Evidence for an Upper Threshold for Resistance Training Volume in Trained Women

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ABSTRACT
BARBALHO, M., V. S. COSWIG, J. STEELE, J. P. FISHER, A. PAOLI, and P. GENTIL. Evidence for an Upper Threshold for Resistance Training Volume in Trained Women. Med. Sci. Sports Exerc., Vol. 51, No. 3, pp. 515–522, 2019. Introduction: The purpose of the present study was to compare the effects of different volumes of resistance training (RT) on muscle performance and hypertrophy in trained women. Methods: The study included 40 volunteers that performed RT for 24 wk divided into groups that performed 5 (G5), 10 (G10), 15 (G15), and 20 (G20) sets per muscle group per session. Ten-repetition maximum (10RM) tests were performed for the bench press, lat pulldown, 45° leg press, and stiff-legged deadlift. Muscle thickness (MT) was measured using ultrasound at biceps brachii, triceps brachii, pectoralis major, quadriceps femoris, and gluteus maximus. Results: All groups significantly increased all MT measures and 10RM tests after 24 wk of RT (P < 0.05). Between-group comparisons revealed no differences in any 10RM test between G5 and G10 (P > 0.05). G5 and G10 showed significantly greater 10RM increases than G15 for lat pulldown, leg press, and stiff-legged deadlift. 10RM changes for G20 were lower than all other groups for all exercises (P < 0.05). G5 and G10 showed significantly greater MT increases than G15 and G20 in all sites (P < 0.05). MT increased more in G15 than G20 in all sites (P < 0.05). G5 increases were higher than G10 for pectoralis major MT, whereas G10 showed higher increases in quadriceps MT than G5 (P < 0.05). Conclusions: Five to 10 sets per week might be sufficient for attaining gains in muscle size and strength in trained women during a 24-wk RT program. There appears no further benefit by performing higher exercise volumes. Because lack of time is a commonly cited barrier to exercise adoption, our data support RT programs that are less time consuming, which might increase participation and adherence. Key Words: MUSCLE HYPERTROPHY, MUSCLE STRENGTH, BODYBUILDING, OVERTRAINING, DOSE–RESPONSE

Resistance training (RT) has become one of the most popular methods of exercise for improving physical fitness (1). For women, RT has been shown to bring many benefits, such as increased muscle strength (2) and bone mineral density (3), improvements in maternal health and perinatal outcomes during pregnancy (4), changes in body composition (5), and improvements in health-related outcomes in old age (6) and in breast cancer survivors (7). It is argued that the optimization of the results produced from an RT program depends on the manipulation of several variables, including order of exercise, rest interval, number of exercises performed, exercise selection, and training volume (8,9). Training volume has been the focus of several studies and discussions that aim to establish an optimal dose between the amount of training performed and the results obtained by an RT intervention (10–13).

Several studies have evaluated the use of lower- compared with higher-training volumes, supporting the efficacy of lower training volume in body composition, muscle thickness (MT), and strength (6,14–16), whereas some studies show a superiority for higher volumes of training (17–20). Meta-analyses by Schoenfeld et al. (10) and Ralston et al. (21) noted a linear dose–response relationship suggesting the superiority of higher volume training and recommended that, for maximizing muscle hypertrophy and strength, respectively, one should perform at
least 10 sets per week for each muscle group. However, the use of meta-analyses within RT has been questioned recently because of the considerable heterogeneity of experimental designs in studies within the field (8,11). More recently, a review by Teixeira et al. (12) concluded that it is not possible at present to suggest that high volume of sets offers better results than low volume of sets for upper body muscle hypertrophy.

The extent to which volume should be increased has been questioned by some evidence that suggested a plateau in anabolic response after a given volume is reached or even the existence of an inverted U-shaped curve in the dose–response relationship between training volume and hypertrophy. A recent study by Ogaswara et al. (22) reported that muscle protein synthesis reached a plateau after three or five sets of resistance exercise, and no further increase was observed when going up to 20 sets, suggesting a threshold effect for exercise volume within a session. Previously, Wernbom et al. (13) suggested the occurrence of a plateau in muscle hypertrophy after a threshold volume is reached, and according to the authors, there might be a decline in training response when the volume is extended beyond the point of the plateau.

