HIGH RESISTANCE-TRAINING FREQUENCY ENHANCES MUSCLE THICKNESS IN RESISTANCE-TRAINED MEN

RAFAEL S. ZARONI,1 FELIPE A. BRIGATTO,1 BRAD J. SCHOENFELD,2 TIAGO V. BRAZ,1,3 JULIO C. BENVENUTTI,1 MOISES D. GERMANO,1 PAULO H. MARCHETTI,4 MARCELO S. AOKI,5 AND CHARLES R. LOPES1,6

1Human Performance Research Laboratory, Methodist University of Piracicaba, Piracicaba, Sao Paulo, Brazil; 2Department of Health Sciences, CUNY Lehman College, Bronx, New York; 3Faculty of Americana, Americana, Sao Paulo, Brazil; 4Department of Kinesiology, California State University, Northridge, California; 5School of Arts, Sciences and Humanities, University of Sao Paulo, Sao Paulo, Brazil; and 6Adventist Faculty of Hortolandia, Hortolandia, Sao Paulo, Brazil

ABSTRACT
Zaroni, RS, Brigatto, FA, Schoenfeld, BJ, Braz, TV, Benvenutti, JC, Germano, MD, Marchetti, PH, Aoki, MS, and Lopes, CR. High resistance-training frequency enhances muscle thickness in resistance-trained men. J Strength Cond Res XX(X): 000–000, 2018—The purpose of this study was to compare the effect a split training routine with muscle groups trained once per week (SPLIT) vs. whole-body split training routine with muscle groups trained 5 days per week (TOTAL) on neuromuscular adaptations in well-trained men. Eighteen healthy men (height = 177.8 ± 6.6 cm; total body mass = 84.4 ± 8.1 kg; age = 26.4 ± 4.6 years) were recruited to participate in this study. The experimental groups were matched according to baseline strength and then randomly assigned to 1 of the 2 experimental groups: SPLIT (n = 9) or TOTAL (n = 9). Prestudy and poststudy testing included 1RM for bench press, parallel back-squat and machine close-grip seated row, as well as an ultrasound analysis of the muscle thickness (MT) of the elbow flexors, triceps brachii, and vastus lateralis. After 8 weeks of training, no significant difference between groups was noted for all 1RM tests (p > 0.05). TOTAL induced a significantly greater increase in MT of the forearm flexors and vastus lateralis (p < 0.05). In conclusion, muscle strength increment is similar regardless of the experimental conditions studied; however, TOTAL may confer a potentially superior hypertrophic effect.

KEY WORDS split-body routine, total-body routine, resistance-training frequency, muscle hypertrophy

INTRODUCTION
Primary goals of individuals engaged in resistance-training (RT) programs are to improve strength and muscle hypertrophy. In this context, it is well accepted that the proper manipulation of RT variables is a key factor in maximizing these musculoskeletal adaptations (12,23). The main RT variables are volume, intensity, amount of resistance or load, frequency of training, rest interval, choice and order of exercises, velocity of execution, muscular action, and range of motion (23).

Resistance-training frequency refers to the number of sessions performed during a specific period, usually described on a weekly basis. Frequency can be further characterized by the number of training sessions per week (sessions·wk⁻¹) in which the same muscle group is trained (30). A majority of those involved in RT programs, with muscle hypertrophy as a primary goal, train each muscle group with low frequency (once a week) and perform high volume of work per muscle group in a session. This is accomplished using a split-body routine (SPLIT), where multiple exercises and sets are performed for a specific muscle group in a training session (30).

The American College of Sports Medicine (ACSM) position stands on progression models in RT, which is specific to maximizing the improvement in muscle strength and hypertrophy, recommends 4 to 6 split-body training sessions·wk⁻¹ for resistance-trained subjects, whereby muscle groups are trained once or twice a week (23). A meta-analysis conducted by Rhea et al. (24) concluded that trained individuals demonstrated a maximum strength gain when they performed 2 sessions·wk⁻¹ for each muscle group. With respect to muscle hypertrophy, a recent meta-analysis (27) concluded that at least 2 sessions·wk⁻¹ per muscle group result in a superior hypertrophic adaptation compared with 1 session·wk⁻¹ per muscle group.

The aforementioned findings are especially interesting because bodybuilders (the sport in which maximizing muscle hypertrophy is a crucial factor for success in competition) usually train each muscle group only once...
a week (11). Therefore, a discrepancy seems to exist between the current literature and common practice in regard to optimal RT frequency. It is important to note that, although the scientific evidence indicates that higher frequencies result in greater hypertrophic gains (27), to the authors’ knowledge, only one previous study compared a high (3 sessions·wk⁻¹ per muscle group) vs. a low RT frequency (1 sessions·wk⁻¹ per muscle group) in resistance-trained subjects using validated diagnostic imaging methods (e.g., ultrasound) to assess a change in muscle size (30). This study showed a general trend toward a greater muscle growth in the higher frequency condition.

Dankel et al. (7) speculated that, from a muscle building standpoint, resistance-trained subjects might benefit by reducing the training volume (number of sets per muscle group per session) and increasing weekly frequency. This assumption is based on the hypothesis that trained subjects likely complete an RT volume per session above that needed to maximize the postexercise muscle protein synthetic (MPS) response and thereby were “wasting” some of the per-session volume (7). Based on this hypothesis, Dankel et al. (7) proposed that resistance-trained individuals may see a greater benefit in muscle hypertrophy by keeping the same number of sets performed per week but simply dispersing them over a greater number of RT sessions (e.g., 2 sessions per muscle group per week, with 9 sets per session vs. 6 sessions per muscle group per week, with 3 sets per session). However, this hypothesis has yet to be investigated in a randomized trial, and to the authors’ knowledge, no published study using validated diagnostic imaging methods has compared the volume equated effects of 1 vs. more than 3 sessions per muscle group per week on muscular adaptation in trained men.

