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# THE EFFECT OF RESISTIVE EXERCISE REST INTERVAL ON HORMONAL RESPONSE, STRENGTH, AND HYPERTROPHY WITH TRAINING

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## ABSTRACT

Buresh, R, Berg, K, and French, J. The effect of resistive exercise rest interval on hormonal response, strength, and hypertrophy with training. *J Strength Cond Res* 23(1): 62–71, 2009— The purpose of this study was to compare the effects of different between-set rest periods (1 and 2.5 minutes) on changes in hormone response, strength, arm cross-sectional area (CSA), thigh muscular cross-sectional area (MCSA), and body composition during a 10-week training period. Twelve untrained males ( $24.8 \pm 5.9$  years) engaged in resistance training using either 1 minute (short rest [SR],  $n = 6$ ) or 2.5 minutes (long rest [LR],  $n = 6$ ) of rest between sets, with a load that elicited failure on the third set of each exercise. Body composition, thigh MCSA, arm CSA, and five-repetition maximum (RM) squat and bench press were assessed before and after training. Blood samples were collected after exercise in weeks 1, 5, and 10. In week 1, postexercise plasma testosterone levels were greater in SR ( $0.41 \pm 0.17$  mmol·L<sup>-1</sup>) than in LR ( $0.24 \pm 0.06$  mmol·L<sup>-1</sup>,  $p < 0.05$ ), and postexercise cortisol levels were greater in SR ( $963 \pm 313$  mmol·L<sup>-1</sup>) than in LR ( $629 \pm 127$  mmol·L<sup>-1</sup>,  $p < 0.05$ ). Week 1 postexercise GH levels were not different ( $p = 0.28$ ). The differences between hormone levels in weeks 5 and 10 were not significant. Arm CSA increased more with LR ( $12.3 \pm 7.2\%$ ) than with SR ( $5.1 \pm 2.9\%$ ,  $p < 0.05$ ). There were no differences in strength increases. These results show that in healthy, recently untrained males, strength training with 1 minute of rest between sets elicits a greater hormonal response than 2.5-minute rest intervals in the first week of training, but these differences diminish by week 5 and disappear by week 10 of training.

Furthermore, the hormonal response is highly variable and may not necessarily be predictive of strength and lean tissue gains in a 10-week training program.

**KEY WORDS** growth hormone, testosterone, cortisol, bodybuilding, periodization

## INTRODUCTION

Two objectives of resistance training are improved strength and hypertrophy. Investigators have attempted to determine training methods that maximize results and efficiency of training programs and that enhance the general understanding of the mechanisms of increasing strength and hypertrophy.

The concentrations of several hormones known to affect muscle protein synthesis (e.g., testosterone [TEST], human growth hormone [GH], and cortisol [CORT]) are acutely modulated in response to resistance exercise. Testosterone is an anabolic hormone. It works by increasing rates of protein synthesis and inhibiting protein degradation (6). Most TEST is synthesized and secreted by the Leydig cells of the testes via the hypothalamic-pituitary-gonadal axis. Small amounts are derived from the ovaries, adrenals, and via conversion of other androgens.

Human growth hormone is also an anabolic hormone. It is secreted by the anterior pituitary gland, and many of its anabolic effects are mediated through insulin-like growth factor 1 (IGF-1). Like TEST, GH works by increasing protein synthesis rates and inhibiting protein catabolism (6).

Cortisol, a glucocorticoid, is a catabolic hormone. Secreted by the adrenal cortex and released via the hypothalamic-pituitary-adrenal axis, its catabolic effects result in a decrease in protein synthesis and an increase in rates of protein degradation (19). Chronically elevated levels are associated with stress-mediated lifestyle diseases. However, acutely CORT is thought to play a vital role in tissue remodeling (19).

Many studies have examined the effects of alterations in various program components (e.g., load, numbers of sets and repetitions, and amount of rest between sets) on hormonal responses. It seems to be well accepted that the acute

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response of GH, TEST, and CORT to resistance exercise is optimized in hypertrophy training protocols and in protocols that elicit pronounced lactate responses: those that use moderate loads, high volume, and short interset rest periods (7,8,15,17,18).

Although the acute hormonal response to resistance exercise has been well reported, the differences in hormonal responses to resistance exercise before and after a period of training have not been widely examined. The acute TEST response to resistance training has been shown to be greater in junior lifters (between the ages of 14 and 18 years) with > 2 years of training experience than in those with < 2 years of training experience (16). However, Ahtiainen et al. (1) have shown that the acute TEST response to a bout of resistance exercise was the same in non-strength trained men as in men who had undergone 21 weeks of training.

