximum at 70%–80 % of 1RM) for 8 weeks, 5 days per week with differences only in the routine. Whole-body and regional fat were assessed using DXA at the beginning and at the end of the study. Full-body RT elicited greater losses compared to split-body in whole-body fat mass (–0.775 ± 1.120 kg vs. +0.317 ± 1.260 kg; p = 0.040), upper-limb fat mass (–0.085 ± 0.118 kg vs. +0.066 ± 0.162 kg; p = 0.019), gynoid fat mass (–0.142 ± 0.230 kg vs. +0.123 ± 0.230 kg; p = 0.012), lower-limb fat mass (–0.197 ± 0.204 kg vs. +0.055 ± 0.328 kg; p = 0.040), and a trend in interaction in android fat mass (–0.116 ± 0.153 kg vs. +0.026 ± 0.174 kg; p = 0.051), with large effects sizes ($\eta^2_p \geq 0.17$). This study provides evidence that full-body is more effective in reducing whole-body and regional fat mass compared to split-body routine in well-trained males.

KEYWORDS

body composition, split routine, strength training, total-body routine

Highlights

- For strength and conditioning professionals, as well as practitioners aiming to optimize fat mass loss while minimizing delayed onset muscular soreness induced by training, the full-body routine should be considered and recommended.

Marcelo A. S. Carneiro and Paulo Ricardo P. Nunes share first authorship for contributing equally to this work.

- Our findings shed new light on the manipulation of resistance training variables, particularly training routines, to optimize fat mass loss in the late stages of resistance training.
- This strategy appears to be particularly relevant for individuals aiming for esthetic physique performance.

1 | INTRODUCTION

Bodybuilding competitions involve both professional and amateur esthetic competitors who are assessed based on their muscle hypertrophy, symmetry, and low levels of fat mass (Hackett et al., 2013). As a result, many of these competitors employ various strategies, such as manipulating resistance training (RT) variables, to improve muscle hypertrophy and reduce fat mass to attain their desired physique (American College of Sports Medicine, 2009). While significant progress has been made in understanding the RT strategy for muscle hypertrophy increase, there remains limited knowledge about its impact on fat mass loss.

The split-body routine, where muscle groups are trained once a week, is commonly favored by bodybuilding competitors, including well-trained individuals, for optimizing muscle hypertrophy gains compared to the full-body routine (Hackett et al., 2013). Although existing literature has demonstrated that both routines are similarly effective in promoting muscle hypertrophy under different conditions (Benton et al., 2011; Colquhoun et al., 2018; Gomes et al., 2019; Yue et al., 2018), there is a scarcity of research exploring their effects on fat mass loss. However, a study by Crewther et al. (2016) investigated the effects of full-body RT versus split-body RT on fat mass loss in well-trained individuals and showed that the full-body routine yielded superior improvements in fat mass reduction compared to the split-body routine ($\Delta = -1$ kg vs. -0.5 kg, respectively) (Crewther et al., 2016). Although this study utilized anthropometry, an indirect method to evaluate fat mass changes that can potentially impact the results, it provides evidence suggesting that the full-body routine may be more effective in reducing fat mass compared to the split-body routine.

Furthermore, the full-body routine may be a more effective strategy for fat reduction than the split-body routine due to its potential to induce higher energy expenditure and positively influence fat mass loss (Farinatti et al., 2016; Farinatti & Castinheiras Neto, 2011; Ormsbee et al., 2007, 2009). For instance, a full-body routine that engages large muscle groups on most training days can lead to a greater excess post-exercise oxygen consumption (Farinatti et al., 2016; Farinatti & Castinheiras Neto, 2011), resulting in increased energy expenditure throughout the week (Ormsbee et al., 2007, 2009). This elevated energy expenditure has been associated with higher fat mass loss (Bouchard et al., 2009; Farinatti et al., 2016; Miller et al., 2018; Ormsbee et al., 2007, 2009).

In contrast, the split-body routine, characterized by multiple sets per muscle group, can induce greater muscle fatigue (i.e., substrate energy depletion and accumulated metabolic by-products), delayed onset muscle soreness (DOMS), and reduced training volume due to motor performance impairment along of sets (American College of Sports Medicine, 2009; Gomes et al., 2019; Hotfiel et al., 2018). Previous studies have suggested that muscle fatigue and elevated levels of DOMS may contribute to decreased non-exercise physical activity, such as activities of daily living (Gray et al., 2018; Swelam et al., 2022). Effective fat mass loss requires maintaining a consistent negative caloric balance, achieved through a reduction in food intake, increased energy expenditure, or a combination of both (Christian von Loeffelholz & Birkenfeld, 2018). Physical activity's energy expenditure, a crucial component primarily influenced by individual behavior (King et al., 2007), assumes a pivotal role. Muscle fatigue and increased levels of DOMS can lead to behavioral compensation, resulting in reduced non-exercise physical activity (Martin et al., 2007; Redman et al., 2009), which poses a risk to fat mass loss. Indeed, our previous findings strongly indicate that the split-body routine leads to higher levels of DOMS, especially in the lower limbs (Gomes et al., 2019). Thus, within the split-body routine, training days targeting smaller muscle groups may result in lower energy expenditure and higher levels of DOMS (Farinatti et al., 2016; Farinatti & Castinheiras Neto, 2011; Hotfiel et al., 2018), impairing fat mass loss, given its dependency on energy expenditure (Bouchard et al., 2009; Miller et al., 2018).

