
EFFECTS OF DIFFERENT VOLUME-EQUATED RESISTANCE TRAINING LOADING STRATEGIES ON MUSCULAR ADAPTATIONS IN WELL-TRAINED MEN

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ABSTRACT

Schoenfeld, BJ, Ratamess, NA, Peterson, MD, Contreras, B, Sonmez, GT, and Alvar, BA. Effects of different volume-equated resistance training loading strategies on muscular adaptations in well-trained men. *J Strength Cond Res* 28(10): 2909–2918, 2014—Regimented resistance training has been shown to promote marked increases in skeletal muscle mass. Although muscle hypertrophy can be attained through a wide range of resistance training programs, the principle of specificity, which states that adaptations are specific to the nature of the applied stimulus, dictates that some programs will promote greater hypertrophy than others. Research is lacking, however, as to the best combination of variables required to maximize hypertrophic gains. The purpose of this study was to investigate muscular adaptations to a volume-equated bodybuilding-type training program vs. a powerlifting-type routine in well-trained subjects. Seventeen young men were randomly assigned to either a hypertrophy-type resistance training group that performed 3 sets of 10 repetition maximum (RM) with 90 seconds rest or a strength-type resistance training (ST) group that performed 7 sets of 3RM with a 3-minute rest interval. After 8 weeks, no significant differences were noted in muscle thickness of the biceps brachii. Significant strength differences were found in favor of ST for the 1RM bench press, and a trend was found for greater increases in the 1RM squat. In conclusion, this study showed that both bodybuilding- and powerlifting-type training promote similar increases in muscular size, but powerlifting-type training is superior for enhancing maximal strength.

KEY WORDS muscle hypertrophy, muscle strength, volume load, bodybuilding, powerlifting

INTRODUCTION

Skeletal muscle is a highly plastic tissue that shows a remarkable ability to adapt to imposed demands. Mechanical overload leads to a hypertrophic response while unloading results in atrophy (37). Resistance training is the primary model that has been used to promote muscular adaptations in humans. Regular resistance training has consistently been shown to produce rapid and marked increases in both muscle strength and hypertrophy across a wide variety of populations (34,46). Optimization of muscular adaptations is influenced by the prescription of resistance training variables including load, volume, and intersets rest interval. Although there is a clear and direct relationship between muscle cross-sectional area (CSA) and the ability to produce force, the acquisition of strength also has a significant neural component (10). Thus, different training strategies have been proposed for optimizing these outcome measures.

Prevailing theory suggests that maximal strength gains are achieved by training with heavy loads and lengthy rest intervals, whereas the hypertrophic response is maximized by using moderate loads with relatively brief rest between sets (21). This view is consistent with the training practices of strength and physique athletes. Powerlifters often train with heavy loads for ≤ 5 repetitions taking at least 3 minutes between sets using several structural exercises during specific strength training phases. It is believed that such heavy loads are necessary to optimize neural recruitment patterns necessary for exerting maximal force. However, bodybuilders predominantly train with loads of 8–12 repetitions with rest intervals of 2 minutes or less. It has been hypothesized that this loading strategy provides an ideal combination of mechanical tension and metabolic stress to maximize the hypertrophic response (38).

Studies show that resistance training volume is an important variable in postexercise muscular adaptations. A clear dose-response association has been reported, with

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multiple set protocols showing a superiority to those using single sets for increasing both strength (22) and hypertrophy (23). Although there is undoubtedly an upper threshold to the dose-response relationship, there is evidence that additional improvements can extend to at least as many as 8 sets per exercise (25).

A number of studies have attempted to compare and contrast muscular adaptations associated with powerlifting- vs. bodybuilding-type training. Results of these trials have been conflicting. Choi et al. (7) randomly assigned 11 young men to either a “bulk-up” protocol consisting of 9 sets of knee extensions at 40–80% 1 repetition maximum (RM) with 30 seconds rest between sets or a “power-up” protocol consisting of 5 sets at 90% 1RM with a 3-minute rest interval. After 8 weeks, those in the “bulk-up” group showed greater increases in quadriceps CSA, whereas those in the “power-up” group displayed greater increases in strength. Masuda et al. (27) subsequently used an identical protocol and reported similar findings. Although these studies provide support for current resistance training recommendations across the strength-endurance continuum, it should be noted that volume was substantially higher in the “bulk-up” protocol, raising the possibility that the hypertrophic findings may have been confounded by differences in workload.