Kraemer et al. (14) examined GH responses to acute resistance exercise before and after training, and again after a period of detraining. It was found that subjects who underwent training that included concentric and eccentric exercise saw a greater GH response to an acute exercise bout after a period of detraining than they did immediately after a period of training. Similarly, Ahtiainen et al. (2) found that, in previously strength trained men, no difference was seen in acute hormonal responses (GH, TEST, and CORT) to resistance exercise between groups who used 2 vs. 5 minutes between sets.

Although it has been shown that specific program designs induce different hormonal responses acutely, it is not clear whether those differences in hormonal responses to an acute bout of resistance exercise are sustained after a period of training. It may be that the body adapts to the specific demands of weight training, regardless of the training protocols employed, resulting in a blunted hormone response over time, as occurs with endurance training (10,21,22,26). Consequently, the acute hormonal responses to resistance exercise may change with chronic training.

Therefore, the primary purpose of this study was to compare the effects of two different interset rest periods (1 vs. 2.5 minutes) on acute responses of TEST, GH, and CORT before and after a period of training. In addition, differences in the changes in strength, muscle cross-sectional area, and body composition achieved in the two training groups were compared.

## METHODS

### Experimental Approach to the Problem

Previously untrained subjects were recruited and randomly assigned to a 10-week resistance training program with either 1 or 2.5 minutes of rest between sets, training four times per week. Strength and anthropometric measurements were taken before and after training. In addition, in weeks 1, 5, and 10, blood samples were collected 10–15 minutes after training, and concentrations of plasma TEST, CORT, and GH were subsequently determined. Differences between groups in hormonal responses, changes in lean mass, thigh muscle

cross-sectional area, arm muscle cross-sectional area, and five-repetition maximum (RM) strength were compared.

### Subjects

A total of 12 healthy males between the ages of 19 and 27 served as subjects (Table 1). All subjects had some experience in weight training, but none were competitive athletes, and none had engaged in consistent training (i.e., resistance training more than one time per week) for at least the previous 3 months. The study was approved by the institutional review board of the University of Nebraska Medical Center, and, after initial screening, subjects gave their written informed consent to participate.

### Procedures

Subjects were instructed throughout the 10-week training period to consume a minimum of 1.7 g of protein per kilogram of body mass per day for the course of the study (3). In addition, subjects were asked to refrain from using any dietary supplements or ergogenic aids. Subjects were randomly assigned to one of two resistance training exercise groups: those who took 1 minute of rest between sets of exercise (SR), and those who took 2.5 minutes of rest between sets of exercise (LR).

*Exercise Protocol.* The training program had a 2-day split design and addressed all of the major muscle groups. Session 1 consisted of exercises for the lower extremities, shoulders, and abdominal muscles. Session 2 consisted of exercises for the chest, back, and upper extremities. Table 2 contains the specifics of training sessions 1 and 2. Major muscle groups (thighs, back, and chest) were trained using multiple-joint exercises first in each session, followed by single-joint movements. Multiple-joint exercises were included because, in addition to the influence of training volume cited earlier, acute TEST levels have been shown to be affected by the amount of muscle mass involved in training (13).

On the first two training days, subjects were given guidance in performing the study exercises by an NSCA-certified instructor (CSCS). Subjects were allowed to practice the exercises associated with training sessions 1 and 2, and any performance errors were corrected. On the next two training days, subjects went through abbreviated workouts, and an NSCA-certified instructor (CSCS) provided assistance in determining loads that produced failure in the final set.

Subjects performed sessions 1 and 2 on successive days, followed by a day of rest, and they repeated sessions 1 and 2 on the following two successive days. Subjects then took 2 days of rest to complete the week. This cycle was repeated for the duration of the study (10 weeks). Subjects were contacted weekly for the purposes of answering questions and providing guidance regarding training loads. Most exercise sessions were unsupervised, and subjects completed training logs during each training session (training loads, sets, repetitions, and start and finish times for each session) to help in quantifying compliance and confirming prescribed

