Influence of Rest Interval Length on Acute Testosterone and Cortisol Responses to Volume-Load–EQUITED Total Body Hypertrophic and Strength Protocols

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Abstract

Villanueva, MG, Villanueva, MG, Lane, CJ, and Schroeder, ET. Influence of rest interval length on acute testosterone and cortisol responses to volume-load–equated total body hypertrophic and strength protocols. J Strength Cond Res 26(10):2755–2764, 2012—We hypothesized that total body strength (S) and hypertrophic (H) resistance training (RT) protocols using relatively short rest interval (RI) lengths between sets will elicit significant acute increases in total testosterone (TT) and cortisol (C) in healthy young men. Six men, 26 (±2.4) years, completed 4 randomized RT sessions, after a control session (R). The S and H protocols were equated for volume load (sets x repetitions x load); S: 8 sets x 3 repetitions at 85% 1RM; H: 3 sets x 10 repetitions at 70% 1RM, for all exercises. The RI used 60 seconds (S60, H60) and 90 seconds (S90, H90). Blood was drawn preexercise (PRE), immediately postexercise (POST), 15 minutes postexercise (15 MIN), and 30 minutes postexercise (30 MIN). The H60 elicited significant increases in TT from PRE (7.32 ± 1.85 ng·ml⁻¹) to POST (8.87 ± 1.83 ng·ml⁻¹) (p < 0.01), 15 MIN (8.58 ± 2.15 ng·ml⁻¹) (p < 0.01), and 30 MIN (8.28 ± 2.16 ng·ml⁻¹) (p < 0.05). The H90 also elicited significant increases in TT from PRE (8.37 ± 1.93 ng·ml⁻¹) to POST (9.90 ± 1.25 ng·ml⁻¹) (p < 0.01) and 15 MIN (9.46 ± 1.27 ng·ml⁻¹) (p < 0.05). The S60 elicited significant increases in TT from PRE (7.73 ± 1.88 ng·ml⁻¹) to 15 MIN (8.35 ± 1.64 ng·ml⁻¹) (p < 0.05), and S90 showed a notable (p < 0.10) difference in TT from PRE (7.96 ± 2.29 ng·ml⁻¹) to POST (8.75 ± 2.45 ng·ml⁻¹). All the protocols did not significantly increase C (p > 0.05). Using relatively short RI between RT sets augments the acute TT response to hypertrophic and strength schemes. Shortening RI within high-intensity strength RT may lead to concomitant enhancements in muscle strength and size over a longer period of training.

Key Words: hypertrophy, maximal strength, resistance training, hormonal response, rest periods

Introduction

Resistance training robustly stimulates skeletal muscle growth (hypertrophy) (18), and although several physiological mechanisms contribute to the regulation of muscle growth, research demonstrates the importance of androgen signaling for mediating resistance training (RT)-induced hypertrophy (21) and long-term adaptations to RT (14,22). Testosterone is a powerful anabolic hormone that stimulates muscle protein synthesis and intramuscular amino acid uptake, which result in enhanced net protein balance (36). Testosterone also increases androgen receptor (AR) content in muscle cells and associated myonuclei and satellite cells (9,16,34).

Elevated endogenous testosterone concentrations, specifically, transient RT-induced elevations in circulating testosterone, prevent catabolism of the muscle AR after acute bouts of RT (34) and potentiate gains in muscle strength after long-term RT (22). Therefore, maximizing the acute testosterone response to various types of RT (e.g., strength, hypertrophic, power), via evidence-based manipulation of acute program variables, such as intensity, volume, rest interval (RI) length between sets, and exercise selection and sequence, may ultimately promote greater tissue anabolism and enhanced recovery over a longer-term training period (34).

Evidence suggests that several RT program design–related factors influence the acute testosterone responses to resistance exercise. Regarding exercise selection and sequencing, large muscle-mass and multijoint exercises should be performed before small muscle-mass and single-joint exercises (21). Intensity (i.e., load or %1-repetition maximum) and volume
(i.e., sets × repetitions) have also been shown to affect the acute testosterone response (20,21,26,33). Evidence demonstrates that protocols of sufficient intensity and volume produce substantial elevations in testosterone in men; the interaction between intensity and volume (i.e., volume load, sets × repetitions × load) has yielded interesting results favoring training programs with a higher glycolytic component (moderate-intensity [e.g., 65–85% 1-repetition maximum], high volume [e.g., 3–5 sets × 10–15 repetitions], and relatively short RI lengths between sets [e.g., 60 seconds to as long as 2 minutes]), typically described as hypertrophic or muscular endurance resistance exercise (6,26).