It is important to note that the majority of previous studies have been carried out in males, with the few conducted with females using elderly women and/or untrained participants. The few studies performed with young trained participants involved men (23–26) or a mixed sample of men and women (27). Although many studies reported that men and women show similar results after an RT program (2), their acute responses have been shown to differ, especially regarding fatigability (28,29) and muscle recovery (30), which might suggest that manipulating training volume might have a different effect on women when compared with men. Therefore, it is important to consider sex differences in response to different manipulations of training variables.

No previous studies have considered trained women, and many have not considered set volumes much higher than 10 per muscle group per week. Considering the controversy around the topic and the importance of defining an adequate dose–response for muscle hypertrophy and performance in women, the aim of the present study was to compare the effects of different volumes of RT in these outcomes in trained women. Our hypothesis was that different training volumes will result in similar increases in muscle size and strength.

MATERIALS AND METHODS

Study overview. To examine the effects of performing different weekly RT volumes on muscle performance and upper and lower body MT, 40 young women with at least 3 yr of previous RT experience were randomly divided into four groups of 10 participants. Each performed an RT program consisting of weekly volumes of 5 sets per muscle group (G5), 10 sets per muscle group (G10), 15 sets per muscle group (G15), or 20 sets per muscle group (G20). The training program followed a nonlinear periodization model for 24 wk. Before and after the training period, participants were tested for 10-repetition maximum (10RM) for the bench press, lat pulldown, 45° leg press, and stiff-legged deadlift. MT was measured using ultrasound at biceps brachii, triceps brachii, pectoralis major, quadriceps femoris, and glutes maximus before and after evaluation.

Participants. A priori sample analysis revealed that to achieve a 0.6 effect size with a power of 0.8, a total of 35 participants would be necessary. Recruitment was performed from January through to June 2017, until achieving 40 participants. To participate in the study, the volunteers had to be at least 18 yr old and have no clinical conditions that limited their participation or that could be aggravated by the study protocol, as attested by a physician. Participants also had to have been performing RT uninterruptedly for the previous 3 yr with a frequency of at least 3 sessions per week. All participants were habituated to training each muscle group once or twice per week with the performance of 18 sets for upper body and 24 sets for the lower body. The minimum attendance for the training intervention was established as 80% (31). Although there was no control over participants’ diets, they were instructed to maintain their usual diets and were regularly questioned to see if any notable changes had occurred (e.g., the use of ergogenic aids, significant changes to protein or carbohydrate intake, becoming vegetarian, etc.). There were no dropouts or exclusions in the study, and mean attendance was 93%, with no difference between groups. After being informed about the experimental procedures and the risks and benefits, the participants signed an informed consent form. The study was approved by the CESUPA Ethics Committee under the number CAAE 69724617.7.0000.5169.

10RM test. Before and after 24 wk of the intervention, participants performed 10RM tests on the bench press, lat pulldown, 45° leg press, and stiff-legged deadlift (Life Fitness, Hammer Strength, São Paulo, Brazil). The tests were divided into three consecutive days. On the first day, participants were tested in the bench press, the second day involved the lat pulldown, and the third day involved the leg press and stiff-legged deadlift. The 10RM was chosen over the 1RM because when participants are training at high repetition ranges, it seems more appropriate to evaluate performance through multiple repetition tests (32).

Before the tests, the participants warmed up with 10 reps at a comfortable self-selected load and then rested for 5 min. Then the initial load was defined based on the participants’ training history. If the volunteer could not perform 10 repetitions or performed more than 10 repetitions, the load was adjusted by 1–10 kg and another attempt was performed after 5 min of rest. No more than three attempts were necessary in any occasion. The ICC of this procedure was determined in our laboratory before the study by performing two identical test sessions separated in 1 wk, and values ranged from 0.93 to 0.99. In this analysis, the SEM was generally less than 3%.

MT. Participants were tested before and after 24 wk training period for MT of the biceps brachii, triceps brachii, pectoralis major, quadriceps femoris, and glutes maximus muscles in the right side of the body. For the biceps and triceps
bralii, measurements were taken 60% distal between the lateral epicondyle of the humerus and the acromion process of the scapula. Pectoralis major MT was measured four centimeters below the coracoid process at 60% of the distance between the acromion process of the scapula and the middle of the sternum (50% of the distance between the xiphoid process and the jugular notch). Quadriceps femoris MT was measured at 50% between the lateral condyle of the femur and greater trochanter. Gluteus maximums measurement was performed at 50% of the distance between the sacral vertebra and the greater trochanter. Gluteus maximums measurement was performed at 50% of the distance between the acromion process of the scapula and the middle of the sternum (50% of the distance between the xiphoid process and the jugular notch). Quadriiceps femoris MT was measured at 50% between the lateral condyle of the femur and greater trochanter. Gluteus maximums measurement was performed at 50% of the distance between the sacral vertebra and the greater trochanter.