Therefore, the purpose of this study was to compare the effects of a SPLIT routine (training a muscle group 1 day per week) vs. a TOTAL routine (training a muscle group 5 days per week) on musculoskeletal adaptations in resistance-trained men with the number of sets per muscle group per week equated between conditions. It was hypothesized that a TOTAL routine would promote a greater strength gain compared with the SPLIT routine as a result of more frequent neural stimulation for the same muscle group. For muscle hypertrophy, based on hypothesis developed by Dankel et al. (7), we hypothesized that the TOTAL routine would promote a greater increase in muscular hypertrophy compared with the SPLIT routine as a result of more frequent elevation in MPS.

**METHODS**

**Experimental Approach to the Problem**

This study followed a randomized, longitudinal design (34). Subjects were pair matched according to baseline strength and then randomly assigned to 1 of 2 experimental groups: SPLIT, where multiple exercises were performed for a specific muscle group in a session (n = 9) or the TOTAL, where 1 exercise was performed per muscle group in a session with all muscle groups trained in each session (n = 9). All other RT variables (e.g., exercise selection, exercise order, range of repetitions, rest interval between sets and exercises, range of motion, and velocity of execution) were held constant. The experimental period lasted 11 weeks as follows: 1st week—familiarization period; 2nd week—preintervention period (baseline); 3rd–10th week—training intervention period; 11th week—postintervention period. The training intervention period lasted 8 weeks and the total load lifted (TLL) and internal training load (ITL) were calculated for every RT session to compare the accumulated external training load (assessed by TLL) and the ITL between experimental groups across the intervention period.

Testing was performed in the preintervention and postintervention periods for maximal voluntary muscle strength (1RM test for bench press, parallel back-squat, and machine close-grip seated row exercises) and muscle thickness (MT) of the elbow flexors (biceps brachii and brachialis), triceps brachii, and vastus lateralis. In the 1st week, subjects attended 2 familiarization sessions in the laboratory reporting to have refrained from performing any exercise other than activities of daily living for at least 48 hours before the first familiarization session. In the first session, subjects were familiarized to 1RM test. The following day (24 hours after), subjects were familiarized to standardized procedures adopted in all RT exercises such as body position, cadence, range of motion, rest period, etc. In addition, subjects were trained and instructed as to how to record their dietary intake.

**Subjects**

Eighteen healthy men (26.4 ± SD 4.6 years [range 18 to 30 years]; 177.8 ± 6.6 cm; total body mass = 84.4 ± 8.1 kg; RT experience = 6.4 ± 2.4 years) volunteered to participate in this study. The sample size was justified by a priori power analysis based on a pilot study where the vastus lateralis MT was assessed as the outcome measure with an effect size

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**TABLE 1. Baseline descriptive data of TOTAL and SPLIT (mean ± SD).**

<table>
<thead>
<tr>
<th>Groups</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Total Body Mass (Kg)</th>
<th>RT Experience (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL (n = 9)</td>
<td>25.6 ± 3.7</td>
<td>179.1 ± 6.7</td>
<td>83.4 ± 11.7</td>
<td>6.4 ± 2.4</td>
</tr>
<tr>
<td>SPLIT (n = 9)</td>
<td>26.4 ± 4.7</td>
<td>177.8 ± 6.6</td>
<td>84.4 ± 8.1</td>
<td>6.6 ± 2.4</td>
</tr>
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</table>

*RT = resistance-training; TOTAL = total-body routine group; SPLIT = split-body routine group.
Subjects were well trained; all had been performing RT a minimum of 3 days to weeks for at least 1 year in the University RT facility. The range of RT experience was 2–10 years. All subjects regularly performed (minimum frequency of once a week) all exercises used in the training intervention and in the strength tests for at least 1 year before entering the study. Moreover, subjects were free from any existing musculoskeletal disorders, history of injury (with residual symptoms of pain, or “giving-away” sensations) in the trunk, upper, and lower limbs within the last year, and stated they had not taken anabolic steroids or any other illegal agents known to increase muscle size currently and for the previous year. Thus, participation in the study required that the subjects answered negatively to all questions on the Physical Activity Readiness Questionnaire (32) and had a minimum 1RM parallel back squat of ×1.25 total body mass and a 1RM bench press of at least equal to total body mass (35). All subjects read and signed an informed consent document approved by the Methodist University of Piracicaba research ethics committee (protocol #1.749.141).

**Procedures**

**Resistance-Training Program.** The RT protocol consisted of 25 exercises targeting each of the major muscle groups. Subjects were instructed to refrain from performing any additional RT for the duration of the study. Over the course of each training week, all subjects performed the same exercises and similar repetition volume throughout the duration of the study. The external load was adjusted for each exercise as needed on successive sets to ensure that subjects achieved failure in the target repetition range. The specific protocols for TOTAL and SPLIT are outlined in Table 2. The exercises were chosen based on their common inclusion in bodybuilding and strength-type RT programs (12). The RT protocol for both groups consisted of 5 weekly sessions performed on

**Table 2. Training protocols for TOTAL and SPLIT.***

<table>
<thead>
<tr>
<th></th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
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<tbody>
<tr>
<td></td>
<td>Biceps curl 3 × 10–12 RM</td>
<td>Dumbbell incline curl 3 × 10–12 RM</td>
<td>Dumbbell preacher curl 3 × 10–12 RM</td>
<td>Barbell preacher curl 3 × 10–12 RM</td>
<td>Dumbbell hammer curl 3 × 10–12 RM</td>
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<tr>
<td></td>
<td>Parallel back-squat 3 × 10–12 RM</td>
<td>Leg press 3 × 10–12 RM</td>
<td>Barbell split squat 3 × 10–12 RM</td>
<td>Hack squat 3 × 10–12 RM</td>
<td>Deadlift 3 × 10–12 RM</td>
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<td></td>
<td>Cable triceps 3 × 10–12 RM</td>
<td>Nosebreaker 3 × 10–12 RM</td>
<td>Cable overhead triceps extension 3 × 10–12 RM</td>
<td>Cable triceps press-down 3 × 10–12 RM</td>
<td>Cable triceps kickback 3 × 10–12 RM</td>
</tr>
</tbody>
</table>