In contrast, strength RT has typically been prescribed using higher training intensities (e.g., ≥85% 1-repetition maximum), significantly less volume (e.g., 3–5 sets × ≤6 repetitions), and longer RI (e.g., 3–5 minutes) compared with hypertrophic or endurance RT (17,19,40). Importantly, traditionally prescribed higher intensity strength protocols have also been observed to be less effective at eliciting an increased acute anabolic hormonal response compared with moderate-intensity hypertrophic protocols (33).

The differences in volume load examined between strength and hypertrophic RT cannot be eliminated as a critical determinant of the blunted acute anabolic hormonal response observed after higher intensity strength RT (19,28). Furthermore, many investigations have not controlled for resistance exercise volume load when attempting to examine the influence of other acute program variables on acute hormonal response patterns (11,19,33).

The influence of RI length between sets on acute hormonal response patterns after strength RT has received little attention in the scientific literature, and very few investigations have examined the effects of total body hypertrophic and strength RT protocols when attempting to characterize acute hormonal response patterns in a population of healthy men (19). Additionally, no investigations have examined the effects of high-intensity strength protocols performed with substantial volume (sets × reps) distributed over several sets (e.g., >3–5 sets) and employing relatively short RI (e.g., <3 minutes). Therefore, the purpose of this study was to determine the acute hormonal response in healthy men to 4 RT protocols, in a volume load controlled, randomized investigation. The 4 protocols examined include (a) total body strength and (b) total body hypertrophic, each incorporating 2 different RI: 60 and 90 seconds.

Specifically, this investigation aimed to determine if the use of relatively short RI lengths between sets in a strength-type protocol can augment the acute testosterone response. If the use of relatively short RI lengths significantly increases the acute testosterone response to a total body strength-type protocol, then, from a practical standpoint, repeated exposure to this type of acute strength (i.e., neuronal) training stimulus and consequent acute testosterone response may promote augmented neural and tissue adaptations over a longer period of higher intensity strength training, by increasing both the muscle strength and size. We hypothesized that volume-load–equated total body hypertrophic RT protocols and strength RT protocols employing relatively short RI lengths between sets will elicit significant acute increases in total testosterone (TT) and cortisol.

METHODS

Experimental Approach to the Problem

The central premise for this study is based on evidence suggesting that RT can induce significant protocol-dependent changes in acute hormonal response patterns lasting up to 30 minutes post RT. Substantial evidence suggests different combinations of volume, intensity, and RI length between sets can influence the acute RT-induced anabolic hormone response (i.e., testosterone), but additional research is needed to fully elucidate if and how this response may have important implications for modulating short- and long-term adaptations to RT, such as muscle protein synthesis, AR content and half-life, and intramuscular amino acid uptake, leading to improved net protein balance, muscle growth, and strength gains (22,34,36).

Novel to this area of research, the comparisons in this investigation assisted in determining the acute testosterone and cortisol response patterns in healthy men that occur as a result of RI length manipulation within 2 different volume–load–equated, total body protocols (strength-type and hypertrophic). Furthermore, this investigation assisted in determining if the use of relatively short RI lengths between sets enhanced the acute training stimulus by eliciting an elevated acute anabolic hormonal response to strength-type resistance exercise.

Subjects

Six men volunteered to participate in this study. The mean (SD) age, height, and mass of the participants were 26 (2.4) years, 178.6 (5.9) cm, and 86.4 (1.2) kg, respectively (Table 1). All the subjects were healthy and characterized as recreational resistance trainees, training at least 2 d wk−1 (>2 years); none of the subjects were considered competitive weight lifters or engaged in any specific training or training cycle outside of this investigation. None of the subjects were taking any dietary or performance enhancing supplements. Each subject had the risks of the investigation explained to him and signed an informed consent form before participation in this study. The University of Southern California Health Sciences Campus Institutional Review Board approved all the procedures involved in the study.