All tests were performed between 7:00 and 8:00 AM. The participants were instructed to have a normal breakfast at least 1 h before the examination and to hydrate normally 24 h before the test. Measurements were performed 3–5 d after the last training session to avoid the influence of swelling. During this period, participants were instructed not to participate in any exercise or intense activity. MT was measured using B mode ultrasound (Toshiba Tossbe model, 7.5 MHz linear transduction). A water-soluble transmission gel was applied to the measurement site, and a 7.5-MHz ultrasound probe was placed perpendicular to the tissue interface, but care was taken not to compress the skin. Once the technician was satisfied with the quality of the image produced, the image was frozen. A cursor was then used to measure MT, which was taken as the distance from the subcutaneous interface of adipose muscle tissue to a muscle–bone interface. All MT measures were performed in a specialized clinical center by the same experienced technician, who was not involved in the study and who was blind to group allocation. The ICC was 0.93–0.98, and the SEM was 3%–5%.

Training. Training was performed three times a week, divided into three different programs, as shown in Table 1. Each muscle group was trained once a week, and all sessions were supervised with a ratio of at least one supervisor to five trainees (33), by exercise specialists that were not involved in the study design. All groups performed the same exercises in the same order, and these exercises and number of sets per exercise are presented in Table 1. Although we recognize that there are many forms of manipulating volume, including changing movement velocity, number of repetitions, load, training frequency, etc., we decided to manipulate sets to follow previous studies (10,12) and also because this is a common training frequency, etc., we decided to manipulate sets to follow previous studies (10,12) and also because this is a common strategy in real-world settings. Repetition intervals and rest intervals were also the same, and all groups trained to momentary failure as previously defined (34). Therefore, the groups differed only in the number of sets performed. The protocol followed a model of nonlinear periodization, as shown in Table 2. The volunteers were instructed to perform the concentric and eccentric phases in 2 s each, without pausing between muscle actions.

Statistical analysis. Between-group effects were examined using ANCOVA, comparing the delta change (post-minus preintervention values) values while using preintervention values as covariates. Post hoc comparisons were made with multiple comparison corrections using the Bonferroni procedure. Estimated marginal means were calculated for the change in outcome measures, and within-groups changes were determined by examination of the 95% confidence intervals (CI) for these. Significant change within the group was considered to have occurred if the 95% CI for changes did not cross zero. Statistical analysis was performed using JASP (version 0.8.5.1, University of Amsterdam, The Netherlands), with alpha for significance accepted at <0.05. Multipaired estimation plots were produced for data visualization using Estimation Statistics (https://www.estimationstats.com/).

RESULTS

The characteristics of the participants are presented in Table 3. Both pre- and postintervention results, in addition to estimated marginal means for changes in each outcome and their 95% CI, are reported in Table 4.

10RM tests. Statistically significant between-group effects were found for change in bench press ($F_{1,35} = 9.737, P < 0.001$), lat pulldown ($F_{1,35} = 13.251, P < 0.001$), leg press ($F_{1,35} = 58.631, P < 0.001$), and stiff-legged deadlift ($F_{1,35} = 51.662, P < 0.001$).

For bench press change, post hoc between-group comparisons revealed the following results: G5 did not differ from G10 ($P > 0.999$) or G15 ($P > 0.999$) but was significantly greater than G20 ($P < 0.001$), G10 did not differ from G15 ($P = 0.342$) but was significantly greater than G20 ($P < 0.001$), and G15 was significantly greater than G20 ($P = 0.030$).

For lat pulldown change, post hoc between-group comparisons revealed the following results: G5 did not differ from G10 ($P > 0.999$) or G15 ($P = 0.151$) but was significantly greater than G20 ($P < 0.001$), G10 was significantly greater than G15 ($P = 0.013$) and G20 ($P < 0.001$), and G15 did not differ from G20 ($P = 0.112$).

