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# The Effect of Weight Training Volume on Hormonal Output and Muscular Size and Function

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**Reference Data**

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**ABSTRACT**

This study examined the effects of different volumes of resistance training on muscle size and function over a 10-wk period. Low volume = 3 sets per muscle group per week; moderate = 6 sets; high = 12 sets. Twenty-seven men with 1–4 yrs weight training experience were randomly assigned to the different training volumes and trained 4 days a week. A periodized routine was used; exercises, training intensity, and number of training days were the same for each group. The only variation between conditions was the number of sets per exercise. Pre and post measurements assessed muscular size via ultrasound; strength via maximum squat and bench press; and power via vertical jump and bench press throw. Urinary concentrations of testosterone and cortisol were also analyzed to assess the responses to training conditions. All 3 training volumes significantly ($p < 0.05$) increased muscle size, strength, and upper body power, with no significant between-group differences. There were no significant changes in hormonal concentrations. The results support the use of low volume training for muscular development over a 10-wk period.

***Key Words:*** strength training, hormonal responses, muscular development

## Introduction

Muscle hypertrophy, strength, and power are desired by recreational and professional athletes alike. In the recreational setting, muscle hypertrophy is avidly pursued for reasons of health and aesthetic appeal, while in the sporting arena it is desirable for the improvements in strength associated with increases in muscle cross-sectional area (20, 22, 30, 35, 43). Athletes pursue strength and power increases for the improvements in dynamic performance that accompany these increases (15).

Along with the intensity of a given training regimen, the volume prescribed is believed to be crucial to the adaptations invoked by the program (16, 19, 30, 35, 38, 40). Yet despite the integral role it plays in the structure of a training program, there is little research as to the effect of volume manipulation on muscle size or function. Verhoshansky (38) claimed, "no one has attempted to study seriously how volume functions as the most important training load parameter; neither has anyone elucidated the principles of employing high-volume workloads" (p. 189).

While scientific training studies have typically employed 1 to 4 sets per muscle group per session (6, 30, 43), elite bodybuilders are reputed to perform from 9 to 24 sets per muscle group in a single training session (32). Consequently, it is generally accepted that high training volumes, say, 3–6 sets per exercise for 3–4 exercises (9–24 sets per muscle group), while using moderate to heavy loads of 60–80% max, represent the best way to achieve myogenic increases (8). Indeed, in light of the paucity of data in this area, practitioners have tended to implement the simple principle, "the more, the better."

Hakkinen and Alen (14) examined the effects of resistance training volume on the amount of serum creatine kinase produced. One group of weight trainers trained 5 times a week for approximately 1.5 hrs a session. The other group trained 10 times a week, also for 1.5 hrs a session. Training volume had only a minor influence on the increase in serum creatine kinase in response to training. In a review on the effects of resistance training, Stone et al. (34) stated that, "Some physiological variables such as aerobic power, blood lipids, and body composition appear to be more affected by the volume of resistance training, while performance variables such as strength and power are more influenced by the intensity of training" (p. 224).

Fry et al. (9) examined the effects of a dramatic increase in training volume for 1 week on hormonal output and strength. Nine elite male junior weightlifters doubled their training volume for 1 week with 4 training sessions a day. The protocol was repeated after a further year of training. Resting hormonal levels and strength were assessed before and after the high volume period. There was no significant change in strength after the high volume stimulus in either year. In the first year the stimulus resulted in attenuated exercise-induced testosterone concentration. But in the second year it actually augmented the exercise-induced testosterone concentration. Fry et al. concluded, "One year of chronic weightlifting and prior exposure to the overreaching (high volume) stimulus appears to decrease the detrimental effects of stressful training on the endocrine system" (p. 400).

These studies notwithstanding, there has been a paucity of research examining the importance of training volume to the adaptations invoked from resistance training. The major shortcomings of past research include the use of different training methods between groups (30, 35), the differences in exercise type between groups (1), and the frequency of training between groups (19). Thus the purpose of this study was to examine the effect of three training volumes of controlled intensity on the development of muscle size, strength, and power in moderately trained subjects. Also examined were the underlying hormonal mechanisms that may possibly influence such adaptations.