Procedures

After maximal strength testing in visit 1, the subjects participated in a control session (R) during visit 2 to account for the effects of the circadian rhythm on hormonal concentrations. After visits 1 and 2, all study subjects performed 4 experimental RT sessions in a randomized order (visits 3–6), to determine hormonal response patterns among 2 RT protocols with 2 different RI lengths between sets (60 and 90 seconds) (Figure 1). The 2 training protocols
TABLE 1. Baseline strength and anthropometric data.*†

<table>
<thead>
<tr>
<th>Measure</th>
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<tr>
<td>Age (y)</td>
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<td>Weight (kg)</td>
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<td>Height (cm)</td>
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<td>Percent body fat (%)</td>
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<td>Smith machine back squat 1RM (kg)</td>
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<td>Unilateral knee extension 85% 1RM (kg)</td>
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</table>

*1RM = 1-repetition maximum; 3–8RM = 3- to 8-repetition maximum.
†Values are given as mean ± SD.

Consisted of 4 exercises that activated large muscle masses, performed in the following sequence in every RT session: (a) Smith machine barbell back squat (Life Fitness, Schiller Park, IL, USA), (b) flat barbell bench press (Proformance Series by Tuff Stuff, Pomona, CA, USA), (c) narrow-neutral grip lat pulldown (Proformance Series by Tuff Stuff), and (d) seated unilateral knee extension (Proformance Series by Tuff Stuff). The control session and acute RT sessions were performed on 5 separate occasions, separated by exactly 7 days. All study participants experienced no symptoms of dizziness or nausea during and after any of the 4 acute RT sessions.

Each subject completed visits 2–6 on the same day, and at the same time, throughout the investigation. Each subject was also instructed to continue his normal activities of daily living and exercise regimen and to not engage in any strenuous activity or exercise 48 hours before all study visits.

Before undergoing any of the experimental RT sessions, all the subjects had their blood pressure taken to ensure normal levels and completed a Physical Activity Readiness Questionnaire. Participant characteristics were also obtained during visit 1. These included age, height, weight, and training history (years).

During visit 1, maximum strength 1-repetition maximum (1RM) for the Smith machine barbell back squat and flat barbell bench press exercises were measured with a 1RM method and the narrow-neutral grip lat pulldown and seated unilateral knee extension exercises with a 3–8RM indirect method (to estimate 1RM).

The 1RM was assessed as previously described by Matuszak et al. (24). The indirect method involved 1–2 warm-up sets, followed by a working set that allowed completion of (no less than) 3 repetitions to (no more than) 8 repetitions. From the indirect method, the repetition maximum was used to estimate 1RM based off of an estimated repetition maximum/%1RM relationship chart (4).

All the subjects participated in a control session (R) to account for the effects of the circadian rhythm on hormonal concentrations. The control session was performed during visit 2, before all experimental exercise sessions. During the control session, the subjects sat quietly for 45 minutes in lieu of training.

**Maximum Strength Protocol**

In the total body maximum strength protocol (S), the intensity of training was 85% 1RM for all RT exercises; 3 repetitions were performed each set for 8 sets. The subjects performed 2 experimental S protocols, each with different RI lengths between sets (RI). The RIs incorporated in this protocol were 60 seconds (S60) and 90 seconds (S90).

**Muscular Hypertrophy Protocol**

In the total body muscular hypertrophy protocol (H), the intensity of training was 70% 1RM for all RT exercises; 10 repetitions were performed each set for 3 sets. The subjects performed 2 experimental H protocols, each with different RI. The RIs incorporated in this protocol were 60 seconds (H60) and 90 seconds (H90).

**Volume Load**

All exercise techniques were structured according to anatomical characteristics of each subject, with grip widths and positions marked and kept constant for each exercise throughout the study. Volume load was equated for the S and H protocols for each subject; the only acute program variable manipulated throughout the study was the RI length between sets.