<table>
<thead>
<tr>
<th>DAYS</th>
<th>Mondays</th>
<th>Thursdays</th>
<th>Fridays</th>
<th>No. Sets</th>
</tr>
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<tbody>
<tr>
<td>Barbell bench press</td>
<td>Lat pulldown</td>
<td>45° leg press</td>
<td>G5</td>
<td>2</td>
</tr>
<tr>
<td>Inclined barbell bench press</td>
<td>Cable row</td>
<td>Barbell squat</td>
<td>G10</td>
<td>4</td>
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<tr>
<td>Military press</td>
<td>Upright barbell row</td>
<td>Stiff-legged deadlift</td>
<td>G15</td>
<td>5</td>
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<td></td>
<td></td>
<td></td>
<td>G20</td>
<td>7</td>
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<table>
<thead>
<tr>
<th>No. Sets</th>
<th>G5</th>
<th>G10</th>
<th>G15</th>
<th>G20</th>
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<tr>
<td>2-3 min</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>7</td>
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<table>
<thead>
<tr>
<th>GROUP</th>
<th>Age</th>
<th>Height</th>
<th>Body Mass</th>
<th>Experience</th>
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<tbody>
<tr>
<td>G5</td>
<td>24.9 ± 1.97</td>
<td>165.3 ± 4.06</td>
<td>63.4 ± 4.14</td>
<td>3.3 ± 0.95</td>
</tr>
<tr>
<td>G10</td>
<td>24.6 ± 1.17</td>
<td>168.2 ± 3.68</td>
<td>64.7 ± 4.90</td>
<td>3.2 ± 1.03</td>
</tr>
<tr>
<td>G15</td>
<td>25.1 ± 1.20</td>
<td>167 ± 4.40</td>
<td>62.6 ± 4.67</td>
<td>3.6 ± 0.70</td>
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<tr>
<td>G20</td>
<td>24.1 ± 1.20</td>
<td>166.4 ± 4.20</td>
<td>62.9 ± 3.84</td>
<td>3.5 ± 0.97</td>
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G5—5 sets per week per muscle group, G10—10 sets per week per muscle group, G15—15 sets per week per muscle group, G20—20 sets per week per muscle group.
As seen in Table 4, all groups produced statistically significant within-group changes in all 10RM outcomes based on their 95% CI. Figure 1 shows multipaired estimation plots, including individual pre- and postintervention data and paired delta with bootstrapped 95% CI for each group and for each 10RM outcome measure.

**MT.** Statistically significant between-group effects were found for change in biceps brachii MT ($F_{1, 35} = 23.219, P < 0.001$), triceps brachii MT ($F_{1, 35} = 31.503, P < 0.001$), pectoralis major MT ($F_{1, 35} = 36.59, P < 0.001$), quadriceps MT ($F_{1, 35} = 44.232, P < 0.001$), and gluteus maximus MT ($F_{1, 35} = 37.647, P < 0.001$).

For biceps brachii MT change, post hoc between-group comparisons revealed the following results: G5 did not differ from G10 ($P > 0.999$) but was significantly greater than G15 ($P < 0.001$) and G20 ($P < 0.001$), G10 was significantly greater than G15 ($P < 0.001$) and G20 ($P < 0.001$), and G15 did not differ from G20 ($P = 0.057$).

For triceps brachii MT change, post hoc between-group comparisons revealed the following results: G5 did not differ from G10 ($P > 0.999$) but was significantly greater than G15 ($P < 0.001$) and G20 ($P < 0.001$), G10 was significantly greater than G15 ($P < 0.001$) and G20 ($P < 0.001$), and G15 did not differ from G20 ($P = 0.051$).

As seen in Table 4, all groups produced statistically significant within-group changes in all MT outcomes based on their 95% CI. Figure 1 shows multipaired estimation plots, including individual pre- and postintervention data and paired delta with bootstrapped 95% CI for each group and for each MT outcome measure.

### Table 4. Pre- and postintervention measures of 10RM tests and MT for each group.

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Post</th>
<th>G5</th>
<th>G10</th>
<th>G15</th>
<th>G20</th>
<th>Changes (95% CI)</th>
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<tr>
<td><strong>10RM tests (kg)</strong></td>
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<tr>
<td>Bench press</td>
<td>24.2</td>
<td>30.1</td>
<td>3.9</td>
<td>4.1</td>
<td>5.6</td>
<td>3.7</td>
<td>5.1 (3.7–6.5)</td>
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<tr>
<td>Leg press</td>
<td>33.0</td>
<td>30.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0 (0.0–6.0)</td>
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<td><strong>MT (mm)</strong></td>
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<tr>
<td>Biceps brachii</td>
<td>26.8</td>
<td>30.1</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3 (0.0–6.0)</td>
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<td>([T][T])</td>
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</table>

For leg press change, post hoc between-group comparisons revealed the following results: G5 did not differ from G10 ($P > 0.999$) but was significantly greater than G15 ($P < 0.001$) and G20 ($P < 0.001$), G10 was significantly greater than G15 ($P < 0.001$) and G20 ($P < 0.001$), and G15 did not differ from G20 ($P = 0.057$).