**SPLIT** (n = 9)

|          | Incline dumbbell press 3 × 10–12 RM | Biceps curl 3 × 10–12 RM | Parallel back-squat 3 × 10–12 RM | Lat pull-down 3 × 10–12 RM | Cable triceps 3 × 10–12 RM |
|          | Bench press 3 × 10–12 RM | Dumbbell preacher curl 3 × 10–12 RM | Barbell split squat 3 × 10–12 RM | Machine close-grip seated row 3 × 10–12 RM | Cable overhead triceps extension 3 × 10–12 RM |

*TOTAL = total-body routine group; RM = repetition maximum; SPLIT = split-body routine group.
consecutive days (Monday–Friday) for 8 weeks. Subjects performed 3 sets per exercise for a total of 15 sets per session. Each set involved 10–12 maximum repetitions (RM) with 60 seconds of rest between sets and 120 seconds between exercises (8). All sets were performed to the point of momentary concentric muscular failure and defined as the inability to perform another concentric repetition while maintaining proper technique. Cadence of repetitions was performed in a controlled fashion, with concentric and eccentric actions of approximately 1.5 seconds for total repetition duration of approximately 3 seconds. All subjects reported a rating of perception exertion (RPE) based on the RPE/RIR scale (13) of 9.5–10 for all sets and exercises across RT sessions.

All routines were directly supervised by research assistants to ensure proper performance and technique of the respective routines. Before the training intervention period, all subjects underwent 10RM testing (according to guidelines established by the National Strength and Conditioning Association [NSCA] (12)) to determine individual initial training loads for each exercise. Attempts were made to progressively increase the external loads lifted each week while maintaining the target repetition range. No injuries were reported and the adherence to the program was 100% for both groups.

Estimate of Food Intake. To avoid potential dietary confounding of results, subjects were advised to maintain their customary nutritional regimen and to avoid taking any supplements during the study period. Dietary nutrient intake was assessed by 24-hour food recalls on 2 nonconsecutive weekdays and 1 day of the weekend. The subjects were instructed to record in detail: time of consumption, types, and quantity of food preparations consumed during 24 hours. The quantity of food was recorded in cooking units (spoons, cups, and glass) and transformed into grams. The estimation of energy intake (macronutrients) was analyzed by NutWin software (UNIFESP, Sao Paulo, Brazil). The estimated food intake was assessed during weeks 1, 4, and 8 of the training intervention period.

Criterion Measurements: Muscle Strength. Upper-body and lower-body maximum strength was assessed by 1RM testing in the bench press (1RM\text{Bench}), parallel backsquat (1RM\text{Squat}), and machine close-grip seated row (1RM\text{Row}) exercises. Subjects reported to the laboratory having refrained from any exercise other than activities of daily living for at least 48 hours before baseline testing and at least 48 hours before testing at the conclusion of the study. Maximum strength testing was consistent with recognized guidelines as established by the NSCA (12). Before testing, subjects performed a general warm-up consisting of 5-minute cycling (Schwinne, AC Sport) at 60–70 rpm and 50 W; next, a specific warm-up set of the
The given exercise of 5 repetitions was performed at ~50% 1RM followed by 1–2 sets of 2–3 repetitions at a load corresponding to ~60–80% 1RM. Subjects then performed sets of 1 repetition of increasing weight for 1RM determination. The external load was adjusted by ~5–10% in subsequent attempts until the subject was unable to complete 1 maximal concentric muscle action. The 1RM was considered the highest external load lifted. A 3- to 5-minute rest was afforded between each successive attempt. All 1RM determinations were made within 5 attempts.

Table 4: Preintervention vs. Postintervention Muscle Strength measures for TOTAL and SPLIT (mean ± SD).*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pre</th>
<th>Post</th>
<th>Δ%</th>
<th>p</th>
<th>d (±90% CL) classification</th>
<th>Qualitative assessment</th>
<th>Chances (%)</th>
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<tbody>
<tr>
<td>TOTAL (n = 9)</td>
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<tr>
<td>1RM_BENCH (kg)</td>
<td>104.2 ± 17.6 113.5 ± 19.3†</td>
<td>8.5 &lt; 0.001 0.48 (±0.11) small</td>
<td>Possibly trivial</td>
<td>38/62/0</td>
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<tr>
<td>1RM_SQUAT (kg)</td>
<td>105.6 ± 20.2 125.1 ± 24.6†</td>
<td>18.5 &lt; 0.001 0.87 (±0.21) moderate</td>
<td>Most likely</td>
<td>100/0/0</td>
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<tr>
<td>1RM_ROW (kg)</td>
<td>107.0 ± 14.8 114.7 ± 14.4†</td>
<td>6.6 &lt; 0.001 0.49 (±0.19) small</td>
<td>Possibly trivial</td>
<td>46/54/0</td>
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<tr>
<td>1RM_BENCH (kg)</td>
<td>93.2 ± 13.5 100.9 ± 12.9†</td>
<td>8.2 &lt; 0.001 0.58 (±0.25) small</td>
<td>Possibly</td>
<td>71/29/0</td>
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<tr>
<td>SPLIT (n = 9)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>1RM_SQUAT (kg)</td>
<td>111.9 ± 18.8 121.8 ± 18.7†</td>
<td>8.8 0.002 0.53 (±0.25) small</td>
<td>Possibly</td>
<td>58/42/0</td>
<td></td>
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</tr>
<tr>
<td>1RM_ROW (kg)</td>
<td>89.7 ± 11.7 95.6 ± 11.9†</td>
<td>6.6 0.001 0.50 (±0.22) small</td>
<td>Possibly</td>
<td>50/50/0</td>
<td></td>
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</tr>
</tbody>
</table>

*d = Effect Size; CLs = confidence limits; chances = rate of having better/similar/poorer chances; TOTAL = total-body routine group; 1RM_BENCH = 1 maximal repetition test in bench press exercise; kg = kilograms; 1RM_SQUAT = 1 maximal repetition test in parallel back-squat exercise; 1RM_ROW = 1 maximal repetition test in seated row machine exercise; SPLIT = split-body routine group.

†Significantly greater than the corresponding preintervention value (p < 0.05).