Minimal assistance (i.e., spotting) was given to the study participants only occasionally, when necessary to ensure maximum safety, and not systematically during the study. This was done to ensure all the repetitions were completed during every set of exercise. The hydration status of the study participants entering each study visit was not controlled for in this investigation. However, during the training workouts and the recovery periods, the subjects were allowed to drink water ad libitum.
Dietary Recall Questionnaire

The subjects completed a diet recall questionnaire for the day before and the day of the control session and all 4 experimental acute RT sessions (i.e., five 2-day diet recalls throughout the duration of the study). These questionnaires were qualitative in nature and used to ensure that each subject’s individualized dietary intake and nutrient timing remained similar throughout the study. Specifically, each subject recalled the types of foods, approximate quantities of those foods, and at what time of day those foods were consumed. All the subjects were instructed to repeat their pattern of eating for the day before and the day of the control session and all 4 experimental acute RT sessions, and to have their last light meal no <2 hours before the control session and all 4 experimental acute RT sessions.

Blood Draws

To avoid the effects of the circadian rhythm on hormonal concentrations, each subject performed the control and experimental acute resistance exercise sessions on the same day of the week and at the same time of day. Before each experimental resistance exercise session, the subjects rested for approximately 15 minutes in a seated position, and then a preexercise (PRE) blood sample (~10 ml) was drawn with a single needle stick. Blood samples were also drawn immediately postexercise (POST; within 2 minutes postexercise), 15 minutes postexercise (15 MIN), and 30 minutes postexercise (30 MIN) via an indwelling venous catheter placed into an antecubital vein for the determination of TT and cortisol (C) concentrations. In the control session (R; visit 2), the same blood sampling procedures were followed. The subjects did not perform an RT protocol, however, and sat passively for 45 minutes after which blood samples were obtained at the same time points as in the experimental acute RT sessions.

All blood samples were drawn with the subjects in a seated position, collected in 10-ml serum tubes and allowed
to coagulate, and centrifuged at 3,000 rpm for approximately 10 minutes at room temperature. The serum was then separated from the blood cells and stored at −80°C until analyzed. Receptors in the tissues targeted in training are exposed to the specific serum levels of hormone concentrations; therefore, hormone concentrations were not adjusted due to changes in plasma blood volume (29). Serum samples for hormone analyses were only thawed once prior to analysis. Serum concentrations of TT and C were determined in duplicate using enzyme-linked immunosorbent assay kits from DRG Diagnostics International (Berlin, Germany). All assays were carried out as advised by manufacturer’s directions. To determine the results/hormone concentrations, we calculated the average absorbance values for each set of standards and participant samples. Then, we constructed a standard curve by plotting the mean absorbance obtained from each standard against its concentration with a line of best fit. Lastly, using the mean absorbance value for each sample, we determined the corresponding concentration from the standard curve. All samples for each subject were assayed in the same assay for each hormone to avoid interassay variation (1). The intraassay coefficients of variation were 4.5 and 5.6 for TT and C, respectively.

Results

Baseline anthropometric data are presented in Table 1. There were increases in testosterone from pretest in most conditions. Across conditions, there was a significant effect of condition ($p = 0.06$). Post hoc analysis showed that this was due to the difference between H90 and the Control condition ($p = 0.02$). This represented a very large effect size (Cohen’s $d = 1.2$). Although not statistically significant, the effect sizes (Cohen’s $d$) between many of the conditions were moderate to large: Control vs. S90 = 0.6, H90 vs. H60, S60, and S90 = 0.7, 0.9, 0.6, respectively.

Analyses of the raw hormone data revealed (Figure 2): the H60 protocol elicited a significantly different percent change ($p < 0.05$) from rest (PRE) to immediately postexercise (POST), pre to 15 minutes postexercise (15 MIN), and preexercise to 30 minutes postexercise (30 MIN) for the each of the 2 resistance training protocols: strength-type with 60-second rest interval length (S60 protocol; closed triangles/dashed line), and strength-type with 90-second rest interval length (S90 protocol; closed squares/solid line). The numbers represent the absolute hormone concentration (nanograms per milliliter) from preexercise (PRE) to the 3 different postexercise time points.