Only a few studies have evaluated powerlifting- vs. bodybuilding-type training on a volume-equated basis. Chestnut and Docherty (6) compared performance of 6 sets of 4RM with 3 sets of 10RM over the course of a 10-week upper-body resistance training program. Results showed that both groups displayed significant increases in both strength and hypertrophy with no differences between groups in either measure. However, Campos et al. (5) found that lower-body strength improvements were greater with low (3–5) vs. high (9–11) repetitions, but increases in muscle CSA between groups were similar between groups. These findings suggest that volume plays a role in exercise-induced muscular adaptations.

A limitation of the research to date is that no studies have evaluated muscular adaptations in well-trained individuals. It is well established that highly trained individuals respond differently than those who lack training experience (34). A “ceiling effect” makes it progressively more difficult for trained individuals to increase muscular gains, thereby necessitating more demanding resistance training protocols to elicit a hypertrophic response. Moreover, there is emerging evidence that consistent resistance exercise can alter anabolic intracellular signaling in rodents (32) and humans (9), indicating an attenuated hypertrophic response. Given the contradictory findings of previous studies and their inherent limitations, the purpose of this study was to evaluate muscular adaptations in a volume-equated hypertrophy-type training program using moderate-intensity loads and short rest intervals vs. a strength-type routine using high-intensity loads and long rest intervals in well-trained men.

METHODS

Experimental Approach to the Problem

Prevailing opinion among strength and conditioning professionals is that gains in muscular strength are maximized using heavy loads and long rest periods between sets, whereas hypertrophy is best enhanced using moderate loads and relatively short rest intervals. It is not clear, however, whether these outcomes hold true when volume is equated between protocols. Moreover, no study to date has investigated the veracity of these beliefs in experienced lifters. Therefore, this study was designed to investigate and compare muscular adaptations in a powerlifting-type routine using 3 repetitions per set with a 3-minute rest between sets vs. a bodybuilding-type protocol using 10 repetitions per set with a 1.5-minute rest between sets. A randomized parallel design was used to answer the question: Are there differences in muscular adaptations between powerlifting- and bodybuilding-type resistance training programs in well-trained men when volume is equated?

Subjects

Subjects were 20 male volunteers (age = 23.2 ± 2.7 years; age range = 20–31 years; body mass = 81.4 ± 13.4 kg) recruited from a university population. This sample size was justified by a priori power analysis using a target effect size of 0.8, alpha of 0.05, and power of 0.80. Subjects were between the ages of 18 and 35, did not have any existing musculoskeletal disorders, were not allergic to whey or soy protein, claimed to be free from consumption of anabolic steroids or any other legal or illegal agents known to increase muscle size for the previous year, and were considered experienced lifters, defined as consistently lifting weights at least 3 times per week for a minimum of 1 year. The average training experience of the subjects was 4.2 ± 2.4 years with a range of 1.5–10 years.

Participants were pair-matched according to baseline strength and then randomly assigned to 1 of 2 experimental groups: a strength-type resistance training routine (ST) designed to induce high levels of mechanical tension ($n = 10$) or a hypertrophy-type resistance training routine (HT) designed to induce high levels of metabolic stress ($n = 10$). Three subjects did not complete the study—2 as a result of injury and another for personal reasons—so that the 8 subjects completed ST and 9 subjects completed HT. Baseline descriptive statistics for the completers in each group are provided in Table 1. Approval for the study was obtained from the Institutional Review Boards at Rocky Mountain University and Lehman College. Informed consent was obtained from all participants before beginning the study.

Resistance Training Procedures

The resistance training protocol consisted of 3 exercises per session drawn from a pool of 9 total exercises. These included 3 exercises targeting the anterior torso muscles (incline barbell press, flat barbell press, and Hammer Strength chest press), 3 exercises targeting the posterior

TABLE 1. Mean (\pm SD) baseline descriptive statistics.