**TABLE 1.** Baseline and posttraining strength and anthropometric data.

	SR group	LR group	Total
Age (y)	25.3 ± 2.0*	21.5 ± 3.6	23.4 ± 3.4
Pretraining weight (kg)	84.5 ± 5.4	79.8 ± 8.5	82.1 ± 7.2
Posttraining weight (kg)	86.6 ± 6.1†	80.9 ± 9.6	83.8 ± 8.2
Pretraining percent body fat (%)	14.1 ± 5.4	19.2 ± 5.3	16.6 ± 5.8
Posttraining percent body fat (%)	13.6 ± 4.9	18.8 ± 5.1	16.2 ± 5.5
Pretraining lean weight (kg)	72.4 ± 3.6	64.4 ± 7.4	68.4 ± 6.9
Posttraining lean weight (kg)	74.7 ± 3.7†	65.6 ± 7.9	70.1 ± 7.6†
Pretraining arm CSA (cm <sup>2</sup> )	60.2 ± 9.6	53.2 ± 9.5	56.7 ± 9.8
Posttraining arm CSA (cm <sup>2</sup> )	63.2 ± 10.1†	59.3 ± 8.5†	61.3 ± 9.1†
Pretraining thigh MCSA (cm <sup>2</sup> )	173.3 ± 13.0	156.6 ± 22.8	164.9 ± 19.7
Posttraining thigh MCSA (cm <sup>2</sup> )	178.9 ± 16.7†	167.1 ± 26.6†	173.0 ± 22.1†
Pretraining bench 5-RM (kg)	84.8 ± 11.6	69.7 ± 14.5	77.3 ± 14.8
Posttraining bench 5-RM (kg)	93.2 ± 12.1†	78.8 ± 13.9†	86.0 ± 14.5†
Pretraining squat 5-RM (kg)	118.9 ± 20.5*	98.1 ± 17.2	108.5 ± 21.0
Posttraining squat 5-RM (kg)	140.9 ± 24.0†	125.0 ± 30.9†	133.0 ± 27.7†

SR = 1 minute of rest between sets of exercise; LR = 2.5 minutes of rest between sets of exercise; CSA = arm cross-sectional area; MCSA = thigh muscle cross-sectional area; 5-RM = five-repetition maximum.

\*Significantly different from LR at baseline ( $p \leq 0.05$ ).

†Significantly different from pretraining ( $p \leq 0.05$ ).

intersert rest periods. Completed training logs were submitted to study personnel at the conclusion of each week. Training loads were increased as strength improvements allowed; when subjects were able to complete an 11th repetition during their third set in two consecutive workouts, the resistance was increased by approximately 5%. Therefore, subjects performed between 8 and 11 repetitions in their final set throughout the training period. The SR group was instructed to rest for 1 minute between sets, and the LR group was instructed to rest for 2.5 minutes between sets.

*Body Composition/Lean Tissue Determination.* Before and after the training intervention, subjects had body composition

determined through hydrostatic weighing. Residual volume was determined using helium dilution on a Collins spirometer. Results were used to determine total lean body mass. In addition, thigh muscle cross-sectional area (MCSA) was estimated using the equation of Knapik et al. (12). That equation is

$$\text{Thigh MCSA} = 0.649 \times ((\text{CT}/\pi - \text{SQ})^2 - (0.3 \times \text{dE})^2)$$

where CT = circumference of the midthigh, SQ = skinfold thickness at the thigh, and dE = distance across the medial and lateral femoral epicondyles. The estimated muscle cross-sectional area derived from this equation correlated highly with cross-sectional area (CSA) determined by magnetic

**TABLE 2.** Resistance training protocol.

Exercise session 1			Exercise session 2		
Exercise	Sets	Reps	Exercise	Sets	Reps
Squat	3	10	Pull-downs	3	10
Leg curl	3	10	Machine rows	3	10
Leg extensions	3	10	Machine bench press	3	10
Standing heel raise	3	10	Pec flies	3	10
Seated dumbbell press	2	10	Incline dumbbell curls	2	10
Dumbbell lateral raises	2	10	Machine biceps curls	2	10
Rear delts on Pec-Deck	2	10	Dumbbell kickbacks	2	10
Abdominal crunches	2	To fatigue			
Lying leg raises	2	To fatigue			

resonance imaging ( $r = 0.96$ ,  $SEE = 10.1 \text{ cm}^2$ ) (12). Similarly, CSA at the arm was estimated using the equation of Heymsfield et al. (11). That equation is

$$\text{Arm CSA} = \pi ((\text{CA}/2\pi) - (\text{TA}/2))^2 - 5.5$$

where CA = midarm circumference and TA = triceps skinfold thickness. Arm CSA estimated using this equation was strongly correlated with measures derived by computed tomography scans ( $r = 0.97$ ) (11). Identical tests were done at the conclusion of the 10-week study period, and results were compared for differences in lean tissue mass, thigh MCSA, and arm CSA.

**Determination of Strength.** Strength was assessed through a 5-RM on two exercises: the Smith Machine squat (thighs parallel with floor) and the Smith Machine chest press. The 5-RM was used as a measure of muscular strength instead of the 1-RM in an effort to minimize the chances of injury. Likewise, the Smith Machine exercises were chosen, in part, for their inherent safety.

The estimated 5-RM load was determined using several sources of information. Previous training information was used, if applicable. In addition, loads used during the familiarization sessions were also considered. Estimations of 5-RM were made using the conversion table of Wathen (26).