Statistical Analyses

Descriptive statistics were performed on all baseline strength and anthropometric variables. To determine whether there was an effect of exercise protocol across each experiment, longitudinal linear mixed effects modeling was used to assess whether there was a difference across exercise protocol (Control, H60, H90, S60, and S90). Because each individual was his own control, and experimental conditions were closely controlled across visits, comparison of the different protocols was made without adjusting for covariates. Variances across conditions were constrained to be equal. Because this was a pilot study, and therefore not fully powered, all $p \leq 0.10$ were examined for effect size. All analyses were performed using SPSS (V20).

Figure 3. Spaghetti graph of total serum testosterone concentration mean (SD) from rest (PRE) to immediately postexercise (POST), pre to 15 minutes postexercise (15 MIN), and preexercise to 30 minutes postexercise (30 MIN) for the each of the 2 resistance training protocols: strength-type with 60-second rest interval length (S60 protocol; closed triangles/dashed line), and strength-type with 90-second rest interval length (S90 protocol; closed squares/solid line). The numbers represent the absolute hormone concentration (nanograms per milliliter) from preexercise (PRE) to the 3 different postexercise time points.

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Acute Hormonal Responses to Various Resistance Training Schemes

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<td>45</td>
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<td>45</td>
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<td>12.0</td>
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<tr>
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<td>8.8</td>
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</table>

*Figure 4. Comparison of total serum testosterone concentration mean (SD) from rest (PRE) to immediately postexercise (POST), Preexercise to 15 minutes postexercise (15 MIN) and Pre to 30 minutes postexercise (30 MIN) for the each of the 4 resistance training protocols: hypertrophic with 60-second rest interval length (H60 protocol; black bars), hypertrophic with 90-second rest interval length (H90 protocol; open bars), strength-type with 60-second rest interval length (S60 protocol; light grey bars), and strength-type with 90-second rest interval length (S90 protocol; hatched bars). The numbers represent the percent change from preexercise (PRE) to the 3 different postexercise time points. *Significant (p < 0.05) difference from Prevalue in comparison with the control (R) condition.*

in TT concentrations from PRE to POST (22.5 ± 13.4%), 15 MIN (17.4 ± 10.0%), and 30 MIN (13.2 ± 11.5%) in comparison with the R condition (p < 0.05). The H90 protocol elicited a significantly different percent change in TT concentrations from PRE to POST (20.7 ± 12.7%; p < 0.05), and a notable (p = 0.077) percent change from PRE to 15 MIN (15.4 ± 14.6%) in comparison with the R condition. The S60 protocol elicited a significantly different percent change in TT concentrations from PRE to POST (12.0 ± 7.3%; p < 0.05), a notable (p = 0.068) percent change from PRE to 15 MIN (10.8 ± 9.7%), and a notable (p = 0.088) percent change from PRE to 30 MIN (9.8 ± 9.8%) in comparison with the R condition. The S90 protocol elicited a significantly different percent change in TT concentrations from PRE to POST (13.8 ± 10.8%; p < 0.05), and a notable (p = 0.068) percent change from PRE to 15 MIN (14.3 ± 12.9%) in comparison with the R condition. All 4 acute exercise protocols did not elicit significantly different percent changes in C concentrations from PRE to any time point postexercise in comparison to the R condition (p > 0.05).

**Discussion**

The primary findings from this investigation suggest that using relatively short RI lengths (60 and 90 seconds) within volume load-equated total body hypertrophic and strength-type protocols lead to significant enhancements in the acute anabolic (serum TT) hormonal response, while eliciting nonsignificant changes in the acute catabolic (serum cortisol) hormonal response. This investigation also suggests that traditional hypertrophic protocols augment the acute serum TT response to a greater absolute and relative magnitude, when compared with strength-type protocols equal in volume load to the hypertrophic protocols and employing relatively short RI lengths between sets. This is the first study to examine volume load-equated total body protocols aimed at promoting different training adaptations, specifically, muscle hypertrophy versus muscle strength, and the influence of RI length manipulation on acute hormonal responses.