Variable	ST group	HT group
Age (y)	23.6 \pm 3.1	22.7 \pm 2.5
Weight (kg)	84.5 \pm 14.5	78.4 \pm 12.3
Resistance training experience (y)	4.8 \pm 3.0	3.6 \pm 1.7

muscles of the torso (wide-grip lat pull-down, close-grip lat pull-down, and seated cable row), and 3 exercises targeting the thigh musculature (barbell back squat, machine leg press, and machine leg extension). These exercises were chosen based on their common inclusion in bodybuilding- and strength-type resistance training programs (4,8). Both groups performed the same exercises over the course of a training week as illustrated in Table 2. Subjects were instructed to refrain from performing any additional resistance-type training for the duration of the study.

Total volume load (i.e., number of repetitions performed multiplied by the load lifted) was equalized between routines to control for influence of this variable on muscle thickness (MT). Training for both routines consisted of 3 weekly sessions performed on nonconsecutive days for 8 weeks. Both groups completed each set at the point of muscular failure—the inability to perform another concentric repetition while maintaining proper form. Failure training is a common practice in both the research and real-world settings, and it has been used in previous studies on the topic (5–7,27). Although hypertrophic programs tend to use training to failure more frequently, it was important to have the ST

group also conclude sets at failure to avoid confounding the criteria for set termination. Repetitions were performed quickly but in a controlled manner on the concentric phase and were lowered under control on the eccentric phase. All routines were directly supervised by the research team, which included a National Strength and Conditioning Association (NSCA)-certified strength and conditioning specialist and certified personal trainers, to ensure proper performance of the respective routines. Attempts were made to progressively increase the loads lifted each week within the confines of maintaining the target repetition range. Before training, the ST group underwent 3RM testing and the HT group underwent 10RM testing to determine individual initial loads for each exercise. Repetition maximum testing was consistent with recognized guidelines as established by the NSCA (4).

The HT was a split routine where multiple exercises were performed for a specific muscle group in a session, with only 1 muscle group trained per session (Table 2). Split routines are typical of bodybuilding-style training and serve to increase muscular metabolic stress by increasing volume load within a muscle group (15). A moderate number of repetitions (target of 10 repetitions per set within a range of 8–12 repetitions) were performed with rest periods of 90 seconds afforded between sets and exercises. Moderate repetition routines with short rest intervals have been shown to heighten the magnitude of metabolic stress in a resistance training routine (17–20) and the combination of these variables seemingly allowed for greater accumulation of metabolites during the HT routine. The load was adjusted for each exercise as needed on successive sets to ensure that subjects achieved momentary muscular exhaustion within the target repetition range.

The ST was a total-body routine where 1 exercise was performed per muscle group in a session, with several major

TABLE 2. Exercises, sets, repetitions, and rest intervals for each weekly session in ST and HT.

Protocol	Session 1	Session 2	Session 3
ST	Exercises: Incline barbell press, machine leg press, and wide-grip lat pull-down Sets: 7 Repetitions: 3 Rest interval: 3 min	Exercises: Flat barbell press, barbell back squat, and close-grip lat pull-down Sets: 7 Repetitions: 3 Rest interval: 3 min	Exercises: Hammer Strength chest press, machine leg extension, and cable seated row Sets: 7 Repetitions: 3 Rest interval: 3 min
HT	Exercises: Incline barbell press, flat barbell press, and Hammer Strength chest press Sets: 3 Repetitions: 10 Rest interval: 90 s	Exercises: Wide-grip lat pull-down, close-grip lat pull-down, cable seated row Sets: 3 Repetitions: 10 Rest interval: 90 s	Exercises: Barbell back squat, machine leg press, and machine leg extension Sets: 3 Repetitions: 10 Rest interval: 90 s

TABLE 3. Volume loads for each exercise displayed as absolute values in kilograms and scaled by body weight in $\text{kg} \cdot \text{kg}^{-1}$ (shown in parentheses).

Exercise	ST	HT
Incline press	4,140 (49.0)	3,693 (47.1)
Flat press	4,504 (53.3)	4,014 (51.2)
Hammer strength chest press	5,115 (60.5)	3,318 (42.3)
Squat	5,751 (68.1)	6,625 (84.5)
Leg press	17,833 (211.0)	17,656 (225.2)
Leg extension	4,791 (56.7)	3,065 (39.1)
Wide-grip lat pull-down	4,397 (52.0)	4,428 (56.5)
Reverse pull-down	5,226 (61.8)	4,516 (57.6)
Seated row	5,063 (59.9)	3,968 (50.6)

muscle groups trained in each session (Table 2). To minimize metabolite buildup in a given muscle, ST sessions began with an upper-body exercise, followed next by a lower-body exercise, and then concluded with an upper-body exercise. A low repetition range (target of 3 repetitions per set within a range of 2–4 repetitions) was used with a 3-minute rest afforded between sets. Similar programs have been shown to produce minimal metabolic stress in the body (17,18,20). As with HT, the load was adjusted as needed to ensure that subjects achieved momentary muscular exhaustion within the target repetition range.