All subjects performed a warm-up set (48 kg for the squat, 30 kg for the bench press) of 10 repetitions. The weight was then adjusted to a midpoint between the warm-up resistance and the estimated 5-RM load, and a set of five repetitions was performed. Thereafter, the weight was set at the estimated 5-RM load, and subjects attempted five repetitions. Successful completion led to an additional attempt with an increased load, and all sets were separated by a minimum of 3 minutes of rest. This was repeated until subjects could no longer perform five repetitions in good form. The heaviest resistance at which five good repetitions were performed was recorded as the 5-RM. Data for all sets were recorded, and each set up to the 5-RM was repeated during the testing at the end of the study period. The resistance used in the final one or two sets during the posttesting session was increased to accommodate strength increases.

**Hormone Concentration Determination.** To control for diurnal variability, exercise began at the same time each day in which blood was to be collected for later hormone analysis, and blood was collected between 10 and 15 minutes after the completion of exercise. The results of Gotshalk et al. (7) suggest that growth hormone, cortisol, and testosterone levels are at or near peak approximately 10–15 minutes after exercise. Additionally, for the sake of consistency, all blood samples were obtained after the completion of exercise session 2 (back, chest, and upper extremities). A maximum of 8.5 ml of blood was taken from an antecubital vein in each subject during each of the three sampling periods. Blood was centrifuged at 5°C, and plasma was frozen until samples were analyzed. Radioimmunoassays were performed to determine

the concentrations of GH, TEST, and CORT in each plasma sample. Testosterone and CORT concentrations were assayed in duplicate for each sample using coated tube kits from ICN (Costa Mesa, Calif). Human growth hormone (22-kd GH) levels were determined with a double-antibody kit, also from ICN. Intra- and interassay coefficients of variation for each hormone were 7.3 and 1.8% (TEST), 5.6 and 14.2% (CORT), and 8.8 and 8.0% (GH).

Blood samples were collected from all subjects after the first full back, chest, and arms training session, after the final back, chest, and arms training session in the fifth week, and after the final back, chest, and arms training session in the study period. Blood samples were collected three times during the 10-week training period to allow assessment of acute and chronic effects of weight training on hormonal concentration.

**Dietary Logs.** During week 3, and again during week 8, subjects were asked to complete and return a 2-day dietary log. This request was made to encourage adherence to protein-intake guidelines (1.7 g per kilogram of body weight).

#### Statistical Analyses

Mixed-measures analyses of variance (ANOVAs) were performed to locate significant differences between pre- and posttraining 5-RM strength, thigh MCSA, arm CSA, and body composition, both within groups (repeated measures) and between groups. Likewise, mixed-measures ANOVAs were performed to identify differences in postexercise hormone levels over time (repeated measures) and between groups. Correlations were performed to determine relationships among hormonal responses and changes in strength, muscle size, and body composition outcome measures. Alpha levels for all statistical tests were set at 0.05, and Tukey post hoc procedures were used after significant ANOVAs. All data are presented as mean  $\pm$  SD.

## RESULTS

#### Protein Intake, Training Duration, Loads, and Compliance

Subjects were advised to consume 1.7 g of protein per kilogram of body mass each day to ensure adequate nutritional resources for training-stimulated adaptation, and to complete 2-day dietary logs in weeks 3 and 8 of the study to encourage adherence and allow for objectively quantifying intake. Overall, subjects consumed  $81.7 \pm 26.7\%$  of that target in week 3, and  $86.3 \pm 24.2\%$  of that target in week 8. There was no difference between groups in protein intake (see Table 3).

Adherence was quantified via the tabulation of training logs submitted for a maximum of 40 training sessions (four sessions per week for 10 weeks). The overall mean compliance rate was  $88.8 \pm 11.5\%$ , and there was no difference in compliance rates between groups. Mean duration of both resistance training sessions was greater in the LR group than in the SR group as a result of the longer intersession rest periods in the LR group. Resistance used in training for the squat and bench press exercises was

**TABLE 3.** Protein intake and training compliance, and training load data.

	SR group	LR group	Total
Exercise compliance (%)	94.3 ± 4.6	83.2 ± 14.0	88.8 ± 11.5
Week 3 protein compliance (%)	83.0 ± 24.1	79.0 ± 37.3	81.7 ± 26.7
Week 8 protein compliance (%)	82.4 ± 22.8	94.0 ± 30.1	86.3 ± 24.2
Session 1 duration (min)	42.0 ± 4.0*	65.9 ± 6.1	53.9 ± 13.4
Session 2 duration (min)	37.3 ± 2.0*	63.3 ± 5.2	50.5 ± 13.9
Week 2 bench press training load (% of pretraining 5-RM)	78.9 ± 10.5	76.6 ± 15.1	77.7 ± 12.5
Week 10 bench press training load (% of pretraining 5-RM)	83.9 ± 9.8*†	103.1 ± 17.9†	93.5 ± 17.0†
Week 2 squat training load (% of pretraining 5-RM)	72.2 ± 11.1	71.6 ± 5.6	71.9 ± 8.5
Week 10 squat training load (% of pretraining 5-RM)	91.2 ± 14.6†	88.7 ± 11.4†	89.9 ± 12.6†

