

Effects of different volume-equated resistance training loading strategies on muscular adaptations in well-trained men

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Abstract: 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 versus a powerlifting-type routine in well-trained subjects. 17 young men were randomly assigned to either an HT group that performed 3 sets of 10RM with 90 seconds rest or an ST group that performed 7 sets of 3RM with 3 minutes rest. 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 both bodybuilding- and powerlifting-type training promote similar increases in muscular size, but powerlifting-type training is superior for enhancing maximal strength.

Keywords: muscle hypertrophy; muscle strength; volume load; bodybuilding; Powerlifting

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 (38). Resistance training is the primary model that has been employed 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 (35, 47). Optimization of muscular adaptations is influenced by the prescription of resistance training variables including load, volume, and interset 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 while the hypertrophic response is maximized by using

moderate loads with relatively brief rest between sets (20). 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. On the other hand, 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 (39).

Studies show that resistance training volume is an important variable in post-exercise muscular adaptations. A clear dose-response association has been reported, with multiple set protocols showing a superiority to those employing single sets for increasing both strength (22) and hypertrophy (23). While 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- versus 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% 1RM with 30 seconds rest between sets or a "power-up" protocol consisting of 5 sets at 90% 1RM with 3 minutes rest. After 8 weeks, those in the "bulk-up" group showed greater increases in quadriceps CSA while those in the "power-up" group displayed greater increases in strength. Masuda et al. (27) subsequently employed 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- versus bodybuilding-type training on a volume-equated basis. Chestnut et al. (6) compared performance of 6 sets of 4RM versus 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. On the other hand, Campos et al. (5) found that lower body strength improvements were greater with low (3-5) versus 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 (35). 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 (34) 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 employing moderate intensity loads and short rest intervals versus a strength-type routine employing high intensity loads and long rest intervals in well-trained men.

Methods

Experimental Approach to the Problem

Prevailing opinion amongst strength and conditioning professionals is that gains in muscular strength are maximized using heavy loads and long rest periods between sets while 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 employing 3 repetitions per set with 3 minutes rest between sets versus a bodybuilding-type protocol employing 10 repetitions per set with 1.5 minutes 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; body mass = 81.4 ± 13.4 kgs) 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 18-35, 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 to 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 (IRB) at Rocky Mountain University and Lehman College. Informed consent was obtained from all participants prior to beginning the study.

Insert Table 1 here

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 muscles of the torso (wide grip lat pulldown, close grip lat pulldown, 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. Training for both routines consisted of 3 weekly sessions performed on non-consecutive 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 employed in previous studies on the topic (5-7, 27). Although hypertrophic programs tend to utilize 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. Prior to training, the ST group underwent 3 repetition maximum (RM) testing and the HT group underwent 10 RM testing to determine individual initial loads for each exercise. Repetition maximum testing was consistent with recognized guidelines as established by the NSCA (4).

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 (see 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 (16-19) 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.

ST was a total-body routine where 1 exercise was performed per muscle group in a session, with several major muscle groups trained in each session (see Table 2). In order 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 employed with 3 minutes rest afforded between sets. Similar programs have been shown to produce minimal metabolic stress in the body (16-18). As with HT, the load was adjusted as needed to ensure that subjects achieved momentary muscular exhaustion within the target repetition range.

Insert Table 2 here

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 three reference days. To ensure adequate protein intake, subjects were provided with a supplement on training days containing 24g protein and 1g carbohydrate (Iso100 Hydrolyzed Whey Protein Isolate, Dymatize Nutrition, Farmers Branch, TX). The supplement was consumed within one hour post-exercise, as this time frame has been purported to help potentiate increases in muscle protein synthesis following a bout of resistance exercise (3).

Muscle Thickness Measurements

Ultrasound imaging was used to obtain measurements of muscle thickness (MT). The reliability and validity of ultrasound in determining MT is reported to be very high when compared to the "gold standard" magnetic resonance imaging (36) and poses no known harmful effects (30). A trained technician performed all testing using an A-mode ultrasound imaging unit (Bodymetrix Pro System, Intelametrix Inc., Livermore, CA). 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 and colleagues (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, 46) and has been used in numerous studies to evaluate hypertrophic changes (1, 13, 31, 32, 48). The repeatability of ultrasound measurements was assessed in a pilot 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 muscle thickness return to baseline within 48 hours following a resistance training session (33).