Dietary Adherence

To avoid potential dietary confounding of results, subjects were advised to maintain their customary nutritional regimen and to avoid taking any supplements other than that provided in the course of the study. Self-reported food records were collected twice during the study: 1 week before the first training session (i.e., baseline) and during the final week of the training protocol. A 3-day dietary recall log was provided to subjects to assess potential differences in total

energy and macronutrient intakes between groups. Subjects were instructed on properly completing the logbook and to record all food items and their respective portion sizes that were consumed for the designated period of interest. The Interactive Healthy Eating Index (Center for Nutrition Policy and Promotion, United States Department of Agriculture; <http://www.usda.gov/cnpp>) was used to analyze food records. Each item of food was individually entered into the program, and the program provided relevant information as to total energy consumption, as well as amount of energy derived from proteins, fats, and carbohydrates over the 3 reference days. To ensure adequate protein intake, subjects were provided with a supplement on training days containing 24 g of protein and 1 g of carbohydrate (Iso100 hydrolyzed whey protein isolate; Dymatize Nutrition, Farmers Branch, TX, USA). The supplement was consumed within 1-hour postexercise, as this time frame has been purported to help potentiate increases in muscle protein synthesis after a bout of resistance exercise (3).

Muscle Thickness Measurements

Ultrasound imaging was used to obtain measurements of MT. The reliability and validity of ultrasound in determining MT is reported to be very high when compared with the “gold standard” magnetic resonance imaging (35) and poses no known harmful effects (30). A trained technician performed all testing using an A-mode ultrasound imaging unit (Bodimeter Pro System; Intelametrix Inc., Livermore, CA, USA). Water-soluble transmission gel was applied to each measurement site and a 2.5-MHz ultrasound probe was placed perpendicular to the tissue interface without depressing the skin. 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 at the biceps brachii, 60% distal between the lateral epicondyle of the humerus, and the acromion process of the scapula. Ultrasound has been validated as a good predictor of muscle volume in these muscles (29,45) and has been used in numerous studies to evaluate hypertrophic changes (1,13,31,33,47). The repeatability of ultrasound measurements was assessed in a pilot

TABLE 4. Mean (\pm SD) pre- and posttraining data for biceps brachii thickness in millimeters.

ST		HT	
Preintervention	Postintervention	Preintervention	Postintervention
35.3 \pm 5.7	39.6 \pm 5.1*	34.5 \pm 4.2	38.7 \pm 4.3*

*Represents significant difference.

TABLE 5. Mean ($\pm SD$) pre- and posttraining data for 1RM bench press for ST and HT in kilograms.

ST		HT	
Preintervention	Postintervention	Preintervention	Postintervention
104.8 \pm 26.6	116.2 \pm 21.5*	97.1 \pm 20.6	105.1 \pm 18.0*

*Represents significant difference.

study on 2 separate days in a pilot study of 7 young adult men. The test-retest intraclass correlation coefficient (ICC) for the biceps muscle was 0.84. 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 acute increases in MT return to baseline within 48 hours after a resistance training session (33).

Maximal Strength Assessments

Upper-body strength and lower-body strength were assessed by 1RM testing in the parallel back squat (1RMBS) and bench press (1RMBP) exercises. These exercises were chosen because they are well established as measures of maximal strength. 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. Repetition maximum testing was consistent with recognized guidelines established by NSCA (4). In brief, subjects performed a general warm-up before testing that consisted of light cardiovascular exercise lasting approximately 5–10 minutes. A specific warm-up set of the given exercise of 5 repetitions was performed at ~50% of subjects’ perceived 1RM followed by 1 to 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. A 3- to 5-minute rest was provided between each successive attempt. All 1RM determinations were made within

5 trials. Subjects were required to reach parallel in the 1RMBS for the attempt to be considered successful as determined by a research assistant who was positioned laterally to the subject. Successful 1RMBP 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) and executed full elbow extension. The 1RMBS testing was conducted before 1RMBP with a 5-minute rest period separating tests. Strength testing took place using barbell free weights. Recording of foot and hand placement was made during baseline 1RM testing and then used for post-study performance. All testing sessions were supervised by the research team to achieve a consensus for success on each trial. The repeatability of strength tests was assessed in a pilot study on 2 separate days in a pilot study of 6 young adult men. The test-retest ICC for the 1RMBP and 1RMBS was 0.91 and 0.87, respectively.