SR = 1 minute of rest between sets of exercise; LR = 2.5 minutes of rest between sets of exercise; 5-RM = five-repetition maximum.  
 \*Significantly different from the LR group ( $p \leq 0.05$ ).  
 †Significantly different from Week 2 training load ( $p \leq 0.05$ ).

significantly greater at the end of the 10-week intervention than in week 2 in both groups. See Table 3 for compliance rates, training duration, and resistance progression data.

**Postexercise Hormone Levels**

In week 1, the SR group exhibited a greater overall hormone response to weight training than the LR group. Postexercise TEST (Figure 1) and CORT (Figure 2) levels were significantly greater ( $p \leq 0.05$ ) in SR ( $0.41 \pm 0.17$  and  $963 \pm 313 \text{ mmol}\cdot\text{L}^{-1}$ , respectively) than in LR ( $0.24 \pm 0.06$  and  $629 \pm 127 \text{ mmol}\cdot\text{L}^{-1}$ , respectively) in week 1. However, these differences diminished by weeks 5 and 10, in which postexercise hormone levels in the two groups were similar. The SR group ( $11.6 \text{ ng}\cdot\text{ml}^{-1}$ ) tended to display greater levels of plasma GH in week 1 than the LR group ( $6.3 \text{ ng}\cdot\text{ml}^{-1}$ ), though the difference was not significant ( $p = 0.28$ , see Figure 3).

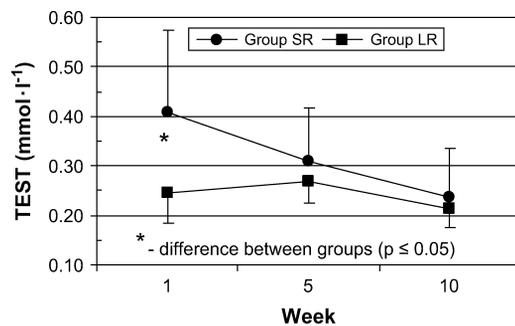
**Strength**

Subjects in the LR group increased 5-RM bench press strength by  $14.9 (\pm 8.72\%, p \leq 0.05)$  and increased 5-RM

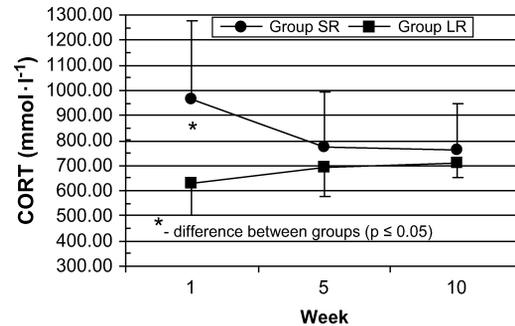
squat strength by  $27.4 (\pm 11.74\%, p \leq 0.05)$ . Likewise, subjects in the SR group experienced an increase of  $10.5 (\pm 3.98\%)$  in 5-RM bench press strength ( $p \leq 0.05$ ) and an increase of  $24.0 (\pm 12.19\%)$  in 5-RM squat strength ( $p \leq 0.05$ ) (see Tables 1 and 4). There was no difference between groups in relative strength increase in either the squat or bench press.

**Muscle Cross-Sectional Area and Body Composition**

In the SR group, the training intervention resulted in significant increases ( $p \leq 0.05$ ) in arm CSA ( $5.1 \pm 2.9\%$ ), thigh MCSA ( $3.1 \pm 3.0\%$ ), weight ( $2.5 \pm 1.6 \text{ kg}$ ), and lean body mass ( $3.1 \pm 2.1\%$ ). The LR group experienced significant increases in arm CSA ( $12.3 \pm 7.2\%$ ) and thigh MCSA ( $6.6 \pm 5.0\%$ ) (see Tables 1 and 4). The difference between groups was significant only for arm CSA. Although the LR group also tended to show a greater increase in thigh MCSA, the difference between groups was not significant. These changes indicate that the training stimulus was adequate to elicit increases in strength and muscle size in each group.