Previous research suggests that testosterone increases protein synthesis, augmenting muscle mass and strength in young and older men (35). Part of the adaptive response to testosterone may be mediated through the growth hormone-insulin–like growth factor-1 (GH-IGF-I) system (10,35). Testosterone administration can stimulate both the peripheral GH-IGF-I system (15) and intramuscular IGF-I system in men (35). Increases in local IGF-I concentrations could increase the rate of muscle protein turnover via effects on either synthesis or degradation. In vitro, IGF-I stimulates myoblasts to express myogenin, which mediates the differentiation of myoblasts to myotubes (10). The IGF-I may also reduce muscle protein degradation, which could potentially influence net muscle protein synthesis.

Furthermore, evidence indicates testosterone-induced muscle fiber hypertrophy is associated with increases in myonuclei and satellite cells (32). Muscle hypertrophy involves the addition of newly formed myonuclei via the fusion of myogenic precursor cells to adult myofibers (2). Therefore, it is possible that testosterone-induced increases in satellite cell number and fusion of satellite cells with muscle fibers precede muscle fiber hypertrophy and the increases in myonuclear number.

To date, only 1 study by Kraemer et al. (19) has examined the influence of RI length manipulation within total body strength-type protocols (i.e., ≥85% 1RM, lower training volume relative hypertrophic) on acute testosterone responses. The investigators used a strength scheme that incorporated 5 upper body exercises (4 multijoint movements: bench press, lat pulldown, seated row, military press; 1 single-joint movement: arm curl), 2 lower body exercises (1multijoint movement: leg press; 1 single-joint movement: bilateral knee extension), and 1 trunk exercise (bent leg, incline sit-ups). All exercises were performed on a Universal weight machine, except for the arm curl and trunk exercises. This study examined the influence of employing a 1- vs. 3-minute RI length within a strength-type protocol that used 3–5 sets of a 5RM for all 8 exercises. Using a 1- or 3-minute RI length, they showed significant acute increases in testosterone concentrations at 0, 5, and 15 minutes postexercise; acute cortisol responses were not investigated in this study. Interestingly, the acute testosterone response patterns to the strength protocol with either RI length (1 or 3 minutes) increased similarly; this is in contrast with more recent investigations suggesting blunted acute hormonal responses to strength-type schemes with relatively long RI lengths (i.e., 3–5 minutes) (5-7,26).

McCaulley et al. (26) examined a strength protocol consisting of 11 sets of 3 repetitions at 90% 1RM, employing
Although several studies have concluded that hypertrophic resistance exercise prescriptions (e.g., multiple sets, 8–12 repetitions, 70–80% 1RM, and relatively short RI lengths between sets of 1–2 minutes) elicit acute increases in anabolic and catabolic hormones (5–7,19–21,26,27,33), possibly differences in volume load when compared with strength-type resistance exercise prescriptions, this investigation suggests that RI length between sets, rather than volume load, may be an acute program variable critical to eliciting an enhanced acute anabolic hormonal response. Specifically, the use of relatively short RI lengths between sets within total body strength-type protocols may provide a stimulus for enhanced acute anabolic hormonal responses from pre-exercise to post-exercise. This, the results of this investigation also indicate that volume load may not be the only factor related to the enhanced acute anabolic hormonal responses to hypertrophic resistance exercise protocols; rather, the combination of volume load, use of relatively short RI lengths between sets, and selection and sequencing of exercises that activate large muscle masses may trigger the drastic acute increases in anabolic hormonal concentrations.

The scheme designs used in our study were total body in nature and incorporated exercises that challenged large muscle masses, such as the quadriceps, pectoralis major, and latissimus dorsi. Thus, exercise selection and sequencing may also be key determinants of the acute hormonal responses elicited by any given training stimulus. Repeated exposure to this type of strength (i.e., neuronal) training stimulus and consequent acute hormonal response may promote augmented neural and tissue adaptations over a longer-term period of higher intensity strength training, by increasing both the muscle strength and size; however, this hypothesis warrants additional investigation. Traditionally, strength programs incorporate relatively long RI lengths between sets (e.g., 3–5 minutes between sets), which, in combination with higher intensities and lower volumes of training, do not elicit significant acute increases in anabolic hormones (5–7,13,19–21,26,27,33) or significant size gains over a longer-term period of training (12).