Therefore, the primary aim of this study was to investigate whether a full-body routine is superior to a split-body routine in promoting fat mass loss among well-trained males. Additionally, the secondary aim was to assess whether a full-body routine induces lower levels of DOMS compared to a split-body routine. Our hypothesis posits that the full-body routine would result in greater fat mass loss and lower levels of DOMS compared to the split-body routine.

2 | MATERIALS AND METHODS

2.1 | Study design

A 10-week randomized, controlled, and parallel study was conducted, which is an extension of a previously published investigation by Gomes et al., in 2019 (Gomes et al., 2019). In the earlier study, it was established that both RT routines (full-body and split-body) yielded improvements in muscular strength and muscle hypertrophy. The results showed enhancements in bench press (9.7 vs. 5.6 kg), squat (12.0 vs. 8.0 kg), and whole-body lean mass (0.8 vs. 0.5 kg), with no statistically significant differences between the two routines (Gomes et al., 2019). Furthermore, the whole-body RT volume for the full-body routine was 410,652.9 ± 51,940.5 kg, compared to

353,243.5 ± 42,255.3 kg for the split-body routine, indicating superiority for the full-body routine (Gomes et al., 2019). In terms of levels of DOMS, a significant statistical difference between groups was identified (Gomes et al., 2019). The split-body routine induced higher levels of DOMS for chest, elbow flexors and extensors, thigh, and calf muscle groups in weeks 1, 4, and 8 compared to full-body RT (Gomes et al., 2019). For more detailed information on whole-body RT volume and levels of DOMS, please refer to Tables 4 and 5 in the study conducted by Gomes et al., in 2019 (Gomes et al., 2019).

Then, the primary outcome of the current study [fat mass (whole-body and regional fat)] was assessed at the baseline and at the end of RT protocols. The secondary outcomes were assessed as follows: dietary intake (baseline, week four, and at the end of RT interventions), whole-body RT volume, and levels of DOMS (week 2, 5, and 7 of training). Thus, both RT protocols were performed for 8 weeks and performed a five-day-a-week (Monday to Friday) routine. After the RT interventions (week 8), all the assessments were performed 48–72 h after the last training session (Gomes et al., 2019).

2.2 | Participants

Recruitment was carried out through local gyms. Interested well-trained males (who performed RT without supervision) completed detailed anamnesis (age, RT experience, labor situation; health indicators; and history of past and present illnesses and therapeutic and physical activities). The following inclusion criteria were adopted: (1) individuals having at least 3 years uninterrupted experience in RT, (2) bench press/body weight ≥1.0 (reported in Table 1), (3) squat/body weight ratio ≥1.5 (reported in Table 1), (4) absence of myopathies and arthropathies, (5) without any alcohol intake in your diet, (6) non-smoker, (7) do not use dietary supplements, (8) and do not use of pharmacological substances (e.g., anabolic steroids) or any illegal muscle growth agents for at least 1 year before study.

Twenty-three participants were selected for this study. The study was approved by the local Research Ethics Committee and was conducted in accordance with the Declaration of Helsinki. All men gave written informed consent. Then, the RT protocols were randomized according to muscle strength-to-body weight ratio to full-body ($n = 11$) or split-body ($n = 12$) routines using statistical MedCalc® tool (create random group) assigned cases to random groups.

2.3 | Anthropometry and body composition assessments

Body mass was assessed by a portable digital scale (Tanita, model 2001 capacity 150 kg, accuracy 0.1 kg) and height using a stadiometer attached to the scale. For body composition (whole-body fat mass, regional fat mass, and fat mass percentage), X-ray double emission densitometry (DXA) was used using the enCORE 14.10 software (GE/Lunar iDXA Corp.).

All scans were performed with participants lying in the supine position along the table's longitudinal centerline axis. Feet were secured together at the toes to immobilize legs, while hands were maintained in a pronated position within the scanning region. All participants wearing the lightest clothes and remained motionless during the evaluation. Participants were instructed to consume 2 L of water the day before the test and urinate immediately before the scan to standardize the body hydration level. Scans and analyses were performed by the same evaluator on the same day (between 08:00 and 10:00 h) after 8–10 h of fasting to minimize interobserver variations. The upper- and lower-limb were delineated and separated from the trunk, android, and ginoyd region by standard lines. Subsequently, upper-limb fat mass (ULFM) and lower-limb fat mass (LLFM) were established through diagonal bifurcation at the glenomemoral joint and femoral neck, respectively (as illustrated in the equipment manual). Finally, the android fat mass (AFM) and ginoyd fat mass (GFM), designated as regions of interest (ROI), were

TABLE 1 Participant characteristics at the baseline.

	Full-body ($n = 11$)	Split-body ($n = 12$)	P
Age (years)	26 (25.0–28.7)	25.5 (24.0–26.5)	0.267[a]
RT experience (years)	7 (6–8)	6 (4.5–7)	0.131[a]
Body weight (kg)	78.8 ± 9.9	78.2 ± 9.8	0.899[b]
Height (cm)	176.8 ± 4.1	174 ± 5.2	0.173[b]
Fat mass (%)	16.5 ± 5.8	19.2 ± 6.1	0.294[b]
1RM bench press (kg)	100.6 ± 14.5	103.5 ± 15.4	0.652[b]
1RM squat (kg)	123.3 ± 17.5	132.9 ± 28.1	0.344[b]
1RM bench press/body weight	1.3 ± 0.2	1.3 ± 0.1	0.567[b]
1RM squat/body weight	1.6 ± 0.2	1.7 ± 0.3	0.285[b]

Abbreviations: 1RM, one repetition maximum test; RT, resistance training.