Figure 1: Efficiency of the group that have trained in the total-body routine (TOTAL) in comparison with the group that have trained in the split-body routine (SPLIT) to improve maximum strength in bench press (1RM_BENCH), parallel back-squat (1RM_SQUAT), and seated row machine (1RM_ROW) exercises; muscle thickness of the triceps brachii (MT_TB), elbow flexors (MT_EF), and vastus lateralis (MT_VL) muscles; accumulated total load lifted (ATLL) and internal training load (ITL_TOTAL) (bars indicate uncertainty in the true mean changes with 90% confidence intervals). Trivial areas were the smallest worthwhile change (SWC) (see methods).
Successful 1RM<sub>BENCH</sub> was achieved if the subject displayed a 5-point body contact position (head, upper back, and buttocks firmly on the bench with both feet flat on the floor), lowered the bar to touch his chest, and executed full elbow extension. The grip width was standardized at 200% of biacromial width (22). In the 1RM<sub>SQUAT</sub>, subjects were required to squat down, so that the top of the thigh was parallel to the ground (~90° of knee joint flexion) for the attempt to be considered successful as determined by a research assistant who was positioned laterally to the subject by 2 research assistants, so that the subject maintained its upper border at the height of the sternum (manubrium). The distance of the pad was adjusted, so that the subject was deemed to be satisfactory, the image was saved to the hard drive, and MT dimensions were obtained by measuring the distance from the subcutaneous adipose tissue–muscle interface per methods used by the manufacturer’s user manual and held constant among testing sessions. When the quality of the image was deemed to be satisfactory, the image was saved to the hard drive, and MT dimensions were obtained by measuring the distance from the subcutaneous adipose tissue–muscle interface to the muscle-bone interface per methods used by Abe et al. (1). Measurements were taken on the right side of the body at 3 sites: elbow flexors (MT<sub>EF</sub>), triceps brachii muscles (MT<sub>TB</sub>), and vastus lateralis muscle (MT<sub>VL</sub>).

Muscle Thickness. Ultrasound imaging was used to obtain measurements of MT. A trained technician performed all testing using an A-mode ultrasound imaging unit (Bodymetrix Pro System; Intelemetrix, Inc., Livermore, CA, USA). After a generous application of a water-soluble transmission gel (Mercur S.A.—Body Care, Santa Cruz do Sul, RS, Brazil) to the measured site, a 2.5-MHz linear probe was placed perpendicular to the tissue interface without depressing the skin. Equipment settings were optimized for image quality according to the manufacturer’s user manual and held constant during familiarization strength testing and then used for preintervention and postintervention performance tests as well as at all training sessions. All testing sessions were supervised by the research team to achieve a consensus for success on each attempt. The test-retest intraclass correlation coefficient (ICC) calculated through the data collected during the familiarization period and the preintervention period for 1RM<sub>BENCH</sub>, 1RM<sub>SQUAT</sub>, and 1RM<sub>ROW</sub> is 0.989, 0.990, and 0.988, respectively. The coefficient of variation (CV) from our laboratory for these measures is 0.8, 0.7, and 0.9%, respectively. The SEM from our laboratory for these measures is 2.05, 1.95, and 2.23 kg, respectively.

Successful 1RM<sub>ROW</sub> was achieved if the subject displayed a 5-point body contact position (head, upper back, and buttocks firmly on the bench with both feet flat on the floor), lowered the bar to touch his chest, and executed full elbow extension. The grip width was standardized at 200% of biacromial width (22). In the 1RM<sub>SQUAT</sub>, subjects were required to squat down, so that the top of the thigh was parallel to the ground (~90° of knee joint flexion) for the attempt to be considered successful as determined by a research assistant who was positioned laterally to the subject. The barbell was positioned on the shoulders (high bar position), and the subjects’ feet were positioned at hip width (5). Successful 1RM<sub>ROW</sub> was achieved if the subject displayed a 4-point body contact position (chest firmly on the pad of the seated row machine, buttocks firmly on the bench, and both feet flat on the floor), executed full elbow extension (while grasping the handles), and pulled the handles back until the elbows reached the trunk line (~0° of shoulder flexion). Seat height was adjusted so that the pad maintained its upper border at the height of the sternum (manubrium). The distance of the pad was adjusted, so that subjects reached full elbow extension at the finish of the eccentric portion of the movement. The handles were given to the subject by 2 research assistants, so that the subject started the test by first performing the eccentric action of the movement (shoulders flexion, elbows extension, and shoulder blades abduction). Subjects were instructed to keep their elbows close to their sides and to avoid swinging the body forward.

The sequence of maximum strength tests was 1RM<sub>BENCH</sub>, 1RM<sub>SQUAT</sub>, and 1RM<sub>ROW</sub> with a 20-minute rest period separating tests. Recording of foot and hand placement were made during familiarization strength testing and then used for preintervention and postintervention performance tests as well as at all training sessions. All testing sessions were supervised by the research team to achieve a consensus for success on each attempt. The test-retest intraclass correlation coefficient (ICC) calculated through the data collected during the familiarization period and the preintervention period for 1RM<sub>BENCH</sub>, 1RM<sub>SQUAT</sub>, and 1RM<sub>ROW</sub> is 0.989, 0.990, and 0.988, respectively. The coefficient of variation (CV) from our laboratory for these measures is 0.8, 0.7, and 0.9%, respectively. The SEM from our laboratory for these measures is 2.05, 1.95, and 2.23 kg, respectively.