## Methods

Thirty-five men who were currently weight training, had been doing so for 1 to 4 years, and had the ability to squat and bench press at least 130% and 100% of their body mass, respectively, were randomly assigned to 3 groups: low volume (3 sets per muscle group per week); moderate volume (6 sets); or high volume (12 sets). The high volume group comprised an active control group, as pretraining questionnaires indicated that this volume of training was similar to that undertaken by the majority of subjects prior to the study.

The study was approved by the university, the potential risks were explained, and all subjects signed an informed consent document prior to testing. Over the 10-week training period 8 subjects withdrew from the study for reasons not related to the training program, leaving 9 subjects in each group. Age, height, body mass, and previous training experience of subjects in each group were as follows:

- High volume: age 22.9 ± 5.0 yrs; Ht 175 ± 4.5 cm; mass 73 ± 9.0 kg; exper. 2.7 ± 1.4 yrs;
- Moderate volume: age 23.7 ± 5.0 yrs; Ht 178.8 ± 4.8 cm; mass 79.7 ± 7.6 kg; exper. 3.1 ± 1.2 yrs;
- Low volume: age 23.2 ± 3.6 yrs; Ht 178.7 ± 2.8 cm; mass 79.1 ± 8.4 kg; exper. 2.8 ± 1.2 yrs.

There were no significant differences between groups in anthropometric variables, training history, performance, or hormonal variables prior to training.

### *Testing Procedures*

Each subject was tested before and after the 10-week training period for hypertrophy, strength, power, and hormonal concentrations. The hypertrophy tests quantified muscle size by ultrasound and weighed subjects' total body mass. Subcutaneous fat was also quantified via ultrasound. Strength tests involved a 1-repetition maximum (RM) squat and bench press. Power tests involved a vertical jump and a bench press throw. Hormonal tests measured urinary concentrations of testosterone and cortisol. The samples were collected in a rested state prior to a warm-up of several minutes of low intensity aerobic activity, submaximal trials of the tests, and stretching.

*Hypertrophic Testing Procedures.* Ultrasound (Acuson 128/10 XP computed sonagraph) was used to quantify the cross-sectional area (6) and circumference (43) of the rectus femoris and the anterior-to-posterior thickness of the triceps brachia. It was also used to measure subcutaneous fat at the muscle measurement sites. It involved application of a conductive gel (Aquasonic 100) to the skin and placement of an ultrasound transducer (Acuson L558) with a 58-mm footprint on the site to be measured. This enabled a clear image to be displayed on the sonograph's monitor with the skin, fat, and muscle tissue easily distinguishable. A 5.0-MHz transducer reflected the fat and muscle boundaries. The ultrasound device was calibrated to the velocities of sound in muscle and fat at 1,580 and 1,450 $ms^{-1}$, respectively (43).

The rectus femoris (RF) was measured midway between the greater trochanter of the femur and the lateral joint line of the knee (43). Additional measures were taken at locations 5% superior and 5% inferior to the midpoint, as research has shown that increases in muscle size may not be uniform throughout a muscle (29). Two measurements were recorded at each of the 3 sites and all 6 values were averaged to reduce the misleading effects of any structural irregularities in the muscle and to more accurately indicate changes in total muscle volume.

For measurement of the long head of triceps brachia (TB), the muscle's midpoint was located by measuring the length of the right side upper arm, from the tip of the acromion process of the scapula to the olecranon process of the ulna (30), and then calculating 50% of this value. At this point, and also at sites 5% superior and 5% inferior, ultrasound was used to measure the anterior-to-posterior thickness of the triceps brachia.

Ultrasound is an accepted method of measuring superficial structures and muscles (6). However, the ultrasound operator is inherently subjective in his or her operation of the ultrasonograph, so a pilot study was conducted to examine the operator's reliability. Thirteen subjects were tested twice, 30 min apart. Intraclass correlations and the coefficient of variation (CV) were used to examine intertrial reliability for TB and RF measurements. Strong correlations were found for both TB muscle thickness and fat thickness ($r$ = 0.91 and 0.88; CV = 5.5 and 6.5%, respectively) and for RF measures of circumference, cross-sectional area, and fat thickness ($r$ = 0.94, 0.97, and 0.99; CV = 2.7, 3.9, and 4.3%, respectively). These intertrial correlations are of similar magnitude ($r$ = 0.81–0.96) to those previously reported for fat thickness (3). Intertrial differences were assessed by a paired $t$-test with no significant ($p < 0.05$) differences observable.