[a]Mann Whitney Test. Data are presented in median and interquartile range (P_{25}—P_{75}).

[b]T Test. Data are presented in mean and standard deviation.

automatically determined by autoROI of the enCORE 14.10 software (GE/Lunar iDXA Corp.). The day-to-day coefficient of variation (CV) in calibration are 1.0% for whole-body, 2.8% for arm, 1.6% for leg, and 2.0% for trunk. It has been demonstrated that the iDXA device exhibits a low CV for fat mass (whole-body and regional fat) (Rothney et al., 2012).

2.4 | Dietary intake assessment

A dietary record was made three times during the study: 3 days before starting the study, at the end of the fourth week and shortly after the 8 weeks of RT intervention. Subjects correctly completed the record of all foods consumed and their respective portion sizes and markings within the indicated period. The record was reviewed by a sports nutrition professional who used DietSmart version 7.7 software. The foods were individually entered into the software, and it provided relevant information such as total energy (kcal), protein amount, carbohydrate, and fat. To avoid nutritional interference in the study, subjects were advised to follow their usual dietary regimen. To ensure adequate protein intake, a whey protein supplement containing 24 g protein and 6.4 g carbohydrate was provided to all volunteers. The supplement was consumed immediately after each section held at the training site itself.

2.5 | Delayed onset muscle soreness

A visual numeric pain rating scale was used to detect DOMS (McCaffery & Pasero, 1999). All volunteers self-reported the subjective DOMS (scale 0–10) according to the body segments (chest, elbow flexors, elbow extensors, thigh, and calf) the day after (24 h) the first and the last RT session, in the weeks one, four and eight. The overall mean DOMS following the 8 weeks of RT of the body segments was calculated.

2.6 | Resistance training protocols

The RT protocol and 1-RM test for load intensity prescription has already been described elsewhere (Gomes et al., 2019). Briefly, RT was performed for 5 days a week from Monday to Friday over 8 weeks. Both groups performed two different RT routines (full-body or split-body) on a weekly set volume-matched condition (75 sets/week), 8–12 repetition maximum at 70%–80% of 1RM and 90 s rest between sets and exercises. A warm-up with 15 repetitions with submaximal loads (50% of 1RM) was performed before each exercise. At the end of the training sessions, stretching exercises were performed to cool down. During the training intervention, if the volunteer were able to perform more than 12 repetitions in the first set of each exercise, the load would be adjusted by 5%–10% to ensure the maximum repetitions between 8 and 12 repetitions and to maintain relative intensity and progressive overload. Total training volume was calculated in all exercise sessions for all exercises, as follows: load × repetitions × sets.

Specifically, the full-body group performed a routine for all body segments from Monday to Friday—two sets (bench press, seated row, hamstring curl, calf standing, lumbar spine flexors and extensors) and one set (leg press, back squat, barbell curl, elbow extensors and lateral raises). Moreover, the full-body group (trained the target muscle groups every day for 5 days) performed all exercises in each training session while the split-body group (trained the target muscle groups once a week) performed 2 exercises in each training session.

On the other hand, the split-body group performed a split training routine according to body segments: Monday—bench press and elbow extensors, Tuesday—leg press and back squat, Wednesday—seated row and barbell curl, Thursday—Hamstring curl and calf standing, Friday—lateral raises, lumbar spine flexors and extensors. In each session, the split-body group performed 10 sets per exercise (except for the elbow extensors, barbell curl, lateral raise, squat, and leg press which performed five sets).

2.7 | Statistical analyses

Data distribution was assessed by the Shapiro-Wilk test. The parametric data are presented as mean and standard deviation or 95% confidence interval (delta values and total training volume). Delta values were calculated by subtracting the baseline value from the post-intervention value. The non-parametric data are presented by median and interquartile range (25–75). The Student's independent *t*-test or Mann-Whitney test were used to compare baseline characteristics between groups (split-body and full-body). Repeated-measure ANOVA was used to determine group effects, time (pre and post) and time interaction by group. The partial eta-squared (η_p^2) effect size and the observed statistical power were performed. Cohen (1988) provided benchmarks to define small ($\eta_p^2 = 0.01$), medium ($\eta_p^2 = 0.06$) and large ($\eta_p^2 = 0.14$) effects (Cohen, 1988). Correlation Coefficient of Pearson was used to verify association between variables. Statistical significance was considered at $p < 0.05$. All analyses were performed in the JAMOVI project 2023 version 2.3.13.0 (Sydney, Australia).

3 | RESULTS

Table 1 shows participants characteristics at the baseline. There were no differences between groups regarding age, RT experience, anthropometric, fat percentage, and muscular strength ($p > 0.05$).

Table 2 shows dietary intake at the baseline, week 4 and week 8 of intervention. There were no differences in within or between subjects at the beginning, week four, and at the end of the study (p Time > 0.05). In addition, adherences to the full-body RT and the split-body RT were 98% and 97%, respectively.

TABLE 2 Dietary intake following 8 weeks of resistance training between groups.