For stiff leg deadlift change, post hoc between-group comparisons revealed the following results: G5 did not differ from G10 ($P > 0.999$) but was significantly greater than G15 ($P < 0.001$) and G20 ($P < 0.001$), G10 was significantly greater than G15 ($P < 0.001$) and G20 ($P < 0.001$), and G15 did not differ from G20 ($P = 0.051$).
their 95% CI. Figure 2 shows multipaired estimation plots, including individual pre- and postintervention data and paired delta with bootstrapped 95% CI for each group and for each MT outcome measure.

DISCUSSION

The present study compared muscle performance and hypertrophy adaptations in trained women performing different volumes of RT. The results showed that all groups had significant improvements in all variables; however, the magnitude of these improvements appeared to differ. Comparison between groups revealed that G5 did not show any statistically significant differences in relation to G10 in any of the 10RM or MT outcomes measured. However, in all instances, G20 showed statistically significantly smaller changes compared with G5 and G10 across all outcome measures, and in some cases G15 also.

To the best of our knowledge, this is the first study to compare different RT volumes in trained women for a relatively long period (24 wk), and our results suggest that five sets per week might be adequate to promote optimal adaptations in terms of muscle size and performance in most outcomes. Moreover, our results suggest that increasing
training volume beyond 10 sets per week might be detrimental to muscle performance and hypertrophy.

Haas et al. (27) studied 42 trained men and women who were habituated to perform one set per exercise. Half of the participants remained training with one set and the other half increased from one to three sets per exercise. Training was performed three times per week; therefore, the groups performed three or nine sets per week, respectively. According to the results, there were no differences in the changes in body composition and 1RM increases in the leg press and chest press between groups. Interestingly, the dropout rate of the group that increased volume was 25%, due to low attendance or injury, whereas there were no dropouts in the lower volume group. Later, Rhea et al. (25) compared 16 recreationally trained men that trained for 12 wk with three weekly training sessions and found different results for lower body strength. In this study, one group performed one set of bench press and leg press and the other performed three sets. No difference between groups were found for body composition, anthropometric measures, and bench press 1RM; however, the increases in leg press 1RM were higher for the three sets group.

Our results are comparable with previous results in trained men. Ostrowski et al. (24) compared three groups, performing 3, 6, or 12 sets per exercise per week. The participants were habituated to train with 12 sets per week; therefore, there was a decrease in training volume for two groups, whereas the other maintained the same routine. The results showed that, after 10 wk, all groups significantly increased 1RM in the bench press and squat, vertical jump, bench throw, rectus femoris MT, and triceps brachii MT, with no difference between them. Interestingly, although there was no difference in testosterone–cortisol ratio among groups, the groups that performed three and six sets per week (and therefore decreased training volume) had a trend to increase testosterone–cortisol ratio, whereas the trend was for a decrease in the group that performed 12 sets per week. This could be interpreted as evidence that the group completing 12 sets per week presented signs of overtraining, which could also explain the impaired results in G15 and G20. These, and the above results, are similar to ours when generally showing no difference in a range between 3 and 12 sets per muscle group per week and agrees with the suggestion of Ogasawara et al. (22). It is important to note that the study by Ogasawara et al. was performed in rats, and there might be important differences in anabolic signaling and protein turnover between rat and humans; however, it presents an interesting evidence of a ceiling effect for anabolic response to RT. When analyzing trained men, Burd et al. (35) reported that a higher number of sets was more anabolic than a lower; however, the study only compared 1 and 3 sets, and the ceiling effect might occur at a higher number of sets, as suggested by our results.

In a recent study, Amirthalingam et al. (23) compared the effects of a higher (~14 sets per muscle group per week) versus lower volume (~9 sets per muscle group per week) RT intervention upon body composition, muscle size, and strength. Training involved a split routine, with each exercise performed once per week for 6 wk. No significant increases were found for leg lean body mass or measures of MT across groups. There were significant increases in lean body mass measures, with greater increases in trunk and arm lean body mass for the lower volume group. Significant increases were found for muscle strength for both groups, with greater increases in the lower volume group for bench press and lat pulldown 1RM. According to the authors, it seems that gains plateau beyond a certain volume and, exceeding that point, may lead to negative results due to overtraining. As noted, despite the heterogeneity in the literature, similar findings were reported in a meta-analysis by Wernbom et al. (13), who suggested that existence of a plateau in muscle hypertrophy evidence for a decline in training response when the volume is extended beyond the point of the plateau. The present study supports these observations and suggests that a threshold seems to be reached near 10 sets per week.