### Table 5: Preintervention vs. Postintervention Muscle Morphology measures for TOTAL and SPLIT (mean ± SD)*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pre</th>
<th>Post</th>
<th>Δ%</th>
<th>p</th>
<th>d (±90% CL) classification</th>
<th>Qualitative assessment</th>
<th>Chances (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL (n = 9)</td>
<td>MT&lt;sub&gt;EF&lt;/sub&gt; (mm)</td>
<td>44.9 ± 5.7</td>
<td>48.7 ± 5.5†</td>
<td>8.5 &lt; 0.001</td>
<td>0.68 (±0.13) moderate</td>
<td>Very likely</td>
<td>99/1/0</td>
</tr>
<tr>
<td></td>
<td>MT&lt;sub&gt;TB&lt;/sub&gt; (mm)</td>
<td>44.4 ± 4.2</td>
<td>49.4 ± 4.2†</td>
<td>11.2 &lt; 0.001</td>
<td>1.22 (±0.25) large</td>
<td>Almost certain</td>
<td>100/0/0</td>
</tr>
<tr>
<td></td>
<td>MT&lt;sub&gt;VL&lt;/sub&gt; (mm)</td>
<td>47.6 ± 4.3</td>
<td>52.2 ± 3.2†</td>
<td>9.7 &lt; 0.001</td>
<td>1.22 (±0.45) large</td>
<td>Almost certain</td>
<td>100/0/0</td>
</tr>
<tr>
<td></td>
<td>MT&lt;sub&gt;EF&lt;/sub&gt; (mm)</td>
<td>40.1 ± 6.2</td>
<td>41.6 ± 6.3†</td>
<td>3.8 0.003</td>
<td>0.24 (±0.12) small</td>
<td>Most likely trivial</td>
<td>0/100/0</td>
</tr>
<tr>
<td>SPLIT (n = 9)</td>
<td>MT&lt;sub&gt;TB&lt;/sub&gt; (mm)</td>
<td>43.9 ± 5.4</td>
<td>46.4 ± 5.7†</td>
<td>5.8 0.001</td>
<td>0.46 (±0.21) small</td>
<td>Possibly trivial</td>
<td>37/63/0</td>
</tr>
<tr>
<td></td>
<td>MT&lt;sub&gt;VL&lt;/sub&gt; (mm)</td>
<td>45.5 ± 3.3</td>
<td>47.9 ± 2.8†</td>
<td>5.4 0.001</td>
<td>0.80 (±0.35) moderate</td>
<td>Likely</td>
<td>92/8/0</td>
</tr>
</tbody>
</table>

*d = Effect Size; CLs = confidence limits; Chances = rate of having better/similar/poorer chances; TOTAL = total-body routine group; MT<sub>EF</sub> = muscle thickness of the elbow flexors muscles; mm = millimeters; MT<sub>TB</sub> = muscle thickness of the triceps brachii muscle; MT<sub>VL</sub> = muscle thickness of the vastus lateralis muscle; SPLIT = split-body routine group.

†Significantly greater than the corresponding preintervention value (p < 0.05).

†Significantly greater than SPLIT (p < 0.05).
and vastus lateralis (MTVL). The upper-arm measurement was conducted while subjects were standing and the measurement of thigh muscle involved subjects lying supine on an examination table.

For the anterior and posterior upper-arm measurements were taken 60% distal between the lateral epicondyle of the humerus and the acromion process of the scapula; for the thigh muscle, measurements were taken 50% of the distance between the lateral condyle of the femur and greater trochanter. For each measurement, the examined limb was secured so as to minimize unwanted movement. To maintain consistency between preintervention and postintervention testing, each site was marked with henna ink (reinforced every week). In an effort to help ensure that swelling in the muscles from training did not obscure results, images were obtained 48–72 hours before commencement of the study and after the final training session. This is consistent with research showing that an acute increase in muscle thickness returns to baseline within 48 hours after an RT session (21).

To further ensure accuracy of measurements, at least 3 images were obtained for each site. If measurements were within 1 mm of one another, a fourth image was obtained and the closest 3 measurements were then averaged. The test-retest ICCs from our laboratory for MTef, MTTB, and MTVL are 0.996, 0.998, and 0.999, respectively. The CVs for these measures are 0.4, 0.6, and 0.6%, respectively. The SEM values for these measures are 0.29, 0.42, and 0.41 mm, respectively.

**Total Load Lifted.** Total Load Lifted: sets × repetitions × external load (kgf) (31) was calculated from training logs filled out by research assistants for every RT session. The weekly TLL (TLLWEEK) was calculated as the values corresponding to the sum of the loads calculated for the 5 RT sessions in each week. The accumulated TLL (ATLL) was the sum of all RT weeks. Only repetitions performed through a full range of motion were included for analysis. The data were expressed in kilogram-force units (kgf).

**Internal Training Load.** Subjects reported their session-RPE (sRPE), according to the OMNI-Resistance Exercise Scale (OMNI-RES), validated to measure RPE in RT (25). Subjects were shown the scale 10 minutes after each session (3,4) and asked “How intense was your session?” and were instructed to make certain that their RPE referred to the intensity of the whole session rather than to the most recent exercise intensity. The ITL for each session was calculated by multiplying the total time under tension spent in the session in minutes by the sRPE (10). The weekly ITL (ITLWEEK) was calculated as the values corresponding to the sum of the ITLs calculated for the 5 RT sessions in each week. Total ITL (ITLTOTAL) was the sum of all RT weeks. The data were expressed in arbitrary units (a.u.).

**Statistical Analyses**

The normality and homogeneity of the variances were verified using the Shapiro-Wilk and Levene tests, respectively. The mean, SD, and 90% confidence intervals (CIs) were used after the data normality was assumed. To compare mean values of the descriptive variables, ATLL and ITLTOTAL between groups (TOTAL vs. SPLIT), a paired t-test was used. A 2 × 2 repeated-measures analysis of variance (ANOVA) (interaction groups [TOTAL and SPLIT] × time [preintervention vs. postintervention]) was used to compare the dependent variables (1RMBENCH, 1RMSQUAT, 1RMROW, MTef, MTTB, and MTVL). A 2 × 3 repeated-measures ANOVA (interaction groups [TOTAL and SPLIT] × time [weeks 1, 4 and 8]) was used to compare the food intake variables, TLLWEEK and ITLWEEK. Post hoc comparisons were performed with the Bonferroni test (with correction). Assumptions of sphericity were evaluated using Mauchly’s test. In cases which sphericity was violated (p < 0.05), the Greenhouse-Geisser correction factor was applied. In addition, effect sizes were evaluated using partial eta squared (ηp²), with <0.06, 0.06–0.14, and >0.14 indicating a small, medium, and large effect, respectively (34). All analyses were conducted in SPSS-22.0 software (IBM Corp., Armonk, NY).
Armonk, NY, USA). The adopted significance was 5%. Furthermore, the magnitudes of the difference were examined using the standardized difference based on Cohen’s $d$ units by means of effect sizes ($d$) (14). The $d$ results were qualitatively interpreted using the following thresholds: $<0.2$, trivial; $0.2–0.6$, small; $0.6–1.2$, moderate; $1.2–2.0$, large; $2.0–4.0$, very large; and $>4.0$, nearly perfect. The quantitative chances for higher or lower differences were qualitatively assessed as follows: $<1\%$, almost certainly not; $1–5\%$, very unlikely; $5–25\%$, unlikely; $25–75\%$, possibly; $75–95\%$, likely; $95–99\%$, very likely; and $>99\%$, almost certain. If the chances for having higher or lower values than the smallest worthwhile difference were $>5\%$, the true difference was considered unclear. Data analysis was performed using a modified statistical Excel spreadsheet (14).