	Pre	Full-body week 4	Post	Pre	Split-body week 4	Post	P group	P time	P interaction
Energy (kcal/kg)	31.2 ± 1.7	31.0 ± 1.3	31.4 ± 1.6	31.2 ± 2.1	31.2 ± 2.0	31.0 ± 1.6	0.946	0.919	0.721
Protein (g/kg)	1.9 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	0.896	0.066	0.758
Carbohydrate (g/kg)	3.3 ± 0.3	3.5 ± 0.3	3.4 ± 0.2	3.3 ± 0.2	3.3 ± 0.3	3.3 ± 0.2	0.369	0.930	0.269
Fat (g/kg)	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	0.615	0.346	0.534

Note: Repeated-measure ANOVA was used to compare the groups, time, and time interaction. Data are presented as mean and standard deviation.

Table 3 displays fat mass measurements at baseline (Pre) and week 8 (Post) of the intervention, along with delta values from the training routines. A significant interaction ($p < 0.05$, time vs. group) was observed for whole-body fat mass (full-body RT: Δ% = −5.7 and split-body RT: Δ% = 2.1, *F*-value = 4.801), ULFM (full-body RT: Δ% = −5.5 and split-body RT: Δ% = 4.2, *F*-value = 6.474), GFM (full-body RT: Δ% = −6.2 and split-body RT: Δ% = 5.1, *F*-value = 7.601), and LLFM (full-body RT: Δ% = −4.5 and split-body RT: Δ% = 1.1, *F*-value = 4.780). A trend in interaction for AFM was also noted (full-body RT: Δ% = −12.5 and split-body RT: Δ% = 2.6%, *F*-value = 4.290). In all cases, the effect size was large, and the observed power was moderate. This indicates that the full-body routine resulted in a more significant decrease in fat mass compared to the split-body routine, highlighting a differential impact of the two training approaches on fat mass outcomes.

Regarding the whole-body RT volume (sum of all RT volume over the 8 weeks), we observed that the full-body RT volume was 16% higher than the split-body group. In addition, when we included all warm-up sets performed in each routine, we found a significant mean difference of 221,100.00 kg ($p < 0.001$) in favor of the full-body routine (615,652.00 ± 76,591.00 kg) over the split-body routine (394,552.00 ± 52,150.00 kg), indicating the superiority of whole-body RT volume.

We also observed that the overall levels of DOMS (mean of all RT sessions over the 8 weeks) was higher in the split-body group when compared to the full-body group. For more specific details regarding whole-body RT volume and levels of DOMS, consult Tables 4 and 5 from the study conducted by Gomes et al. (2019). In week 1, split-body routine resulted in higher levels of DOMS compared to full-body routine. The levels were 6.2 times higher for the chest, 4.3 times higher for the elbow flexors, 5 times higher for the elbow extensors, 6 times higher for the thigh, and 7 times higher for the calf. In week 4, split-body routine continued to show higher levels of DOMS, with increases of 5.5 times for the chest, 4.5 times for the elbow flexors, 3.5 times for the elbow extensors, 7.5 times for the thigh, and 4.5 times for the calf. By week 8, split-body routine still generated higher levels of DOMS, with increases of 5 times for the chest, 3.5 times for the elbow flexors, 4 times for the elbow extensors, 6.5 times for the thigh, and 5.5 times for the calf. Additionally, throughout weeks 1, 4, and 8, we observed greater levels of DOMS in the lower limbs compared to the upper limbs in the split-body routine.

The whole-body RT volume over the 8-week intervention period, excluding warm-up sets, did not show a correlation with fat mass loss, as illustrated in Table 4. However, when including all warm-up sets in whole-body RT volume for each routine, we observed a correlation specifically for ULFM ($r = -0.488$, $p = 0.018$) and GFM ($r = -0.418$, $p = 0.047$). Nevertheless, the whole-body RT volume plus all warm-up sets did not demonstrate a correlation with fat mass loss for whole-body fat mass, LLFM, AFM, and TFM ($r = -0.333$, $p = 0.121$; $r = -0.322$, $p = 0.133$; $r = -0.283$, $p = 0.191$; $r = -0.231$, $p = 0.289$, respectively). Conversely, lower levels of DOMS were correlated with fat mass loss, as indicated in Table 4.

4 | DISCUSSION

The comparison between the full-body routine and the split-body routine was carried out to assess their impact on whole-body and regional fat mass loss and levels of DOMS. The main finding of this study indicates that the full-body routine protocol leads to a greater reduction in whole-body and regional fat compared to the split-body routine. Additionally, lower levels of DOMS were observed with the full-body routine. Therefore, our results suggest that full-body routine, with its lower levels of DOMS, may be more effective for fat mass loss in well-trained males. This strategy appears to be particularly relevant for individuals aiming for esthetic physique performance.

In the context of bodybuilding competitions, participants are evaluated based on low levels of fat mass, muscle hypertrophy, bodily symmetry, and overall performance (Hackett et al., 2013). The strategies employed by esthetic physique competitors in pursuit of muscle hypertrophy and fat mass loss may also be relevant to non-competitive individuals, particularly well-trained males (American College of Sports Medicine, 2009). In our study, the full-body routine protocol was found to be more effective in reducing both whole-body and regional fat mass (including gynoid, upper- and lower-limb) compared to the split-body routine. Importantly, our results demonstrated large effect sizes ($\eta_p^2 \geq 0.17$, Table 3), exceeding the coefficient of variation of DXA (>1.0%, as indicated by individual percentages changes in the results section). These findings are consistent with previous studies by Crewther et al. (2016) (Crewther et al., 2016; ; Pina et al., 2020), which have shown that only the RT protocol resulting in higher energy expenditure throughout the week optimize fat mass loss (Crewther et al., 2016; McCaffery & Pasero, 1999). Therefore, from a practical standpoint, when RT volume is matched, the full-body routine may be a critical training

TABLE 3 Fat mass following 8 weeks of resistance training between groups.