*Muscle Function Testing Procedures.* Lower body maximal strength was assessed using the 1-RM squat as described by Stone et al. (35); upper body maximal strength was assessed using the 1-RM bench press described by Wilson et al. (41). The squat was standardized by having subjects adopt a shoulder-wide stance and descend until the thighs were parallel to the floor.

Belts could be worn, but lifting suits and knee wraps were not allowed. The bench press was performed without a pause on the chest; however, subjects had to keep the buttocks in contact with the bench throughout the lift and could not bounce the bar off the chest.

Peak power and height thrown or jumped were recorded during the vertical jumps and bench press throws using the procedures outlined by Wilson et al. (42). The testing device, called the Plyometric Power System (Plyopower Technologies), enabled subjects to safely perform dynamic throws or jumps with a loaded bar while relevant kinematic data were recorded at approximately 3,000 Hz (42).

The machine allowed only vertical movements of the bar, and mechanical stops permitted the bar's maximum and minimum height to be controlled with an accuracy of 0.02 m. The linear bearings attached to either end of the bar allowed it to slide about two hardened axle steel shafts with low friction. A rotary encoder attached to the machine produced pulses indicating bar displacement. One pulse was generated for each 0.00106 m of bar movement. Each pulse was recorded by a counter timer board installed in a 486DX IBM compatible computer capable of measuring pulse frequencies up to 1 MHz. The above information was recorded by the computer, and software calculated the height thrown and the power output [(mass × gravity × height)/time] of the throws and jumps. The system was calibrated before use by measuring the total number of pulses produced as the bar was being moved through its full vertical range (2.0 m).

Vertical jumps were stretch–shorten cycle in nature and involved starting from an upright position, rapidly executing a countermovement, and jumping for maximal height. The jump depth was a half squat action such that minimum knee angle was approximately 120°. The bench press throws involved lying supine in a bench press position with the feet on the bench. Grip width on the bar was standardized with the hands shoulder-width apart, elbows flexed, and shoulder complex abducted to 90°. A 20-kg bar was held at arms length, then lowered to the chest and propelled into the air. Previous research has shown these tests to be reliable, with bench press throws having a test-retest correlation of 0.85 (41) and the jump test an $r$ value of 0.97 (42).

*Hormonal Testing Procedures.* Urine samples were collected from all subjects 10 min before testing in order to avoid an anticipatory rise in, and exercise-induced fluctuations in, hormone levels (23). Subjects were instructed to refrain from training or from ingesting caffeine or alcohol for 24 hrs before testing. All urine samples were collected between 5:00 and 7:00 p.m. to control for the effects of the body's natural circadian rhythms on daily hormone levels (10). The previous urine evacuation time was a minimum of 2 hrs prior to obtaining the sample. The samples were then analyzed for levels of testosterone and cortisol using reverse-phase high performance liquid chromatography (HPLC) according to the procedures outlined using plasma (7, 25). Each analysis involved duplicate tests performed with an isocratic elution pattern.

Assay sensitivity was determined by examining the coefficient of variance between both tests: it varied between 4.6 and 9.0%. The HPLC comprised a Waters model 510 pump connected to a Phenomenex spherex C18 column, Waters intelligent sample processor model 712, Waters data module model 740, and a Waters UV/VIS detector model 481. Calibration stock standards and working standards were run through the HPLC prior to actual use of internal stock and internal working standards. After determination of total concentrations, testosterone and cortisol were also expressed as a ratio (16) so as to indicate the androgenic anabolic and glucocorticoid catabolic balance during training periods of differing volumes. Urine was used to assess hormonal values because it was simpler and less invasive to collect. While blood would have been preferable, several researchers have demonstrated a similar pattern of urinary and plasma hormone levels (21, 25).