**Figure 1.** Postexercise plasma testosterone.



**Figure 2.** Postexercise plasma cortisol.

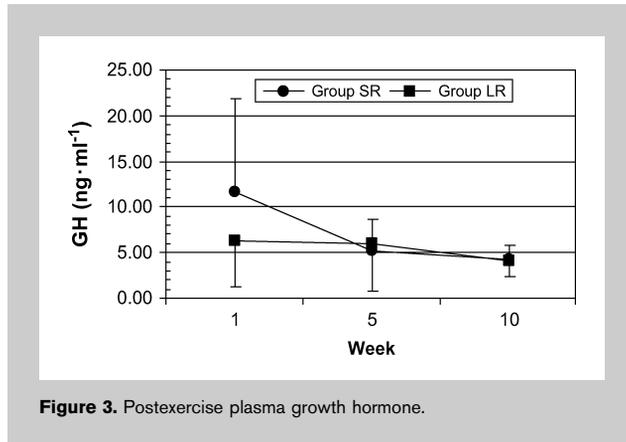


Figure 3. Postexercise plasma growth hormone.

### DISCUSSION

The differences in acute hormonal responses in week 1 of the present investigation were in agreement with results reported previously by others (7,8,17,18). Specifically, a protocol that involves a load designed to elicit a failure on the 10th repetition with a short rest period (1 minute) between sets resulted in a greater hormone response in the first week of exercise than did an identical protocol with a longer rest period (2.5 minutes). However, the difference in hormonal response between the two groups was no longer significant by the end of the fifth week, and it had diminished completely by the end of the 10th week of training, suggesting that the postadaptive hormonal responses to the two rest periods used in this study were similar. These findings lend support for periodic changes in training variables (i.e., periodization). It may be that such periodic variations are required to sustain optimal hormonal responses to training stimuli; the present data show that significant differences in hormone responses between the two training methods used were present for less than 5 weeks.

The results of the current investigation are in agreement with those of Ahtiainen et al. (2). In that study, previously

strength trained men participated in resistance training interventions wherein 2 and 5 minutes between sets were used in a crossover design, and it was found that postexercise total testosterone, free testosterone, CORT, and GH levels were similar after 3 months of each training program. In Ahtiainen et al. (2), and in the current study, a history of training is associated with similarity in hormonal responses to different training protocols that have been shown to produce significantly different hormonal responses in untrained subjects.

Interindividual variability is an important consideration when examining responses to training. Wideman et al. (27) state that interindividual variability in GH response to exercise is large, and they suggest that differences in GH responses to various exercise interventions be interpreted with caution. The current study, too, resulted in widely variable hormone responses to exercise in both groups. Figures 4 and 5 show subject-by-subject postexercise plasma GH concentrations. Although responses were variable, GH levels after exercise tended to be lower, and more similar, in week 10 than in week 1. In week 1, the overall mean postexercise GH was 8.9 ng·ml<sup>-1</sup>, and the coefficient of variability (CV) was 92%. Conversely, in week 10, the overall mean postexercise GH was 4.2 ng·ml<sup>-1</sup>, and the CV was 38% (see Table 5). This pattern was similar in each of the groups (SR and LR). Likewise, variability in plasma TEST and CORT diminished between weeks 1 and 10 (see Table 5). It seems that although subjects were continuing to work hard within the constraints of the protocol used in this study and were using greater loads in most exercises as training progressed (as shown in data included in Table 3), the adaptation associated with training by week 10 precluded hormonal responses of the magnitude seen in week 1. Thus, subjects became more alike, in terms of their hormonal responses, as training progressed. This was true between groups, as well as within both the LR and SR groups (see Figures 1-3).

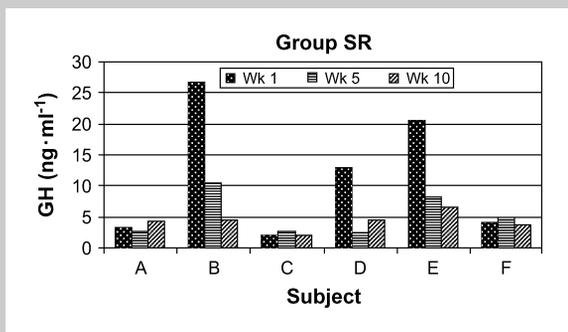
TABLE 4. Relative change in strength, anthropometry, and weight.