	Full-body			Split-body							
	Pre	Post	Δ	Pre	Post	Δ	*P* group	*P* time	*P* interaction	η^2_p	Power
WBFM (kg)	13.50 ± 6.25	12.70 ± 5.89	−0.775 ± 1.120	14.50 ± 4.79	14.80 ± 4.88	+0.317 ± 1.260	0.497	0.368	0.040	0.186	0.55
ULFM (kg)	1.520 ± 0.655	1.430 ± 0.599	−0.085 ± 0.118	1.550 ± 0.558	1.620 ± 0.586	+0.066 ± 0.162	0.671	0.930	0.019	0.236	0.67
GFM (kg)	2.270 ± 1.200	2.120 ± 1.090	−0.142 ± 0.230	2.400 ± 0.721	2.530 ± 0.754	+0.123 ± 0.230	0.502	0.846	0.012	0.266	0.74
LLFM (kg)	4.350 ± 1.890	4.150 ± 1.800	−0.197 ± 0.204	4.980 ± 1.400	5.030 ± 1.490	+0.055 ± 0.328	0.282	0.340	0.040	0.186	0.55
AFM (kg)	0.928 ± 0.695	0.812 ± 0.638	−0.116 ± 0.153	0.974 ± 0.556	1.000 ± 0.552	+0.026 ± 0.174	0.647	0.241	0.051	0.170	0.50
TFM (kg)	6.670 ± 3.760	6.190 ± 3.510	−0.479 ± 0.892	7.090 ± 2.890	7.240 ± 2.900	+0.151 ± 0.969	0.593	0.460	0.121	0.111	0.33

Note: Repeated-measure ANOVA was used to compare the groups, time, and time interaction. Data are presented as mean and standard deviation.
Abbreviations: AFM, android fat mass; GFM, ginoyd fat mass; LLFM, lower limb fat mass; TFM, trunk fat mass; ULFM, upper limb fat mass; WBFM, whole-body fat mass; Δ, post minus pre.

strategy for improving fat mass, which is essential for enhancing esthetic physique performance and promoting a satisfactory body image (Garber et al., 2011).

It has been postulated that fat mass loss is influenced, at least in part, by the imbalance between energy intake and energy expenditure (Bouchard et al., 2007; Miller et al., 2018) and increased fat metabolism (Ormsbee et al., 2007, 2009). RT protocol that engages large muscle groups, such as the full-body routine, induces greater excess post-exercise oxygen consumption, as consequence of a higher energy expenditure (Farinatti et al., 2016; Farinatti & Castinheiras Neto, 2011). Furthermore, evidence suggests that the full-body RT may have a positive acute effect on fat metabolism (Farinatti et al., 2016; Farinatti & Castinheiras Neto, 2011; Ormsbee et al., 2007, 2009). In contrast, performing a higher number of sets (>3) per muscle group in the split-body routine may lead to muscle fatigue, resulting from substrate energy depletion and accumulation of metabolic products (Gomes et al., 2019; McCaffery & Pasero, 1999). These effects can lead to reduced motor performance (McCaffery & Pasero, 1999), manifested by a decrease in the number of repetitions and overall training volume (American College of Sports Medicine, 2009). Additionally, our observations indicate that an increased occurrence of DOMS may be associated with a higher number of sets performed per muscle group in the split-body routine, resulting in more pronounced muscle fatigue (American College of Sports Medicine, 2009). Indeed, previous studies have established a connection between lower levels of non-exercise physical activity (e.g., activities of daily living) and both muscle fatigue and higher levels of DOMS (Gray et al., 2018; Swelam et al., 2022). This, in turn, can lead to impaired muscular performance, such as reduced strength, as well as increased pain, stiffness, and swelling, which may hinder the execution of certain movements (McCaffery & Pasero, 1999). Moreover, studies have demonstrated that a lower volume performed during a RT session in response to a perturbation, such as fatiguing RT routine as a split-body training, affects total energy expenditure (Farinatti et al., 2016; Farinatti & Castinheiras Neto, 2011; Haddock & Wilkin, 2005). Therefore, split-body RT approach may to be less efficient in fat mass loss since it depends, at least partially, on energy expenditure (Bouchard et al., 2007; Miller et al., 2018). Conversely, the full-body routine, with its potential for increased total energy expenditure (Farinatti et al., 2016; Farinatti & Castinheiras Neto, 2011), appears to have a more positive impact on fat mass loss compared to more fatiguing RT protocols (Crewther et al., 2016).

Notably, the greater whole-body RT volume (TTV) did not distinctly correlate with promoting fat mass loss in well-trained men. While an association existed between whole-body RT volume and upper limb fat mass (ULFM) ($r = -0.488$, $p = 0.018$) and gynoid fat mass (GFM) ($r = -0.418$, $p = 0.047$), no correlation was observed with any other fat mass markers. Conversely, levels of DOMS emerged as a more reliable predictor of fat mass loss, exhibiting positive associations with changes (Δ) in all indicators of fat mass (see Table 4). This suggests that factors beyond total RT volume contribute to the interference effect on fat mass loss. These findings

TABLE 4 Correlation between delayed onset muscle soreness, total resistance training volume, and fat mass following 8 weeks of resistance training.