Our findings do seemingly conflict with previous meta-analyses (10,21), suggesting that a linear dose–response relationship exists, supporting at least 10 sets to induce optimal for gains in muscle size and strength and possibly greater gains with higher volumes. However, the use of meta-analysis for determining RT dose has been questioned because of the large number of variables involved in RT and the methodological inconsistencies in the current literature (8,11). Our results are also partially contrary to a recent study conducted by Schoenfeld et al. that compared the effects of different training volumes in trained men and used even greater volumes than those supported in recent meta-analyses (26). In this study, there was no difference in upper body muscle strength or triceps MT among the groups that performed 6, 18, or 30 sets per week. Regarding biceps MT, the increases were higher for 30 sets in comparison to six, with no other significant difference reported. For lower body, the volumes were 9, 27, or 45 sets per week, and the differences for muscle strength were not significantly different among groups. Notwithstanding, the group that performed 45 sets showed larger increases in rectus femoris and vastus lateralis MT when compared with the groups that performed 9 sets, with no other significant differences.

The conflict between these results with our results and the previous literature might be in the protocol used. Schoenfeld et al. (26) had participants train each muscle group three times per week using a full body routine, whereas in the present study, our participants trained each muscle group once per week using a split routine. Thus, the spreading of such extreme volumes over multiple sessions may yield benefits, whereas the completion of such volumes within single sessions may not. However, previous studies showed that it may take at least 4 d for the muscle to recover from 7 to 8 sets (30,36,37); therefore, further studies are needed to analyze the long-term effects (i.e., 24 wk) of high-volume and high-frequency RT because the muscles might be trained without adequate recovery. Different definitions of set end points might also have influenced the results between studies, particularly as momentary failure might be
interpreted in different ways if careful instruction and definitions are not used (34). Even when instructed to reach momentary failure, many participants might not end the set when they are not able to perform another repetition, but rather due to the confounding effects of perceived discomfort, which might be especially true for lower body (33,38). In such cases, an increase in training volume might bring additional benefit (39). Indeed, Schoenfeld et al. (26) noted that the participants in their study did not regularly train to momentary failure, whereas the participants in the present study had previous experience of such training. Indeed, participants in the study of Hass et al. (27) had been engaged in a minimum of 1 yr training performing a circuit of 9 exercises for a single set of each to momentary failure before being randomized to either continue using single sets or to increase to 3 sets per exercise. As noted, they found no difference for any outcomes between groups.

Considering that most people who advocate lower-volume training suggest that exercises should be performed with higher efforts, controlling for intensity of effort might be a key factor when analyzing the effects of different training volumes (11,40,41). In agreement with this, a recent study in older adults showed that supervised training with lower volume and higher effort improved functionality and body composition in older participants, yet when participants changed to performing unsupervised training with higher volumes and lower efforts, they experienced detraining to a degree similar to those who completely ceased training (42). Therefore, one important aspect of the present study is that the participants were closely supervised to reach the defined set end point because previous studies showed that lack of supervision might be associated with a lower likelihood of reaching momentary failure (34).

A limitation of the present study was the absence of dietary control. However, the participants were constantly questioned to see if there were any relevant changes in their dietary habits and no significant changes were reported. Notwithstanding, in addition to the long-term influence of dietary habits in the adaptations to an RT program, there are data showing that water and food consumption may alter anthropometric assessments (43,44); therefore, the lack of a rigid dietary control might have also acutely influenced MT measures.

In conclusion, the present results suggest that as little as five sets per week might be sufficient for attaining optimal gains in muscle strength and size in trained women during a 24-wk RT program, at least when all sets are closely supervised and performed to muscle failure. Because lack of time is a commonly cited barrier to exercise adoption (45,46), our data support training programs that are uncomplicated and time efficient. This is important for exercise prescription from personal trainers, strength coaches, and medical practitioners; that is, the health and fitness benefits associated with RT are attainable with a time efficient volume of training that might suit laypersons and athletes with time commitments that prevent the performance of larger training volumes.

The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

This study has no conflicts of interest to declare. This study was not funded.

REFERENCES