	SR group	LR group	Total
Δ Bench press 5-RM (%)	10.5 ± 3.98*	14.9 ± 8.73*	12.7 ± 6.85*
Δ Squat 5-RM (%)	24.0 ± 12.19*	27.4 ± 11.74*	25.7 ± 11.55*
Δ Arm CSA (%)	5.1 ± 2.9*†	12.3 ± 7.2*†	8.7 ± 6.4*
Δ Thigh MCSA (%)	3.1 ± 3.0*	6.6 ± 5.0*	4.8 ± 4.3*
Δ Body fat (%)	-0.6 ± 1.7	-0.4 ± 0.9	-0.4 ± 1.4
Δ Weight (%)	2.5 ± 1.6*	1.3 ± 2.2	1.9 ± 1.9
Δ Lean weight (%)	3.1 ± 2.1*	1.8 ± 2.3	2.5 ± 2.2*

SR = 1 minute of rest between sets of exercise; LR = 2.5 minutes of rest between sets of exercise; 5-RM = five-repetition maximum; CSA = arm cross-sectional area; MCSA = thigh muscle cross-sectional area.

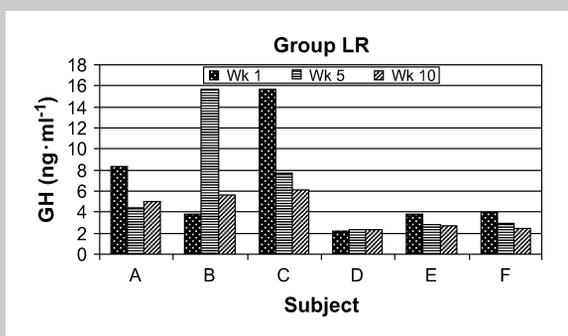
\*Significant difference between pre- and posttests ( $p \leq 0.05$ ).

†Significant difference between SR and LR ( $p \leq 0.05$ ).



**Figure 4.** Postexercise growth hormone in the group that had 1 minute of rest between sets of exercise (group SR).

The exercise routines used by bodybuilders and trainees whose primary goal is hypertrophy typically involve moderate loads, relatively high volume (exercises × sets × repetitions), and short rest periods between sets (5). This type of training protocol may be particularly conducive to muscle protein degradation and, subsequently, hypertrophy; in addition to the muscle damage associated with the mechanical work of contraction, high-volume, short-recovery routines also tend to result in higher lactate levels in the blood and muscle, and it may be that the acidic environment further degrades muscle fibers, thereby eliciting a greater adaptive response. In addition, it has been established that an acidic muscular environment stimulates sympathetic nerve activity through chemoreceptive reflexes (25). Furthermore, it has been shown that vascular occlusion can elicit significant transient increases in GH, norepinephrine, and lactate levels, even with low-intensity resistance exercise, and that GH concentration tends to run in phase with lactic acid concentration (19,21,23). It is likely that in the present investigation, the final set of exercise was performed in the presence of greater concentrations of lactate in the SR group than in the LR group, which may explain the significantly greater hormonal response in the SR group.



**Figure 5.** Postexercise growth hormone in the group that had 2.5 minutes of rest between sets of exercise (group LR).

Regular exposure to high lactate concentration may also influence muscle fiber-type alterations. It has been shown that bodybuilders have a greater percentage of type I fibers than do Olympic or power lifters, who have a greater percentage of type II fibers than do bodybuilders (24). It is also known that resistance training interventions can alter muscle fiber-type profiles (4). It would be an appropriate adaptive response to develop more aerobic, type I muscle fibers in response to regular exposures to high lactate concentrations, and it may be that the increased GH response to training in the presence of elevated lactate levels contributes to that adaptation.

In contrast, trainees for whom maximal strength is the primary goal typically perform low-volume routines with heavy loads and long rest periods between sets (5). Strength trainees attempt to impose near-maximal loads on unfatigued muscles, so rest periods are longer, and fewer repetitions per set are performed, in part to minimize the reductions in muscle and blood pH associated with higher-volume work. Power lifting and Olympic lifting workouts result in lower accumulations of lactate, so an appropriate adaptive response would be a shift toward a higher percentage of type II muscle fibers, and there is some evidence that this is the case (24). The high relative contribution of muscle phosphagens, and the relatively small involvement of the lactic acid system in Olympic and power lifting training, prevent large increases in lactate concentration, and this, in turn, may explain the smaller GH response.

Many studies have examined the effects of various training protocols on hormonal responses, but few have quantified the relationship between hormonal responses and changes in strength or muscle mass. McCall et al. (20) found that acute exercise-induced growth hormone response correlated significantly with biceps brachii muscle fiber hypertrophy ( $r = 0.74$  for type I fibers, and  $r = 0.71$  for type II fibers,  $p \leq 0.05$ ) in fibers obtained by biopsy, but not with biceps brachii cross-sectional area. Although their study used a training protocol similar to that used by the SR group in the present study (eight exercises, three sets with 10-RM loads and 1 minute of rest between sets), their subjects ( $N = 11$ ) were initially recreationally resistance trained (subjects in the present study were untrained for at least the previous 6 months), and it may be that initial neuromuscular adaptations to resistance training were already largely completed. Indeed, it is accepted that much of the strength increase and hypertrophy associated with the early stages of resistance training is attributable to neuromuscular adaptation (9). Muscle biopsies were not performed in the current study, and these results suggest that in untrained subjects, at least during the first 10 weeks of a training program, increases in muscle cross-sectional area and strength are not proportional to the magnitude of the initial hormonal responses to exercise.