	Δ WBFM	Δ ULFM	Δ GFM	Δ LLFM	Δ AFM	Δ TFM	Δ TTV
DOMS	$r = 0.46$	$r = 0.44$	$r = 0.49$	$r = 0.41$	$r = 0.45$	$r = 0.37$	$r = -0.47$
	$p = 0.025$	$p = 0.035$	$p = 0.016$	$p = 0.052$	$p = 0.030$	$p = 0.083$	$p = 0.022$
TTV	$r = -0.12$	$r = -0.30$	$r = -0.18$	$r = -0.11$	$r = -0.06$	$r = -0.05$	
	$p = 0.578$	$p = 0.156$	$p = 0.392$	$p = 0.612$	$p = 0.768$	$p = 0.815$	

Note: Correlation Coefficient of Pearson was used to verify association between variables.

Abbreviations: AFM, android fat mass; DOMS, delayed onset muscle soreness; GFM, ginoyd fat mass; LLFM, lower limbs fat mass; TFM, trunk fat mass; TTV, total training volume; ULFM, upper limbs fat mass; WBFM, whole-body fat mass; Δ, post minus pre.

align with the previously proposed hypothesis that elevated levels of DOMS in the split-body routine may result from restricted movement and reduced daily activities due to increased pain and fatigue (American College of Sports Medicine, 2009; Cheung et al., 2003; Stone et al., 2021). Moreover, the elevated levels of DOMS appear linked to movement restriction (e.g., reduced activities of daily living) due to the severity of pain (Cheung et al., 2003), in comparison to a full-body routine. Muscle fatigue and heightened DOMS can lead to behavioral compensation, resulting in decreased non-exercise physical activity and reduced daily total energy expenditure (Christian von Loeffelholz & Birkenfeld, 2018; King et al., 2007; Martin et al., 2007; Redman et al., 2009), posing a risk to fat loss (Hill et al., 2013; Speakman & Selman, 2003). Thus, our findings suggest that levels of DOMS may be a crucial factor to consider in RT for fat mass reduction. However, it is essential to note that our study did not measure the level of physical activity. Consequently, further research is necessary to comprehensively understand the role of DOMS in RT-induced fat mass reduction.

While this study offers valuable insights, it is essential to recognize its limitations. Despite the large effect sizes and moderate observed power in our results, the small participant size, inherent to the study's focus on well-trained males, may have compromised the statistical analyses. Additionally, there was no assessment of energy expenditure and physical activity. Lastly, an uneven distribution of warm-up sets between the groups resulted in a higher total volume for the full-body group.

While acknowledging certain limitations, this study demonstrates several strengths. Firstly, it employed a controlled and randomized design, incorporating inclusion criteria that guaranteed a representative sample of well-trained males in resistance training, thereby mitigating potential biases. Secondly, meticulous records of all training variables (including intensity, volume, frequency, and movement velocity) were maintained, ensuring specificity. Additionally, diet monitoring was rigorously implemented to further minimize bias and random error. Thirdly, the close supervision of study participants by experienced fitness professionals, coupled with their high compliance throughout the interventions, enhances the reliability of the findings. Lastly, the utilization of dual-energy X-ray absorptiometry (DXA) for assessing fat mass variation during the intervention added precision and minimized potential sources of bias and random error.

In conclusion, this study provides evidence that the full-body routine is more effective in reducing both whole-body and regional fat mass compared to the split-body routine in well-trained males. These findings shed new light on the manipulation of RT variables, particularly training routines, to optimize fat mass loss in the late stages of RT. From a practical standpoint, for strength and conditioning professionals, as well as practitioners aiming to optimize fat mass loss while minimizing levels of DOMS-induced by training, the full-body routine should be considered and recommended as a RT program for promoting fat mass loss in well-trained males.

AUTHOR CONTRIBUTIONS

Substantial contributions to the conception or design of the work; or acquisition, analysis or interpretation of data for the work: Marcelo A. S. Carneiro, Paulo Ricardo P. Nunes, Markus V. C. Souza, Cláudio O. Assumpção, and Fábio L. Orsatti. Drafting the work or reviewing it critically for important intelectual content: Marcelo A. S. Carneiro, Paulo Ricardo P. Nunes, Markus V. C. Souza, Cláudio O. Assumpção, and Fábio L. Orsatti. Final approval of the version to be published: Marcelo A. S. Carneiro, Paulo Ricardo P. Nunes, Markus V. C. Souza, Cláudio O. Assumpção, and Fábio L. Orsatti. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Marcelo A. S. Carneiro, Paulo Ricardo P. Nunes, Markus V. C. Souza, Cláudio O. Assumpção, and Fábio L. Orsatti.

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CONFLICT OF INTEREST STATEMENT

The authors declare there are no competing interests.

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REFERENCES

American College of Sports Medicine. 2009. “American College of Sports Medicine Position Stand. Progression Models in Resistance Training for Healthy Adults.” *Medicine & Science in Sports & Exercise* 41(3): 687–708.

Benton, Melissa J., Mark J. Kasper, Scot A. Raab, Green T. Waggener, and Pamela D. Swan. 2011. “Short-term Effects of Resistance Training Frequency on Body Composition and Strength in Middle-Aged Women.” *The Journal of Strength & Conditioning Research* 25(11): 3142–9: LWW. https://doi.org/10.1519/jsc.0b013e31820f505f.