### *Training Procedures*

Three experimental groups trained 4 times a week for 10 weeks. The training protocol required subjects to exercise a different group of muscles each session employing a variety of standard resistance exercises (Table 1). The training involved free weights. Similar to testing conditions, the squat foot position was standardized as shoulder-width apart, with the depth to a position where the thighs were parallel to the floor. Lifting belts were used, but other lifting aids such as knee wraps and lifting suits were not. The bench press was performed as a "touch and go" lift without any discernible pause on the chest. All training was supervised and the subject was encouraged to give maximum effort on all sets.

Each exercise was performed once a week, a program configuration that many researchers have shown

**Table 1**
**Training Protocol Performed by All Groups**

| *Day 1* | *Day 2* |
|---|---|
| Squat | Bench press |
| Leg press | Incline bench press |
| Leg extension | Decline bench press |
| Stiff-leg deadlift | Shoulder press |
| Leg curl | Upright row |
| Single-leg curl | Lateral raise |
| *Day 3* | *Day 4* |
| Lat pulldown | Barbell curl |
| T-bar pulldown | Preacher curl |
| Seated row | Dumbbell curl |
| Calf raise | Close grip bench |
| Calf press | Triceps pushdown |
| Seated calf raise | Triceps extension |

*Note.* Low volume group, 1 set per exercise; moderate vol. group, 2 sets per exercise; high vol. group, 4 sets per exercise.

can increase muscular strength (11, 12, 18, 28, 36, 37). Although many programs are based on training each major exercise twice a week, for logistical reasons including our desire to control the exercises performed and the training frequency between conditions, each exercise was performed once a week.

The regimen involved all subjects performing approximately 12 reps per set the first 4 weeks, 7 reps per set in Weeks 5–7, and 9 reps per set for the final 3 weeks of the program. These were repetition maximum (RM) loads such that all subjects went to failure on every set. Thus each group was using a load of the same relative intensity (i.e., same RM load) for each exercise. The frequent variation in such a periodized program is essential for eliciting adaptations from well-trained individuals (13, 30, 40). The 3 training programs differed only in volume prescribed and were structured according to low, moderate, and high volume regimens (3 sets per muscle group per week, vs. 6 vs. 9 sets, respectively). As all subjects performed the same numbers of repetitions per set, the moderate group performed twice the volume of the low group, and the high volume group performed four times the volume of the low group. This enabled large differences in the volume of training performed by each group while still employing routines that had relevance to real life.

The high volume regimen comprised the training for the active control group, since questionnaire responses had established that this volume was typically used by most subjects prior to the study. Training intensity, measured as the percentage of maximum load used, exercises performed, and number of training days were held constant between groups. The only difference between the 3 programs was in the number of sets. All sets were performed to muscular failure and a 3-min recovery period was enforced between sets to reduce the effects of fatigue (40).

### *Statistical Analysis*

Prior to training, the groups were statistically compared on all variables using a series of one-way ANOVAs. This provided data that examined whether the subjects in the various groups differed prior to training. After the training period the results of each test were analyzed by MANOVA (3 groups × 2 occasions) with repeated measures on one factor (testing occasion). Significant results were then followed by Scheffe post hoc comparisons in order to identify where and when the differences occurred. In addition, Pearson product moment correlations were used to examine the relationship between the percentage changes in the various functional and anthropometric measures and those in the hormonal measures. Statistical significance was accepted at an alpha level of 0.05.

## Results

Means and standard deviations for each *hypertrophic measure* are listed in Table 2. There was a significant test effect for all morphological measures. Thus, changes in RF circumference, RF cross-sectional area, TB thickness, and body mass from pre- to posttests did not differ significantly among groups but there was a significant increase for all 3 groups combined. For example, the triceps brachia muscle increased in thickness by 2.3, 4.7, and 4.8%, respectively, in the low, moderate, and high volume groups. Changes in body mass were also similar between groups, with increases of 2.0, 2.6, and 2.2%, respectively, for the low, moderate, and high volume groups (Table 2).

Means and standard deviations for each *adipose tissue measure* are also shown in Table 2. There were no significant changes in RF or TB fat thickness.