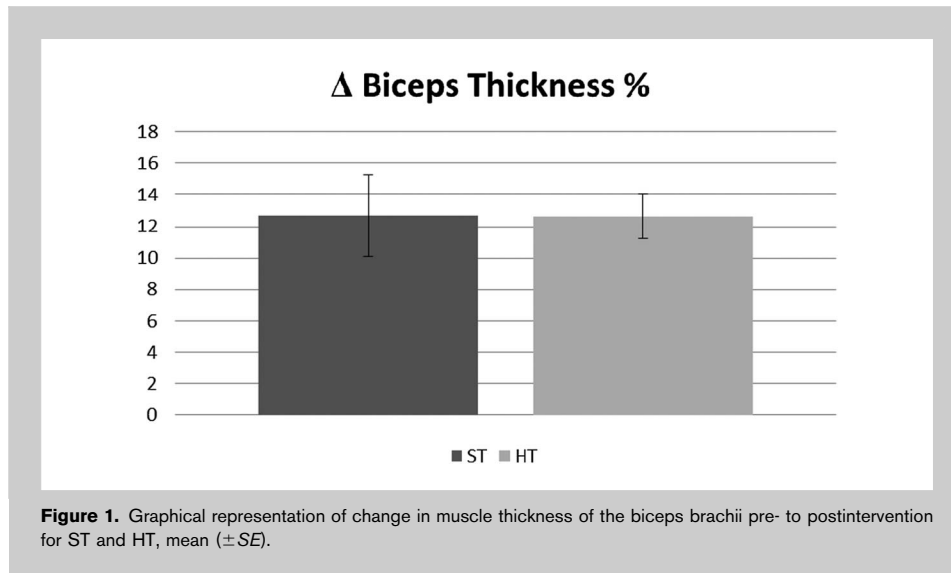
Statistical Analyses

Descriptive statistics were used to explore the distribution, central tendency, and variation of each measurement. The final analytic models were adjusted for age. Descriptive statistics (mean $\pm SE$) for each variable were reported at baseline, at 8 weeks, and as percent change from baseline. To test differences between groups, we incorporated separate multiple regression analyses with postintervention outcomes as the dependent variable and baseline values as covariates. The model included a group indicator with 2 levels and baseline values (centered at the mean values) as predictors. This model is equivalent to an analysis of

TABLE 6. Mean ($\pm SD$) pre- and posttraining data for 1RM back squat for ST and HT in kilograms.

ST		HT	
Preintervention	Postintervention	Preintervention	Postintervention
122.7 \pm 41.4	150 \pm 38.7*	114.5 \pm 36.5	136.1 \pm 30.6*

*Represents significant difference.



covariance but has the advantage of providing estimates associated with each group, adjusted for baseline characteristics that are potentially associated with the outcomes. This was also important because of the fact that using change scores as the dependent variable are subject to regression to the mean. As noted by Vickers and Altman (42) (p. 1123), “analyzing change does not control for baseline imbalance because of regression to the mean: baseline values are negatively correlated with change because (subjects) with low scores at baseline generally improve more than those with high scores.” Despite a fairly homogeneous sample of trained adult men, there was some variability in both strength and MT at baseline. Thus, we decided to incorporate this statistical technique to ameliorate the influence of such imbalances. Each model therefore included a group indicator with 2 levels (0, 1), as well as baseline values (centered at the mean values) as



predictors. Specifically, the coefficient for the ST group indicator was used to estimate the mean difference in the outcome (e.g., MT change) associated with ST compared with HT and the intercept estimated the mean change in HT. Regression assumptions were checked and appropriate transformations (e.g., log) performed if necessary. An independent *t*-test was used to compare volume load between groups. Two-tailed alpha was set at 0.05.