Bouchard, D. R., S. Beliaeff, I. J. Dionne, and M. Brochu. 2007. “Fat Mass but Not Fat-free Mass Is Related to Physical Capacity in Well-Functioning Older Individuals: Nutrition as a Determinant of Successful Aging (NuAge)—The Quebec Longitudinal Study.” *J Gerontol A Biol Sci Med Sci* 62(12): 1382–8: Oxford University Press. https://doi.org/10.1093/gerona/62.12.1382.

Bouchard, Danielle R., Lisa Soucy, Martin Sénéchal, Isabelle J. Dionne, and Martin Brochu. 2009. “Impact of Resistance Training with or without Caloric Restriction on Physical Capacity in Obese Older Women.” *Menopause* 16(1): 66–72: LWW. https://doi.org/10.1097/gme.0b013e31817dacf7.

Cheung, Karoline, Patria A. Hume, and Linda Maxwell. 2003. “Delayed Onset Muscle Soreness: Treatment Strategies and Performance Factors.” *Sports Medicine* 33(2): 145–64. https://doi.org/10.2165/00007256-200333020-00005.

Christian von Loeffelholz, M. D., and A. Birkenfeld. 2018. The Role of Non-exercise Activity Thermogenesis in Human Obesity. Endotext, {Internet}: Last updated Apr 9.

Cohen, J. 1988. *Statistical Power Analysis Forthe Behavioural Sciences*. Hillsdale NJ: Baskı.

Colquhoun, Ryan J., Christopher M. Gai, Danielle Aguilar, Daniel Bove, Jeffrey Dolan, Andres Vargas, Kaylee Couvillion, Nathaniel D. M. Jenkins, and Bill I. Campbell. 2018. “Training Volume, Not Frequency, Indicative of Maximal Strength Adaptations to Resistance Training.” *The Journal of Strength & Conditioning Research* 32(5): 1207–13: LWW. https://doi.org/10.1519/jsc.0000000000002414.

Crewther, Blair, Taati Heke, and Justin Keogh. 2016. “The Effects of Two Equal-Volume Training Protocols upon Strength, Body Composition and Salivary Hormones in Male Rugby Union Players.” *Biology of Sport* 33(2): 111–6: Termedia. https://doi.org/10.5604/20831862.1196511.

Farinatti, P., A. G. C. Neto, and P. R. S. Amorim. 2016. “Oxygen Consumption and Substrate Utilization during and after Resistance Exercises Performed with Different Muscle Mass.” *Int J Exerc Sci* 9(1): 77: Western Kentucky University.

Farinatti, Paulo T. V., and Antonio G. Castinheiras Neto. 2011. “The Effect of Between-Set Rest Intervals on the Oxygen Uptake during and after Resistance Exercise Sessions Performed with Large- And Small-Muscle Mass.” *The Journal of Strength & Conditioning Research* 25(11): 3181–90: LWW. https://doi.org/10.1519/jsc.0b013e318212e415.

Garber, Carol Ewing, Bryan Blissmer, Michael R. Deschenes, Barry A. Franklin, Michael J. Lamonte, I.-Min Lee, David C. Nieman, and David P. Swain. 2011. “American College of Sports Medicine Position Stand. Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise.” *Medicine & Science in Sports & Exercise* 43(7): 1334–59. https://doi.org/10.1249/mss.0b013e318213fefb.

Gomes, Gederson K., Cristiane M. Franco, Paulo Ricardo P. Nunes, and Fábio L. Orsatti. 2019. “High-frequency Resistance Training Is Not More Effective Than Low-Frequency Resistance Training in Increasing Muscle Mass and Strength in Well-Trained Men.” *The Journal of Strength & Conditioning Research* 33(1): S130–9: LWW. https://doi.org/10.1519/jsc.0000000000002559.

Gray, Phillip, Marie Murphy, Alison Gallagher, and Ellen Elizabeth Anne Simpson. 2018. “A Qualitative Investigation of Physical Activity Compensation Among Older Adults.” *British Journal of Health Psychology* 23(1): 208–24: Wiley Online Library. https://doi.org/10.1111/bjhp.12282.

Hackett, Daniel A., Nathan A. Johnson, and C.-Moi Chow. 2013. “Training Practices and Ergogenic Aids Used by Male Bodybuilders.” *The Journal of Strength & Conditioning Research* 27(6): 1609–17: LWW. https://doi.org/10.1519/jsc.0b013e318271272a.

Haddock, B. L., and L. D. Wilkin. 2005. “Resistance Training Volume and Post Exercise Energy Expenditure.” *Int J Sports Med* 27(2): 143–8: © Georg Thieme Verlag KG Stuttgart New York. https://doi.org/10.1055/s-2005-865601.

Hill, James O., Holly R. Wyatt, and John C. Peters. 2013. “The Importance of Energy Balance.” *European Endocrinology* 9(2): 111: Touch Medical Media. https://doi.org/10.17925/ee.2013.09.02.111.

Hotfiel, Thilo, Jürgen Freiwald, Matthias Hoppe, Christoph Lutter, Raimund Forst, Casper Grim, Wilhelm Bloch, Moritz Hüttel, and Rafael Heiss. 2018. “Advances in Delayed-Onset Muscle Soreness (DOMS): Part I: Pathogenesis and Diagnostics.” *Sportverletzung - Sportschaden* 32(04): 243–50: © Georg Thieme Verlag KG. https://doi.org/10.1055/a-0753-1884.