**Results**

No significant difference was noted between groups in any baseline measurements (all $p > 0.05$ [Table 1]). There was no significant difference in any dietary intake variable either within or between groups over the course of the study (all $p > 0.05$ [Table 3]).

**Maximal Strength**

A significant main effect of time ($F_{1,16} = 100.230, p < 0.001, \eta^2_p = 0.862$), but not group $\times$ time interaction ($F_{1,16} = 0.546, p = 0.471, \eta^2_p = 0.033$), was observed for $1\text{RM}_{\text{BENCH}}$. Both groups showed a significant increase from baseline to post-intervention by $9.3 \pm 3.9\text{ kgf} (\Delta\% = 8.5, p < 0.001, d = 0.48)$ and $7.7 \pm 3.1\text{ kgf} (\Delta\% = 8.2, p < 0.001, d = 0.58)$ for TOTAL and SPLIT, respectively (Table 4). In addition, no substantial difference between groups was observed for $1\text{RM}_{\text{SQUAT}} (\Delta\% = 20.8, d = 0.35$ [90% confidence level [CL] = ± 0.39], 0/75/25% [possibly trivial] with changes for greater/similar/lower values, respectively) (Figure 1).

There was a significant main effect of time ($F_{1,16} = 60.073, p < 0.001, \eta^2_p = 0.790$) and group $\times$ time interaction ($F_{1,16} = 6.475, p = 0.022, \eta^2_p = 0.288$) for $1\text{RM}_{\text{ROW}}$. Both groups showed a significant increase from baseline to post-intervention by $19.5 \pm 9.3\text{ kgf} (\Delta\% = 18.5, p < 0.001, d = 0.87)$ and $9.9 \pm 6.6\text{ kgf} (\Delta\% = 8.8, p = 0.002, d = 0.53)$ for TOTAL and SPLIT, respectively (Table 4). Post hoc analysis showed no significant difference between groups at the baseline ($p = 0.501$) and postintervention ($p = 0.750$). Moreover, no substantial difference between groups was observed for $1\text{RM}_{\text{SQUAT}} (\Delta\% = 96.9, d = 1.20$ [90% CL = ± 6.20], 33/10/57% [unclear]) (Figure 1).

A significant main effect of time ($F_{1,16} = 39.280, p < 0.001, \eta^2_p = 0.711$), but not group $\times$ time interaction ($F_{1,16} = 0.347, p = 0.564, \eta^2_p = 0.021$), was observed for $1\text{RM}_{\text{SQUAT}}$. Both groups showed an increase from baseline to postintervention by $7.7 \pm 4.8\text{ kgf} (\Delta\% = 6.6, p < 0.01, d = 0.49)$ and $5.9 \pm 4.0\text{ kgf} (\Delta\% = 6.6, p = 0.001, d = 0.50)$ for TOTAL and SPLIT, respectively (Table 4). In addition, no substantial difference between groups was observed for $1\text{RM}_{\text{ROW}} (\Delta\% = 30.5, d = 0.28$ [90% CL = ± 0.16], 0/99/1% [very likely trivial]) (Figure 1).

**Muscle Thickness**

There was a significant main effect of time ($F_{1,16} = 76.883, p < 0.001, \eta^2_p = 0.828$) and group $\times$ time interaction ($F_{1,16} = 14.516, p = 0.002, \eta^2_p = 0.476$) for $\text{MT}_{\text{EF}}$. A significant increase was noted for both TOTAL $3.8 \pm 0.9\text{ mm} (\Delta\% = 8.5, p < 0.001, d = 0.68)$ and SPLIT $1.5 \pm 1.6\text{ mm} (\Delta\% = 3.8, p = 0.003, d = 0.24)$ from baseline to postintervention (Table 5). Post hoc analyses showed no significant difference between groups at the baseline ($p = 0.108$), but at the postintervention period, a significant difference between groups was observed ($p = 0.021$). In addition, a substantial difference between groups was observed for $\text{MT}_{\text{EF}} (\Delta\% = 153.3, d = 1.79 [90% CL = ± 1.20], 0/4/96% [very likely])$ (Figure 1).

A significant main effect of time ($F_{1,16} = 79.032, p < 0.001, \eta^2_p = 0.832$) and group $\times$ time interaction ($F_{1,16} = 8.422, p = 0.010, \eta^2_p = 0.345$) was observed for $\text{MT}_{\text{TB}}$. A significant increase was noted for both TOTAL $5.0 \pm 1.5\text{ mm} (\Delta\% = 11.2, p < 0.001, d = 1.22)$ and SPLIT $2.5 \pm 2.1\text{ mm} (\Delta\% = 5.8, p = 0.001, d = 0.46)$ from baseline to postintervention (Table 5). Post hoc analysis showed no significant difference between groups at the baseline ($p = 0.839$) and postintervention ($p = 0.227$). Moreover, no substantial difference between groups was observed for $\text{MT}_{\text{TB}} (\Delta\% = 100.0, d = 1.37 [90% CL = ± 1.90], 5/17/78% [unclear])$ (Figure 1).
A significant main effect of time ($F_{1,16} = 67.433$, $p < 0.001$, $\eta^2_p = 0.808$) and group × time interaction ($F_{1,16} = 6.146$, $p = 0.025$, $\eta^2_p = 0.278$) was observed for MTVL. A significant increase was noted for both TOTAL $4.6 \pm 2.1$ mm ($\Delta% = 9.7, p < 0.001, d = 1.22$) and SPLIT $2.4 \pm 1.5$ mm ($\Delta% = 5.4, p = 0.001, d = 0.80$) from baseline to postintervention (Table 5). Post hoc analyzes showed no significant difference between groups at the baseline ($p = 0.245$), but at the postintervention period, a significant difference between groups was observed ($p = 0.009$). In addition, a substantial difference between groups was observed for MTVL ($\Delta% = 91.7, d = 1.17 \{90\% \text{ CL} = \pm 0.69\}$, $0/5/95\% \{\text{likely}\}$) (Figure 1).