RESULTS

A total of 17 subjects were analyzed (9 in the HT group and 8 in the ST group). Adherence was excellent in those who completed the study, with an average compliance of approximately 96% of total sessions. Age, body mass, height, body mass index, and training experience were similar between HT and ST at baseline. Scaled for body weight, total average weekly load lifted for ST vs. HT was 673 kg·kg⁻¹ and 654 kg·kg⁻¹, respectively. Volume load was not statistically different between groups. Table 3 shows the weekly volume loads for each of the muscle regions. The mean duration of each HT session was approximately 17 minutes, whereas the duration of ST sessions was approximately 70 minutes.

Muscle Thickness

Muscle thickness data for the biceps brachii are shown in Table 3. Significant increases occurred from pre- to posttesting for both HT and ST (12.6 and 12.7%, respectively; Figure 1). No differences in the magnitude of hypertrophic changes were noted between groups, even after adjustment for baseline values.

Muscle Strength

Muscle strength data for 1RMBP and 1RMBS are shown in Tables 4 and 5. Significant increases occurred from pre- to posttesting for both HT and ST in 1RMBP (8.1% and 10.9%, respectively; Figure 2) and 1RMBS (18.9% and 22.2%, respectively; Figure 3). Without adjusting for baseline values, no differences in the magnitude of strength changes in either 1RMBP or 1RMBS were noted between the groups. However, after adjusting for baseline values

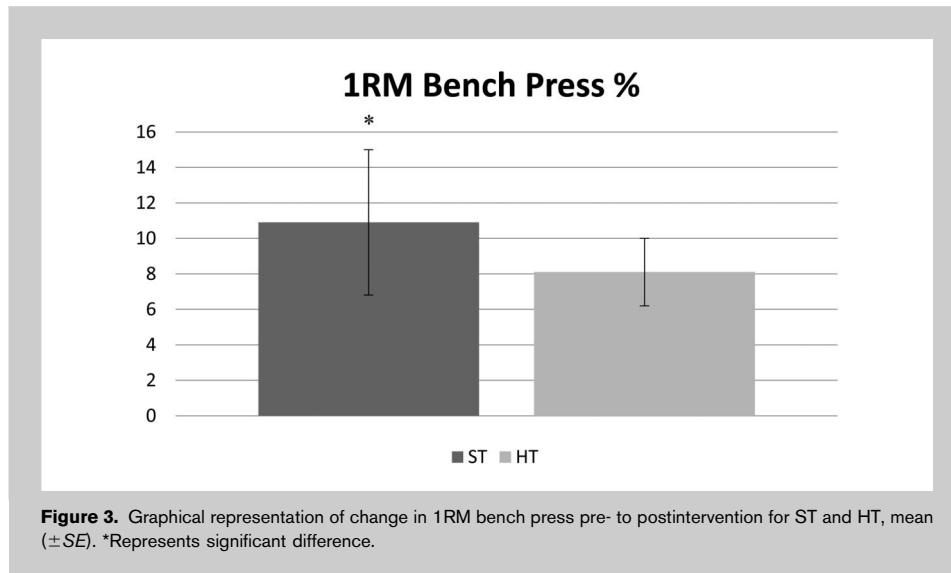


Figure 3. Graphical representation of change in 1RM bench press pre- to postintervention for ST and HT, mean (\pm SE). *Represents significant difference.

as a covariate, there was a significant difference noted in change in 1RMBP favoring ST vs. HT ($p \leq 0.05$). A trend for greater increases in 1RMBS was noted in favor of ST vs. HT as well ($\beta = 15.0$; $p = 0.19$) (Table 6).

DISCUSSION

To the authors' knowledge, this is the first study to evaluate muscular adaptations associated with powerlifting- vs. bodybuilding-type training protocols in well-trained lifters when equating for volume load. The primary finding of the study was that although both protocols significantly increased indices of maximal strength and MT, there were no significant differences in MT observed between groups. With respect to MT, results are consistent with previous studies in untrained subjects that controlled for volume (5,6) but in contrast to those that did not (7,27), thereby lending support to the theory that higher levels of volume mediate the hypertrophic response at least up to a certain point (23). With respect to strength, results of this study are in conflict with those of Chestnut and Docherty (6), who found no differences between upper-body powerlifting- vs. bodybuilding-type training in a volume-equated protocol using untrained subjects. Discrepancies may be related to the different exercises used between studies and training status of the subjects. Although Chestnut and Doherty measured strength using 1RM for the close-grip bench press and biceps curl, this study used the traditional bench press for testing. Alternatively, the results seem to support those of Campos et al. (5), who reported greater lower-body strength improvements in untrained subjects with low (3–5) vs. moderate (9–11) repetition training. After adjusting for baseline values, results of this study showed a significantly greater increase in 1RMBP and a trend toward greater 1RMBS performances in the ST group.