King, Neil A., Phillipa Caudwell, Mark Hopkins, Nuala M. Byrne, Rachel Colley, Andrew P. Hills, James R. Stubbs, and John E. Blundell. 2007. “Metabolic and Behavioral Compensatory Responses to Exercise Interventions: Barriers to Weight Loss.” *Obesity* 15(6): 1373–83: Wiley Online Library. https://doi.org/10.1038/oby.2007.164.

Martin, Corby K., Leonie K. Heilbronn, Lilian de Jonge, James P. DeLany, Julia Volaufova, Stephen D. Anton, Leanne M. Redman, Steven R. Smith, and Eric Ravussin. 2007. “Effect of Calorie Restriction on Resting Metabolic Rate and Spontaneous Physical Activity.” *Obesity* 15(12): 2964–73: Wiley Online Library. https://doi.org/10.1038/oby.2007.354.

McCaffery, M., and C. Pasero. 1999. *Pain: Clinical Manual*. Mosby Incorporated.

Miller, Todd, Stephanie Mull, Alan Albert Aragon, James Krieger, and Brad Jon Schoenfeld. 2018. “Resistance Training Combined with Diet Decreases Body Fat while Preserving Lean Mass Independent of Resting Metabolic Rate: a Randomized Trial.” *International Journal of Sport Nutrition and Exercise Metabolism* 28(1): 46–54: Human Kinetics. https://doi.org/10.1123/ijsnem.2017-0221.

Ormsbee, Michael J., Myung Dong Choi, Justin K. Medlin, Gabriel H. Geyer, Lauren H. Trantham, Gabriel S. Dubis, and Robert C. Hickner. 2009. “Regulation of Fat Metabolism during Resistance Exercise in Sedentary Lean and Obese Men.” *Journal of Applied Physiology* 106(5): 1529–37: American Physiological Society. https://doi.org/10.1152/japplphysiol.91485.2008.

Ormsbee, Michael J., John P. Thyfault, Emily A. Johnson, Raymond M. Kraus, Myung Dong Choi, and Robert C. Hickner. 2007. “Fat Metabolism and Acute Resistance Exercise in Trained Men.” *Journal of Applied Physiology* 102(5): 1767–72: American Physiological Society. https://doi.org/10.1152/japplphysiol.00704.2006.

Pina, Fábio L. C., João Pedro Nunes, Brad J. Schoenfeld, Matheus A. Nascimento, Aline M. Gerage, Renata S. B. Januário, Nelson H. Carneiro, Edilson S. Cyrino, Arli R. Oliveira, and A. R. Oliveira. 2020. “Effects of Different Weekly Sets-Equated Resistance Training Frequencies on Muscular Strength, Muscle Mass, and Body Fat in Older Women.” *The Journal of Strength & Conditioning Research* 34(10): 2990–5. https://doi.org/10.1519/jsc.0000000000003130.

Redman, Leanne M., Leonie K. Heilbronn, Corby K. Martin, Lilian de Jonge, Donald A. Williamson, James P. Delany, Eric Ravussin, and P. C. Team. 2009. “Metabolic and Behavioral Compensations in Response to Caloric Restriction: Implications for the Maintenance of Weight Loss.” *PLoS One* 4(2): e4377: Public Library of Science San Francisco, USA. https://doi.org/10.1371/journal.pone.0004377.

Rothney, Megan P., F.-Pierre Martin, Yi Xia, Maurice Beaumont, Cynthia Davis, David Ergun, Laurent Fay, et al. 2012. "Precision of GE Lunar iDXA for the Measurement of Total and Regional Body Composition in Nonobese Adults." *Journal of Clinical Densitometry* 15(4): 399–404: Elsevier. https://doi.org/10.1016/j.jocd.2012.02.009.

Speakman, John R., and Colin Selman. 2003. "Physical Activity and Resting Metabolic Rate." *Proceedings of the Nutrition Society* 62(3): 621–34: Cambridge University Press. https://doi.org/10.1079/pns2003282.

Stone, Michael H., William G. Hornsby, G. Gregory Haff, Andrew C. Fry, Dylan G. Suarez, Junshi Liu, Jose M. Gonzalez-Rave, and Kyle C. Pierce. 2021. "Periodization and Block Periodization in Sports: Emphasis on Strength-Power Training—A Provocative and Challenging Narrative." *The Journal of Strength & Conditioning Research* 35(8): 2351–71: LWW. https://doi.org/10.1519/jsc.0000000000004050.

Swelam, Brittany A., Simone J. J. M. Verswijveren, Jo Salmon, Lauren Arundell, and Nicola D. Ridgers. 2022. "Exploring Activity Compensation Amongst Youth and Adults: a Systematic Review." *International Journal of Behavioral Nutrition and Physical Activity* 19(1): 1–25: BioMed Central. https://doi.org/10.1186/s12966-022-01264-6.

Yue, Fu Leon, Bettina Karsten, Eneko Larumbe-Zabala, Marcos Seijo, and Fernando Naclerio. 2018. "Comparison of 2 Weekly-Equalized Volume Resistance-Training Routines Using Different Frequencies on Body Composition and Performance in Trained Males." *Applied Physiology Nutrition and Metabolism* 43(5): 475–81: NRC Research Press. https://doi.org/10.1139/apnm-2017-0575.