Means and standard deviations for each *strength measure* are shown in Table 3. There was a significant

**Table 2**
**Morphological Measures ($n$ = 9 per group)**

| | | Training groups (volume) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Low | | Moderate | | High | |
| Variable | Test | *M* | *±SD* | *M* | *±SD* | *M* | *±SD* |
| *Rectus femoris* | | | | | | | |
| Cross-sectional* | Pre | 930 | 213 | 940 | 163 | 860 | 144 |
| area ($mm^2$) | Post | 993 | 247 | 987 | 239 | 973 | 197 |
| Circumference | Pre | 132 | 15 | 133 | 14 | 126 | 11 |
| (mm) | Post | 136 | 16 | 135 | 17 | 134 | 15 |
| Fat thickness | Pre | 6.7 | 2.1 | 6.9 | 1.6 | 7.0 | 2.1 |
| (mm) | Post | 6.4 | 1.6 | 7.1 | 1.7 | 7.0 | 2.3 |
| *Triceps brachia* | | | | | | | |
| Thickness* | Pre | 44 | 4 | 43 | 5 | 42 | 4 |
| (mm) | Post | 45 | 3 | 45 | 4 | 44 | 3 |
| Fat thickness | Pre | 5.5 | 1.1 | 6.0 | 1.3 | 5.5 | 1.8 |
| (mm) | Post | 5.6 | 1.0 | 6.0 | 1.7 | 5.8 | 1.9 |
| Body mass* | Pre | 79.1 | 8.4 | 79.7 | 7.6 | 73.0 | 8.4 |
| (kg) | Post | 80.7 | 8.3 | 81.8 | 7.6 | 74.6 | 8.2 |

*Significant test effect, pre vs. post, $p < 0.05$.

**Table 3**
**Strength and Power Measures ($n$ = 9 per group)**

| | | Training groups (volume) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Low | | Moderate | | High | |
| Variable | Test | *M* | *±SD* | *M* | *±SD* | *M* | *±SD* |
| Maximal squat* | Pre | 134 | 28.4 | 146 | 23.1 | 121 | 20.7 |
| (kg) | Post | 144 | 27.8 | 154 | 20.7 | 135 | 16.3 |
| Maximal bench | Pre | 89.7 | 11.4 | 90.8 | 9.4 | 83.1 | 9.7 |
| press (kg) | Post | 93.3 | 10.9 | 95.3 | 9.5 | 84.7 | 10.3 |
| Bench press | Pre | 171 | 14.2 | 171 | 6.4 | 160 | 15.2 |
| throw power* (W) | Post | 175 | 10.8 | 175 | 7.8 | 165 | 14.2 |
| Bench press throw | Pre | 46.1 | 8.9 | 44.1 | 3.6 | 40.5 | 6.7 |
| height* (cm) | Post | 48.3 | 7.3 | 47.5 | 3.6 | 42.5 | 7.1 |
| Vertical jump | Pre | 931 | 116 | 961 | 98.7 | 824 | 108 |
| power (W) | Post | 919 | 110 | 962 | 79.0 | 862 | 112 |
| Vertical jump | Pre | 36.2 | 6.4 | 35.6 | 2.8 | 33.3 | 6.1 |
| height (cm) | Post | 34.4 | 6.9 | 34.9 | 3.6 | 34.5 | 5.8 |

*Significant test effect, pre vs. post, $p < 0.05$.

test effect for both strength measures. Thus, changes in 1-RM bench press and 1-RM squat from pre- to posttests did not differ significantly among groups, but there was a significant increase for all 3 groups combined. The increases in low, moderate, and high volume groups were 10, 8, and 14 kg, respectively, for the 1-RM squat, and 3.6, 4.5, and 1.6 kg, respectively, for the 1-RM bench press.

Means and standard deviations for each *power measure* are also shown in Table 3. There was a significant test effect for both the bench press throw power and height, but no significant changes in vertical jump power or height. Thus, changes in power measures from pre- to posttest did not differ significantly among groups, but there was a significant increase in bench press throw power and height for all 3 groups combined. The increases in upper body performance were similar between groups, with mean power output increasing by 4 to 5 W and mean throw height increasing by 2.0 to 3.4 cm (Table 3).