Maximal Strength Assessments

Upper- and lower-body strength was 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 prior to baseline testing and at least 48 hours prior to 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 prior to 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 one to two 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. Three to 5 minutes 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 five-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. 1RMBS testing was conducted prior to 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 intraclass correlation coefficient (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 (means \pm SE) for each variable were reported at baseline, at 8 weeks, and as percent change from baseline. In order to test differences between groups, we incorporated separate multiple regression analyses with post-intervention outcomes as the dependent variable and baseline values as covariates. The model included a group indicator with two levels and baseline values (centered at the mean values) as predictors. This model is equivalent to an analysis of 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 due to the fact that using change scores as the dependent variable are subject to regression to the mean. As noted by Vickers and Altman (pg. 1123) (43), “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 muscle thickness 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 two 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. muscle thickness 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 versus HT was 673 kg/kg and 654 kg/kg, 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 while the duration of ST sessions was approximately 70 minutes.

Insert Table 3 here

Muscle Thickness

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

Insert Table 4 here

Insert Figure 1 here

Muscle Strength

Muscle strength data for 1RMBP and 1RMBS are shown in Tables 4 and 5. Significant increases from pre- to post-testing for both HT and ST in 1RMBP (9.1% and 13.0%, respectively -- see Figure 2) and 1RMBS (22.2% and 25.9%, respectively -- see 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 as a covariate, there was a significant difference noted in change in 1RMBP favoring ST versus HT ($p < 0.05$). A trend for greater increases in 1RMBS was noted in favor of ST versus HT as well ($\beta = 15.0$; $p = 0.19$).

Insert Tables 5 and 6 here

Insert Figures 2 and 3 here

Discussion

To the authors' knowledge, this is the first study to evaluate muscular adaptations associated with powerlifting- versus bodybuilding-type training protocols in well-trained lifters when equating for volume-load. The primary finding of the study was that while both protocols significantly increased indices of maximal strength and muscle thickness, there were no significant differences in muscle thickness observed between groups. With respect to muscle thickness, 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 the present study are in conflict with those of Chestnut and Docherty (6), who found no differences between upper body powerlifting- versus bodybuilding-type training in a volume-equated protocol using untrained subjects. Discrepancies may be

related to the different exercises employed between studies and training status of the subjects.

Whereas Chestnut and Doherty measured strength using 1RM for the close-grip bench press and biceps curl, the present 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) versus 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 employ multi-set protocols using moderate repetition schemes and relatively short inter-set rest intervals (24). A recent survey shows that these principles are regularly employed in practice by competitive bodybuilders, with 77% performing 7-12 reps 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 (16-18). As previously noted, there is compelling evidence that metabolic stress mediates anabolism (37, 40, 42) and some researchers have speculated that metabolite accumulation may be more important than high force development in optimizing muscle growth (41). Given that increases in muscle thickness 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 due to 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 et al. (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 muscle thickness. Results of the present study indicate that while mechanical tension alone appears to play a central role in the hypertrophic response, other factors appear 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 to ST. While 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, 21). Results of the present 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 to 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, while 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 while 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 while 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 to 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 since it has been shown that experienced lifters can benefit from greater volumes of work (35).

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, the present study gives credence to the veracity of these concerns. Two of the 10 subjects in the ST group dropped out of the study due to joint-related injuries; one subject experienced a knee-related issue while 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. While 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, muscle thickness 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 employed in this study. In addition, thickness of the biceps was measured only at the middle portion of the muscle. While 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 (44, 45). This may be related to exercise-specific intramuscular activation and/or tissue oxygenation saturation (28, 44, 45). The fact that multiple exercises were employed for each muscle group would seemingly diminish the potential for manifestation of these non-uniform differences. However, the possibility that proximal or distal muscle thickness was greater in one protocol versus 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 employed 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 employed "body part" training with muscle groups worked 1 time per week while the powerlifting routine employed a total body training with muscle groups worked 3 times per week. While 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 muscle thickness were attributed to set/reps/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 the present study provide novel insight into muscular adaptations associated with resistance training in well-trained individuals. Based on the findings, strength-related gains appear to be maximized by performing heavy- as compared to moderate-load training, although both protocols significantly and markedly improved indices of maximal strength. On the other hand, increases in muscle thickness in experienced lifters appear 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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Table Captions