General resistance training guidelines for optimizing the hypertrophic response to resistance training recommend

that individuals use multiset protocols using moderate repetition schemes and relatively short interset rest intervals (24). A recent survey shows that these principles are regularly used in practice by competitive bodybuilders, with 77% performing 7–12 repetitions per set and 68.6% resting for 61–120 seconds between sets (12). Hypertrophy-type routines are designed to heighten metabolic stress at the expense of higher levels of mechanical tension (17,18,20). As previously noted, there is compelling evidence that metabolic stress mediates anabolism (36,39,41) and some research-

ers have speculated that metabolite accumulation may be more important than high force development in optimizing muscle growth (40). Given that increases in MT in this study were similar between ST and HT, it may be inferred that metabolic stress is redundant rather than additive with respect to increasing muscle protein accretion. In other words, the higher levels of mechanical tension attained with heavy loading in ST may be offset by a greater generation of metabolites in HT when volume load is similar, but the increased metabolic stress might not provide a sufficient additive anabolic stimulus over and above what is achieved when training with heavier loads. Alternatively, it is possible that results are predominantly a function of mechanical tension and that the greater absolute tension in the ST group was offset by an accumulated time-under-tension in HT. Either way, these findings suggest that any hypertrophic advantages seen with hypertrophy-type training are because of greater volume loads as opposed to inherent aspects of the protocol itself.

There is a paucity of data investigating the effects of graded increases in mechanical tension on intracellular anabolic signaling. Martineau and Gardiner (26) studied this topic in situ by isolating the sciatic nerve and plantaris muscle in female Sprague-Dawley rats. Electrical stimulation was applied to achieve a variety of tension levels across a spectrum of concentric, isometric, and eccentric actions. Results indicated a tension-dependent effect on signaling, with a strong linear relationship noted between MAPK phosphorylation and peak levels of tension over a 15-fold range in tension, pointing to a dose-response effect for mechanical tension and MT. Results of this study indicate that although mechanical tension alone seems to play a central role in the hypertrophic response, other factors seem to be involved as well and may, in fact, be equally as important provided a given threshold of tension is achieved. Although markers

of metabolic stress were not directly investigated in this study, the HT protocol was similar to that of other studies showing that high levels of metabolic stress were present compared with ST. Although it is tempting to extrapolate these findings as evidence that metabolic stress does indeed act as a mediator of hypertrophic gains, caution must be exercised as correlation does not necessarily equate to causation. Further study of the interaction between mechanical tension and metabolic stress is warranted to determine how these factors produce an anabolic response to resistance training, both separately and in combination.

Current theory proposes that strength increases are maximized using heavy loads of approximately 1–5RM. Although significant gains in strength have been reported using higher repetition bodybuilding-type training, it has been postulated that the lighter loads used in these protocols are suboptimal for maximizing strength, particularly in advanced lifters (2,16). Results of this study support this hypothesis. Given that maximal strength has a substantial neural component (10), it can be inferred from this study that loads of ~75% 1RM are not sufficient to optimize improvements in neural mechanisms as compared with heavier loads on a volume load-equated basis in well-trained subjects.

It is important to note that there were substantial differences in the duration of training between the 2 protocols studied. The HT protocol took approximately 17 minutes to perform, whereas the ST protocol required a time commitment of more than 1 hour. Given the similar hypertrophic gains in the biceps brachii between groups, HT was a much more time-efficient strategy for eliciting these increases. Moreover, personal communication with subjects both during and after the study revealed that those in the ST group generally felt highly fatigued both physically and mentally from the workouts, whereas those in the HT group tended to report being willing and able to extend the duration of training sessions. It therefore stands to reason that the HT group could have endured additional volume in their routines, whereas those in the ST group were at their upper limits of tolerance. Previous studies in untrained subjects show that a bodybuilding-type protocol promotes a greater hypertrophic response compared with a powerlifting-lifting protocol when volume is not matched between groups (7,27). Future research should seek to investigate whether well-trained subjects would respond similarly or perhaps even better to an increased volume of resistive exercise using a bodybuilding-type training protocol, particularly because it has been shown that experienced lifters can benefit from greater volumes of work (34).