Means and standard deviations for each *hormonal measure* are shown in Table 4. Due to large variability in the data, there were no significant changes in urinary concentrations of testosterone, cortisol, or the testosterone/cortisol ratio from pre- to posttests. However, the effect sizes of the testosterone/cortisol (anabolic/catabolic) ratio suggested a possibility of overtraining as volume increased. For example, pre- to posttraining changes in the testosterone/cortisol ratio represented an increase in effect size of 0.9 and 0.4 for the low and moderate volume groups, respectively, while for the high volume group the ratio declined by an effect size of approximately 1 (Table 4). Cohen (4) has classified an effect size of 0.8 or greater as a large difference; thus it appears that low subject numbers and high subject variability may have prevented the large changes in hormonal data from being statistically significant.

Pearson product correlations revealed significant relationships ($r = 0.34$–$0.35$) between percentage changes in resting testosterone concentrations and those in both RF circumference and RF cross-sectional area. There was also a significant correlation ($r = 0.34$) between the percentage changes in resting testosterone/cortisol ratio and those in RF circumference.

**Table 4**
**Hormonal Measures ($n = 9$ per group)**

| | | Training groups (volume) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Low | | Moderate | | High | |
| Variable | Test | *M* | ±*SD* | *M* | ±*SD* | *M* | ±*SD* |
| Testosterone | Pre | 12.2 | 4.7 | 8.2 | 4.8 | 15.0 | 18.5 |
| (nmol/L) | Post | 14.3 | 8.9 | 11.3 | 4.9 | 9.4 | 6.5 |
| Cortisol | Pre | 9.8 | 5.5 | 5.8 | 4.6 | 8.7 | 6.9 |
| (nmol/L) | Post | 8.5 | 5.0 | 11.4 | 16.5 | 11.0 | 9.6 |
| Test/Cort | Pre | 1.6 | 0.2 | 2.2 | 1.9 | 2.8 | 2.5 |
| ratio | Post | 2.8 | 2.4 | 3.8 | 5.6 | 1.2 | 0.8 |

## Discussion

The primary findings show that the programs used as low, moderate, and high volume protocols showed no significant differences in their training effects over the 10-week training period in trained men. This may be due to the fact that once a minimum threshold volume level is reached, further increases in volume are no longer advantageous.

The results of this study demonstrate that in moderately trained men the impact of exercise volume on *muscle hypertrophy* is not observed over a 10-week training period, as there were no differential effects between the 3 groups. While higher volumes of training also achieved an increase in muscle size, the increases were similar in magnitude to those of the low volume group (Table 2). DeCarvalho et al. (6) also conducted a training study involving 12 sets a week and reported increases in quadriceps cross-sectional area similar to those of the low volume group in the current study.

The findings of the present study—that the 3 groups of differing training volume had similar muscle size increases—seem to contradict the literature, which suggests that the duration of a tension stimulus is a key factor in hypertrophy (24, 26). Consequently, most investigators have recommended high volumes of moderate intensity training (e.g., 60–80% of max) to stimulate hypertrophy, as this exposes the musculature to a tension stimulus for a long duration (8).

The theory behind the occurrence of muscular hypertrophy in response to resistance training suggests that the strain on the tendons and myofibrils during weight lifting causes disruption of these structures, which forces contractile protein to be deposited in new sites (24, 26). If this is true, then it can be reasoned, based on the current findings, that exposure to a high intensity, concentrated tensile force will effectively rupture or damage the aforementioned tissues, and that further exposure to tensile forces may be unnecessary. Hypothetically, both low and high volume training may lead to microtraumas of the muscle fibers, but the high volume training at the expense of additional time and effort.

*Strength* increases in the upper body, as measured by the bench press, were not significantly different, with improvements of 4.0, 4.7, and 1.9% for the low, moderate, and high volume groups, respectively. A similar pattern has emerged in previous research (19). Strength increases in the lower body, as measured by the squat, were likewise not significantly different, with improvements of 7.5, 5.5, and 11.6% for the low, moderate, and high volume groups, respectively. As with the hypertropy data, what stands out is the significant improvements achieved by the low volume group in less training time. The equality in lower and upper body strength development for all 3 groups indicates that when a minimum (threshold) level of strength training volume has been performed, at a higher intensity the consequent physiological adaptations may be optimized and additional workloads (e.g., 12 sets

per muscle group per week) do not contribute further improvements, at least over a short training period.