**Total Load Lifted**

Figure 2 shows the TLLWEEK measured during the intervention period. A significant main effect of time ($F_{1,429.22,665} = 35.332$, $p < 0.001$, $\eta^2_p = 0.688$), but not group × time interaction ($F_{1,429.22,665} = 0.027$, $p = 0.935$, $\eta^2_p = 0.002$), was observed for TLLWEEK. For TOTAL, there was a significant difference between weeks 1 vs. 4 ($p = 0.047$), 1 vs. 8 ($p = 0.010$), and 4 vs. 8 ($p < 0.001$). For SPLIT, a significant difference was observed between weeks 1 vs. 4 ($p = 0.029$), 1 vs. 8 ($p = 0.001$) and 4 vs. 8 ($p = 0.010$).

A significant difference between groups was noted such that TOTAL produced superior TLL compared with SPLIT ($\Delta% = 22.3, p = 0.029$, $d = 1.13 \{90\% \text{ CL} = \pm 0.82\}$, $0/10/90\% \{\text{likely}\}$) (Figures 1 and 3).

**Internal Training Load**

No significant main effect of time ($F_{1,261.20,176} = 2.940$, $p = 0.094$, $\eta^2_p = 0.155$) and no significant group × time interaction ($F_{1,261.20,176} = 0.203$, $p = 0.713$, $\eta^2_p = 0.013$) was observed for ITLWEEK (Figure 2). Moreover, no significant between groups difference was observed for ITTL(TOTAL ($\Delta% = 5.33, p = 0.406, d = 0.40 \{90\% \text{ CL} = \pm 0.82\}$, $3/55/42\% \{\text{possibly trivial}\}$) (Figures 1 and 3).

**Discussion**

The current study aimed to compare the effect of a split training routine with muscle groups trained once per week vs. whole-body training routine with muscle groups trained 5 days per week on neuromuscular adaptations in resistance-trained men. The main findings were that (a) muscle strength increases were similar regardless of the experimental conditions studied and (b) a whole-body training routine with all muscle groups trained 5 days may confer a potentially superior hypertrophic effect compared with a split routine where muscles are worked just once per week.

To the authors’ knowledge, this is the first study that compared musculoskeletal performance and morphological adaptations between RT protocols using different routines schemes (TOTAL vs. SPLIT) based on different RT weekly frequencies of 1 vs. 5 days per muscle group in resistance-trained individuals. The findings of this study demonstrated that training a muscle group only once a week is as efficient as training 5 times per week to maximize strength gains. Alternatively, from a muscle building perspective, the findings of this study suggest a potential hypertrophic benefit to a higher frequency of training when training volume (number of sets per muscle group) is equated between conditions. This would suggest that the increased muscle mass achieved in TOTAL did not translate into greater strength gains.

The increase in maximal strength from baseline to postintervention between conditions showed a percentage increase in 1RM(BENCH) for TOTAL compared with SPLIT ($\Delta% = 20.8, d = 0.35$), 1RM(SQUAT) ($\Delta% = 96.9, d = 1.20$), and 1RM(BROW) ($\Delta% = 30.5, d = 0.28$). However, these results were not significantly different between conditions. These findings refute the initial hypothesis that the TOTAL approach would elicit a superior strength gain.

This study used a high RT volume because of evidence of a dose-response relationship between RT volume and muscle hypertrophy, with a greater volume (10 or more weekly sets per muscle group) resulting in additional improvement in muscle mass (28) and also because this RT volume is typically associated with bodybuilding-style training (9). Thus, according to the current findings, it seems that weekly RT volume is more important than RT frequency for promoting strength gains in well-trained men. In other words, when a weekly RT volume used is highly enough, there seems to be a diminished neural advantage of the higher training frequency observed in other studies with trained subjects (15,20).

In regard to muscular hypertrophy, significantly greater increase in MT_EF and MT_VL was observed in TOTAL when compared with SPLIT. In addition, in TOTAL, the increase in MT_EF from baseline to postintervention was 153.3% greater than SPLIT, with a large effect size (ES) between groups ($d = 1.79$). To the MT_VL, the percentage difference between groups was 91.7%, with moderate ES ($d = 1.17$). Moreover, the magnitude-based inference (MBI) analysis (14) showed that clinical differences between groups were very likely and likely for MT_EF MT_VL, respectively. Although MT_TB was not statistically different between groups, the percentage difference was 100.0%, with a large ES ($d = 1.37$) that favored TOTAL. Nevertheless, MBI showed that clinical difference between groups for MT TB was unclear. In combination, these data provide evidence that resistance-trained individuals benefit from including periods of training muscle groups more frequently than 1 sessions-wk$^{-1}$ when the goal is to maximize muscle hypertrophy.