Table 1 Mean (\pm SD) baseline descriptive statistics

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

Table 3 Volume-loads for each exercise displayed as absolute values in kg and scaled by body weight in kg/kg (shown in parentheses).

Table 4 Mean (\pm SD) pre- and post-training data for biceps brachii thickness in mm.

Table 5 Mean (\pm SD) pre- and post-training data for 1RM bench press for ST and HT in kg.

Table 6 Mean (\pm SD) pre- and post-training data for 1RM back squat for ST and HT in kg.

Figure Captions

Figure 1 Graphical representation of change in muscle thickness of the biceps brachii pre- to post-intervention for ST and HT, mean (\pm SE)

Figure 2 Graphical representation of change in 1RM back squat pre- to post-intervention for ST and HT, mean (\pm SE)

Figure 3 Graphical representation of change in 1RM bench press pre- to post-intervention for ST and HT, mean (\pm SE)

Table 1

Baseline Descriptive Statistics

Variable	ST Group	HT Group
Age (yrs)	23.6 ± 3.1 years	22.7 ± 2.5 years
Weight (kgs)	84.5 ± 14.5	78.4 ± 12.3
Resistance Training Experience (yrs)	4.8 ± 3.0	3.6 ± 1.7

ACCEPTED

Table 2
Group Protocols

Protocol	Session 1	Session 2	Session 3
ST	<p>Exercises: Incline barbell press, machine leg press, and wide grip lat pulldown Sets: 7 Repetitions: 3 Rest Interval: 3 minutes</p>	<p>Exercises: Flat barbell press, barbell back squat, and close grip lat pulldown Sets: 7 Repetitions: 3 Rest Interval: 3 minutes</p>	<p>Exercises: Hammer Strength chest press, machine leg extension, and cable seated row Sets: 7 Repetitions: 3 Rest Interval: 3 minutes</p>
HT	<p>Exercises: Incline barbell press, flat barbell press, and Hammer Strength chest press Sets: 3 Repetitions: 10 Rest Interval: 90 seconds</p>	<p>Exercises: Wide grip lat pulldown, close grip lat pulldown, cable seated row Sets: 3 Repetitions: 10 Rest Interval: 90 seconds</p>	<p>Exercises: Barbell back squat, machine leg press, and machine leg extension Sets: 3 Repetitions: 10 Rest Interval: 90 seconds</p>

Table 3

Volume Load Per Exercise

EXERCISE	ST	HT
Incline Press	4140 (49.0)	3693 (47.1)
Flat Press	4504 (53.3)	4014 (51.2)
Hammer Strength Chest Press	5115 (60.5)	3318 (42.3)
Squat	5751 (68.1)	6625 (84.5)
Leg Press	17833 (211.0)	17656 (225.2)
Leg Extension	4791 (56.7)	3065 (39.1)
Wide Grip Lat Pulldown	4397 (52.0)	4428 (56.5)
Reverse Pulldown	5226 (61.8)	4516 (57.6)
Seated Row	5063 (59.9)	3968 (50.6)

ACCEPTED

Table 4

Biceps Thickness

ST		HT	
Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention
35.3±5.7	39.6±5.1*	34.5±4.2	38.7±4.3*

*Represents significant difference

ACCEPTED

Table 5
Bench Press

ST		HT	
Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention
104.8±26.6	115.9±21.5*	97.1±20.6	105.1±18.0*

*Represents significant difference

ACCEPTED

Table 6

Squat

ST		HT	
Pre-Intervention	Post-Intervention	Pre-Intervention	Post-Intervention
109.6±59.7	147.7±40.9*	114.5±36.5	136.1±30.6*

*Represents significant difference

ACCEPTED

Figure 1

Mean (\pm SE) pre- to post-training percentage change in biceps brachii muscle thickness for ST and HT.