The training regimen produced no significant changes in lower body *power*, as measured by vertical jump height and power output. This may be due to the nature of the regimen itself. While the training involved dynamic contractions, the lifts were not performed explosively. Research has shown that, compared to traditional weight training, explosive training such as maximal power training is superior for developing power (42).

In contrast, the upper body had significant improvements in power output. The literature has not always reported improvements in upper body power output as a result of heavy resistance training (2, 39). Reasons for this contrast may be related to the specificity of the bench press throw test to the exercises used in the current training program. For example, the bench press throw is similar in movement plane and muscle involvement to resistance exercises such as the bench press. Previous researchers have used performance tests such as throwing velocity (2) and punching power (39) as their tests of upper body power, these tests being less specific to the resistance training used.

The findings of the present study imply that in moderately trained individuals, resistance training may not significantly affect chronic *concentrations of testosterone and cortisol*, at least not over 10 weeks. Research by Hakkinen et al. (16) has reported no significant changes in the concentrations of serum testosterone and cortisol in elite weightlifters, following a 1-year training period.

Studies that measured changes in testosterone levels during periods of prolonged training have often reported that alterations in volume and intensity during a 2- or 3-month training period had no significant effect on serum testosterone concentrations when measured on a nontraining day (17). This finding demonstrates the ability of the endocrine system to maintain a daily homeostatic balance for androgenic hormones. This efficiency in reestablishing preexercise levels of androgenic hormones has already been demonstrated (23, 27, 31) and may confound attempts to establish testosterone responses to prolonged training.

For example, Schwab et al. (31) and McMurray et al. (27) found short-term significant increases in testosterone with resistance training. However, resting levels were retained within 20 min of recovery. Interestingly, Craig and Kang (5) reported that high intensity resistance training resulted in significant elevations in growth hormone that appeared to be volume dependent, such that as more sets were completed, the production of growth hormone increased. Consequently, it is likely that long-term training of differing volumes may cause hormonal concentrations to respond differently to the individual training sessions, but have little effect on day-to-day resting levels.

Pearson product correlations revealed no correlation ($r$ = 0.01–0.28) between the percentage changes in hormonal concentrations and those in strength and power. This indicates there is little relationship between strength or power development and hormonal activity. This result is supported by Hakkinen (13), who suggests that increases in muscle strength in elite athletes could not be directly related to increases in androgen levels.

The significant correlations between the percentage changes in testosterone concentrations and both RF circumference and RF cross-sectional area ($r$ = 0.34–0.35), and between the testosterone/cortisol ratio and RF circumference ($r$ = 0.34), indicate that hormonal activity may have some effect on muscle morphology. Staron et al. (33) also reported significant correlations between hormonal concentrations of untrained men and muscle morphology, although the relationships were somewhat higher. This may have been due to the fact that their subjects were untrained. Further research could shed light on the relationship between testosterone and cortisol concentrations and changes in muscle size.

## Summary

In trained subjects, a low training volume of 3 sets per muscle group per week is as effective as 6 or 12 sets for increasing hypertrophy, strength, and upper body power over a 10-week period when each exercise is performed 1 day a week. There may be a minimum volume for resistance training at which adaptations are optimized, at least in the short term, and beyond which the performance of additional resistance activity provides no further benefit. Higher volumes of training of 6–12 sets per muscle group per week are also effective for enhancing size, strength, and upper body power. However, a trend in the hormone data suggested that such training may effect a state of overtraining in some individuals. The significant correlation between changes in muscle size and changes in hormone concentrations implies that positive alterations in hormone levels could enhance muscle hypertrophy.

## Practical Applications

From the current study the following can be concluded:

1. Over a 10-week training period, a low volume resistance training program of 3 sets per muscle group per week results in significant increases in muscle size, strength, and upper body power in previously trained men.
2. Over a 10-week training period, a low volume program of 3 sets per muscle group per week results in increases in muscle size and function similar to programs with two or four times as much volume.
3. Reducing the training volume by up to half over a brief period does not lead to a significant reduction in muscle size or function over a 10-week period. This has important implications for periodization or for reduced volume resistance training when training time is minimized, for example during in-season training.
4. High volume training (12 sets per muscle group per week) may result in a shift in the testosterone/cor-

tisol (anabolic/catabolic) ratio in some individuals, suggesting the possibility of overtraining.

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