A common area of concern with powerlifting-type training is an increased potential for injury (11). The performance of high training volumes using very heavy loads places substantial stress on the joints and soft tissue structures. This may make an individual more susceptible to muscle and connective strains, as well as increasing the potential for

long-term degenerative changes at the working joints. Although a small sample, this study gives credence to the veracity of these concerns. Two of the 10 subjects in the ST group dropped out of the study because of joint-related injuries; 1 subject experienced a knee-related issue, whereas another suffered a tendinopathy of the shoulder. The injuries occurred despite direct supervision by trained personnel. In contrast, none of those in the HT group reported experiencing a training-related injury. These findings substantiate the need to reduce training volume when training with very heavy loads, as well as for incorporating regular unloading cycles with reduced loading and/or volume to optimize recovery.

The study had several limitations that should be taken into account when interpreting results. First, the time frame of assessment was relatively short, covering only 8 weeks. It is not clear whether results would have changed over a longer duration of training. Furthermore, we chose not to test at the mid-point of the study to avoid disrupting the training protocol. Although this provided better continuity, it prevented assessing the time course of results and therefore precludes our ability to determine whether greater gains were seen initially or occurred consistently over time. Second, MT findings are specific to the biceps brachii; it is not clear whether other muscles might respond differently to the training stimuli provided by the respective protocols used in this study. In addition, thickness of the biceps was measured only at the middle portion of the muscle. Although this region is generally considered to be indicative of overall growth of a given muscle, research shows that hypertrophy manifests in a regional-specific manner, with greater gains sometimes seen at the proximal and/or distal aspects (43,44). This may be related to exercise-specific intramuscular activation and/or tissue oxygenation saturation (28,43,44). The fact that multiple exercises were used for each muscle group would seemingly diminish the potential for manifestation of these nonuniform differences. However, the possibility that proximal or distal MT was greater in 1 protocol vs. the other cannot be ruled out. Third, although the use of failure training is a common practice in strength and conditioning programs, it can increase the potential for overtraining when used frequently over time (14). Considering that the training protocol lasted only 8 weeks and given that the subjects were experienced exercisers who routinely trained to failure (as determined by questionnaire at the onset of the study), it seems unlikely that results were negatively impacted. The robust improvements in muscular adaptations noted would seem to support this position. However, we did not evaluate markers of overtraining and it remains possible that negative effects manifested in a manner that adversely impacted results. Fourth, although volume load is widely considered a good estimate for the amount of work performed in a training bout, it does not account for the distance moved nor does it take actual forces into consideration. Thus, it cannot be stated that work was

completely equated for between groups. Fifth, the protocols were designed to replicate typical training in bodybuilding- and powerlifting-type programs. Accordingly, the bodybuilding protocol used “body part” training with muscle groups worked 1 time per week, whereas the powerlifting routine used a total-body training with muscle groups worked 3 times per week. Although this design provides real-world application, it also introduces additional confounding variables to the mix. We therefore cannot say with certainty that increases in strength and MT were attributed to set/repetitions/load as training frequency and density of training may have contributed to results. Finally, findings are specific to young resistance-trained men and cannot necessarily be generalized to other populations. Specifically, differences in hormonal influences, anabolic sensitivity of muscle, recuperative abilities, and other factors may alter the hypertrophic response in adolescents, women, and the elderly. Future research should seek to determine the generalizability of results to these populations.

PRACTICAL APPLICATIONS

In conclusion, the results of this study provide novel insight into muscular adaptations associated with resistance training in well-trained individuals. Based on the findings, strength-related gains seem to be maximized by performing heavy-load training as compared with moderate-load training, although both protocols significantly and markedly improved indices of maximal strength. However, increases in MT in experienced lifters seem to be similar in bodybuilding- and powerlifting-type when volume load is controlled, at least over a relatively short time period. The greater time efficiency of bodybuilding-type training would seem to make it a superior choice for those seeking to increase muscle mass, although these results are limited to the biceps brachii and cannot necessarily be generalized to other muscles. Whether combinations of different loading schemes would produce a synergistic response that enhances muscular adaptations remains to be determined and requires further study.

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