Schoenfeld et al. (30) observed a significantly greater increase in elbow flexors MT for a higher frequency (3 sessions-wk$^{-1}$) vs. a lower frequency protocol (1 session-wk$^{-1}$). Moreover, although triceps brachii MT was not statistically different between groups as in this study, the ES reported by Schoenfeld et al. (30) for a higher frequency protocol was 96% greater than that of a lower frequency protocol (0.90 vs. 0.46, respectively). Although, vastus lateralis MT was not statistically different between groups,
Schoenfeld et al. (30) also reported a markedly greater ES for vastus lateralis thickness increase on a higher frequency protocol compared with a lower frequency protocol (0.70 vs. 0.18, respectively). This study agrees with the results observed by Schoenfeld et al. (30) (i.e., in comparison with lower frequencies, higher frequencies elicited a similar strength gain, and significantly greater increase in hypertrophy of upper-body muscles) and expands on previous findings by providing direct evidence of a greater MT increase in lower-body muscles with a higher RT frequency (5 sessions·wk⁻¹) in trained subjects. These results confirm the initial hypothesis and seem to support the hypothesis of Dankel et al. (7), who proposed that the magnitude and duration of the elevated MPS in response to RT bout in well-trained RT individuals favored working muscles more frequently (6). Research by Burd et al. demonstrated that a relatively low number of sets (i.e., 4 sets to volitional failure) may be sufficient to elicit a large increase in MPS for up to 24 hours after exercise (2). It therefore can be speculated that performing fewer sets per muscle group per session may be more effective at reducing prolonged neuromuscular fatigue and allowing the same muscle group to be trained more frequently. In this way, the more repetitive stimuli would hypothetically result in a greater time spent in a net-positive protein balance. Hence, Dankel et al. (7) hypothesized that resistance-trained individuals may see a greater benefit in muscle hypertrophy by simply dispersing the same RT volume (number of sets per muscle group) over a greater weekly frequency (i.e., greater number of training sessions). The present findings seem to experimentally confirm the proposed hypothesis (7).

In relation to TLL, the TOTAL produced a 22.3% greater accumulated external training load with a moderate-associated ES (d = 1.13). Because of the fact that the magnitude of the ITL is determined largely by the external training load (although the individual characteristics also are very relevant) (16), it was hypothesized that the significantly greater ATLL observed in TOTAL compared with SPLIT would result in significantly greater ITL TOTAL. Conversely, although TOTAL produced 2059 a.u. more ITL TOTAL than SPLIT, this difference was not statistically significant.

The ITL for each session was calculated multiplying a measure of volume (total time under tension spent in the session in minutes) by the measure of intensity of the session (sRPE) (10). Although sRPE is indicative of the relative intensity of effort (10,31), it is possible that the relative intensity of the sessions was the same for both groups because all sets were performed until concentric muscle failure. Indeed, if sets are designed to achieve muscular failure, the exertion of subjects should be similar within any intensity level (33). Confirming these assumptions, the sRPE reported by all subjects in all training sessions ranged among 8–9. The other part of the ITL equation considers the time under tension of the session, given that the velocity execution was controlled (3 seconds) and the number of sets and range of repetitions (10–12RM) was the same for both groups, it is plausible to state that both groups were exposed to similar volume and relative intensity of training, consequently the ITL (product of both variables) accumulation was similar.

On the other hand, if the weekly volume (sets and repetitions) was similar for both groups, there remains the question as to how TLL was superior in the TOTAL group. The answer seems to lie in the different RT routine schemes used among experimental groups. Although SPLIT performed 5 exercises for the same muscle group in a session with 2-minute rest intervals between each exercise, TOTAL had a rest of 24 hours between each exercise for the same muscle group. Hence, TOTAL avoided issues with neuromuscular fatigue from the previous exercise (for the same muscle group), thereby promoting a higher TLL. Indeed, evidence shows that longer rest intervals between sets for the same muscle group result in a higher TLL and hypertrophic increases in resistance-trained men (29). Therefore, it seems that a higher weekly frequency per muscle group is able to increase TLL without changing the magnitude of ITL compared with condensing the weekly volume in a single session.

Results observed for TLL expands on previous findings by providing direct evidence of the greater TLL increase with a higher weekly RT frequency (5 vs. 1 weekly session per muscle group) in well-trained men. This is very relevant because the increment in muscle strength and muscle mass is strongly dependent on TLL of RT. A clear dose-response relationship has been reported between TLL and both muscle strength (18) and hypertrophy (19,28). Moreover, a higher load induces a greater mechanical tension, which is purported to be a primary driving force in respect to hypertrophy development (26). Therefore, it is plausible to speculate that the greater ATLL in TOTAL compared with SPLIT played a meaningful role in the superior hypertrophy gains observed in TOTAL.

This study has some limitations that should be considered when interpreting the current results. First, the small sample size affected statistical power. As is the cases in most longitudinal RT studies, a high degree of interindividual variability was noted among subjects, which limited the ability to detect a significant difference in several outcome measures. Despite this limitation, analysis of effect sizes provides a good basis for drawing inferential conclusions from the results. Second, the findings of this study are specific to young resistance-trained men and therefore cannot necessarily be generalized to other populations including adolescents, women, and elderly. It is possible that the higher RT volumes and frequencies may not be as well tolerated in these individuals and perhaps could hasten the onset of overtraining when combined with a high intensity of effort. Future research is required to determine the frequency-related responses to RT across different populations. Finally, results may have been influenced by the novelty of changing RT programs. Prestudy interviews

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revealed that all subjects regularly trained with a frequency between 1 and 2 sessions per muscle group per week. Therefore, the subjects who were randomized to the TOTAL group were exposed to a new stimulus in relation to the weekly frequency (5 times per muscle group per week), whereas the SPLIT group trained with their usual frequency (1 time per muscle group per week). Given evidence that the muscular response is heightened when RT program variables altered outside of traditional recommendations (17), it is feasible that subjects in TOTAL unduly benefited from the unfamiliar stimulus of training with a higher RT frequency. It is also possible that periodizing training frequencies might provide a mean to maintain news of the stimulus and thus promote a continued gain over time. This hypothesis demands additional investigation.

**PRACTICAL APPLICATIONS**

This study provides evidence that frequencies of greater than 1 session per muscle group per week are beneficial to enhancing muscle hypertrophy. Contrarily, this relationship does not seem to persist with strength gains. The study demonstrated that dividing the muscle group RT volume into 5 sessions-wk⁻¹ provides a practical mean to perform a higher TLL per muscle group. It is conceivable that, for those who have as primary goal maximize gains in muscle strength and hypertrophy, periodizing training frequency over the course of a long-term training cycle may be an optimal approach. Such a strategy would maintain the novelty of the training stimulus, thus facilitating a continuous improvement in neuromuscular performance and muscular hypertrophy.

**REFERENCES**