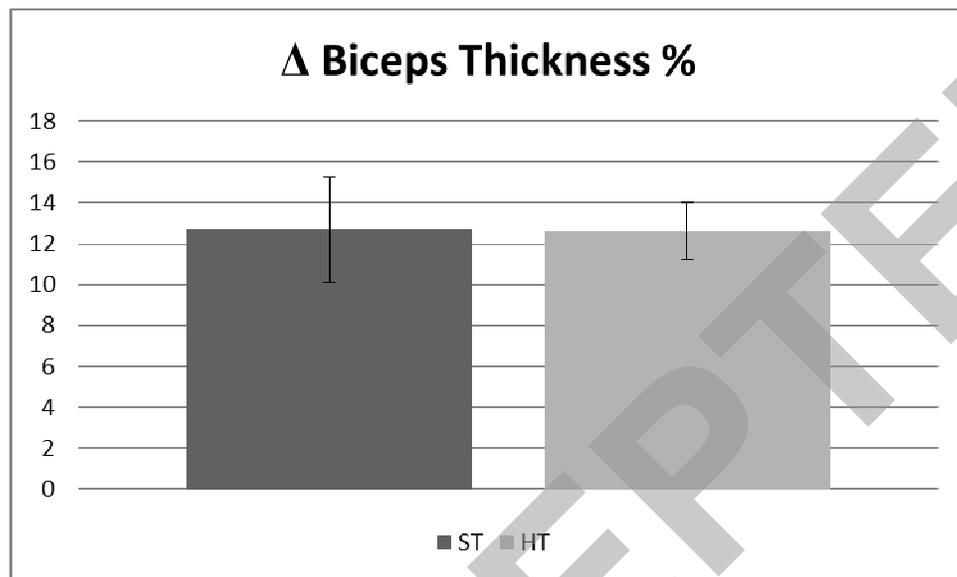


Figure 2

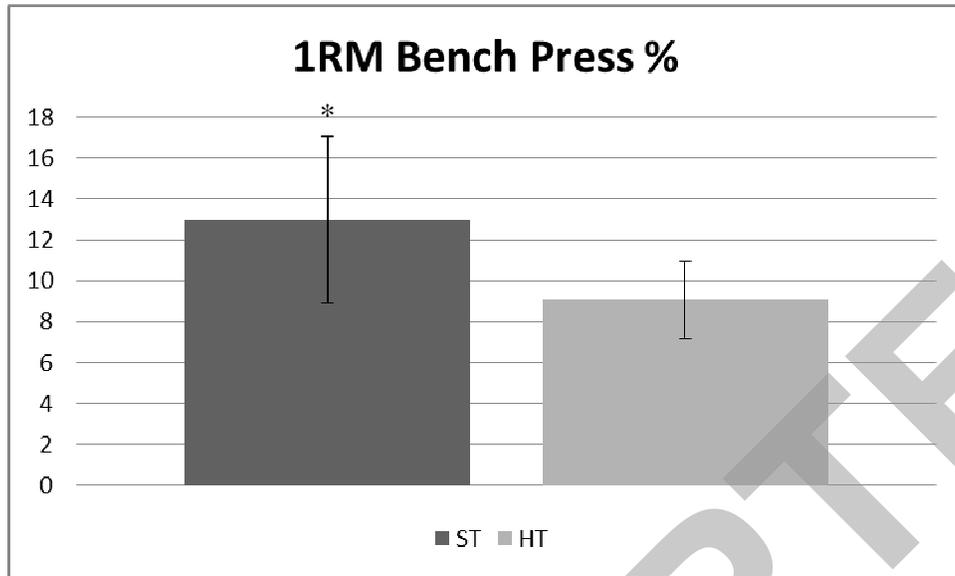
Mean (\pm SE) pre- to post-training percentage change in 1RM back squat for ST and HT.



ACCEPTED

Figure 3

Mean (\pm SE) pre- to post-training percentage change in 1RM bench press for ST and HT.



*Represents significant difference

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