The participants in this study were not competitive weight lifters, but did have several years of experience RT. Therefore, given sufficient training experience (e.g., >2 years) and a trained state, maintenance of repetition performance over repeated sets of higher intensity resistance exercise is attainable, even when using 60- or 90-second RI lengths. This recommendation is in contrast to the current body of literature regarding optimizing RI lengths between sets, which suggests 3- to 5-minute RI lengths are needed for sufficient recovery between “strength training” sets. However, a notable limitation to this research may be that the general suggestion to rest 3–5 minutes between training sets to maximize-maintain repetition performance over repeated sets is derived exclusively from hypertrophic and muscular endurance protocols, none of which are prescribed as <8RM (8,37–40). This study provides evidence to suggest that repetition performance can be maintained throughout a higher intensity strength protocol, even when employing RI lengths typically prescribed for hypertrophic resistance exercise.

The biochemical mechanisms responsible for the observed increases in blood concentrations of testosterone are not fully understood and are largely beyond the scope of this...
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This study was limited by a small number of study participants \( n = 6 \), and this small sample size did not allow for sufficient statistical power to use alternative statistical procedures, such as repeated measures analysis of variance. However, post hoc \( t \)-test power analyses of the mean relative hormone data from the 6 study participants indicated a high average power of 82%. Furthermore, this study only examined young, resistance trained men, so future research in this area should include investigations of older men, and untrained study participants. Lastly, the acute RT protocols in this study did not use “RM loads,” which are commonly prescribed in addition to “%1RM loads,” and this study did not include a determination of the acute hormonal responses to (traditional) strength-type RT protocols employing relatively long RI lengths between sets; within a single investigation, using the same study sample, future research should aim to compare acute hormonal responses to strength-type RT protocols with very dissimilar RI lengths between sets.

The impact of repeatedly elevated acute hormone concentrations after longer-term RT periods (i.e., strength-type RT) on chronic adaptations, such as maximal strength and changes in lean mass, warrants additional investigation. Evidence supports the important role of testosterone in the maintenance of muscle mass and function in men (25), but more research is needed to elucidate the exact role of testosterone in the context of acute RT-induced response patterns and the influence, if any, these acute response patterns have on chronic changes in muscle size and strength after longer-term periods of RT.

Although the mechanism(s) underlying acute bout hormonal responses leading to chronic improvements in muscle size and strength remain to be fully clarified, recent evidence suggests AR in muscle cells are upregulated 3 hours post-RT only when an acute RT bout elicits an increase in circulating testosterone (34). Moreover, testosterone increases the AR in muscle cells and associated myonuclei and satellite cells (16). Nevertheless, the precise mechanism for this upregulation are not fully understood and may also be influenced by nutrient timing (i.e., pretraining and posttraining consumption of carbohydrate- and protein-containing nutrition) (36). Therefore, future research should attempt to more clearly understand the link between acute hormonal responses (i.e., testosterone) and the chronic muscular and functional performance adaptations elicited by variations in RT scheme designs, especially strength-type schemes, in elite athletic, recreationally athletic, pathological, and older populations.

**Practical Applications**

Traditionally, higher intensity training protocols designed to enhance muscular strength (i.e., neuronal schemes using intensities \( \geq 85\% \) 1RM) have employed relatively long RI lengths between training sets (e.g., 3–5 minutes), which lead to no significant acute increases in anabolic hormones. The results of this study demonstrate that the use of relatively short RI lengths (i.e., 60 and 90 seconds) between repeated...
high-intensity training sets elicit significant acute changes in testosterone concentrations from preexercise to postexercise. Strength-power athletes capable of training at higher intensities and with volume loads equal to traditional hypertrophic resistance exercise prescriptions may enhance their adaptations to strength training via the use of shortened RI lengths between sets, if use of relatively short RI lengths during a longer-term strength phase of training results in simultaneous hypertrophic adaptations and increases in strength, because of the enhanced anabolic hormonal environment induced by RI length manipulation (i.e., greater acute increase in testosterone leading to enhanced protein synthesis and recovery from training). Lastly, the hypertrophic protocols examined in this study elicited greater absolute and relative acute changes in testosterone concentrations compared with the strength protocols, and this was most likely because of a combination of training variables, such as volume load, RI length, and exercise selection and sequence.

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