In this study, the LR group displayed a less dramatic initial hormonal response but tended to experience greater increases in strength and muscle cross-sectional area in the arms and

**TABLE 5.** Postexercise plasma hormone levels (mean ± SD[CV]).

	SR group				LR group				Total				
	Week 1	Week 5	Week 10	Week 1	Week 5	Week 10	Week 1	Week 5	Week 10	Week 1	Week 5	Week 10	
	GH (ng·ml <sup>-1</sup> )	11.6 ± 10.3 (88.8%)	5.2 ± 3.4 (65.4%)	4.3 ± 1.5 (34.9%)	6.3 ± 5.0 (79.4%)	6.0 ± 5.2 (86.7%)	4.0 ± 1.7 (42.5%)	8.9 ± 8.2 (92.1%)	5.6 ± 4.2 (75.0%)	4.2 ± 1.6 (38.1%)	0.41 ± 0.17* (40.7%)	0.31 ± 0.11 (34.8%)	0.24 ± 0.10 (40.6%)
TEST (nmol·L <sup>-1</sup> )	963 ± 313* (32.4%)	776 ± 218 (28.1%)	764 ± 182 (24.3%)	629 ± 127 (20.2%)	694 ± 114 (16.3%)	709 ± 59 (8.2%)	796 ± 287 (36.0%)	735 ± 171 (23.3%)	737 ± 132 (18.0%)	0.29 ± 0.08 (28.9%)	0.27 ± 0.04 (16.9%)	0.21 ± 0.04 (16.4%)	0.29 ± 0.08 (28.9%)
CORT (nmol·L <sup>-1</sup> )													

SR = 1 minute of rest between sets of exercise; LR = 2.5 minutes of rest between sets of exercise; GH = human growth hormone; TEST = testosterone; CORT = cortisol.  
\*Significantly different from LR in week 1.

thigh. Therefore, it is apparent that factors other than hormonal response influence strength and hypertrophy adaptations associated with resistive training, perhaps especially in the early stages of resistance training. It should also be noted that subjects in the current study were randomly assigned to training groups, and the squat 5-RM at baseline was significantly lower for LR than for SR. In addition, though not significant, LR tended to have lower 5-RM bench press strength and arm and leg muscle CSA, suggesting lower baseline muscular fitness levels; therefore, it is possible that they had an increased potential for strength improvements and muscle hypertrophy.

Individual variability of hormonal, strength, and body composition responses to training was prominent in this investigation. Hormone concentrations were most variable in the initial weeks of the training program (see Table 5). In week 1, the CV of all 12 subjects for postexercise GH levels was 92.1%, whereas in week 10 it was 38.1%. Likewise, the week 1 CV for postexercise TEST levels for all 12 subjects was 44.7%, whereas in week 10 it was 32.3%. Therefore, the greatest amount of variability in the hormonal response to training occurred early in the intervention. This pattern suggests that the differences in the hormonal responses elicited by various training protocols are highly individualized, that they are most variable and tend to be greater in the early weeks of training, and that some adaptation that results in a blunting of hormonal responses occurs within the first 5 weeks of training. The diminished hormonal response associated with training mimics the adaptation commonly seen in endurance training, wherein lower levels of plasma GH (10,22) and catecholamines (21,28) are seen after several weeks of training. Furthermore, assuming that there is a long-term association between hormonal responses and increases in strength or lean mass, these data lend further support for periodic alterations in training parameters to achieve an elevated hormonal response.

The wide variation in hormonal, strength, and body composition responses associated with training in the present investigation suggests another question: is it possible that a subject who may be a relative nonresponder to one type of training might, perhaps, respond better to another? For example, as shown in Figure 4, subject A in the SR group exhibited a modest postexercise GH concentration throughout the training period, whereas subject B in that group exhibited a pronounced elevation in postexercise GH concentration early in the intervention. In contrast, Figure 5 shows that subject C in the LR group experienced a marked GH response in the initial weeks of training, whereas subject D maintained a modest postexercise GH concentration throughout the training period. It may be that factors such as muscle fiber-type predominance and enzymatic profiles play a role in mediating hormonal responses as well as the overall effectiveness of any particular training program. Individual variability and the response of each trainee to imposed training should be considered by coaches and trainers.

A limited response to one type of training may not preclude a better response to another.

This study had several notable limitations. The *n* size limited statistical power and may have especially affected the GH differences between groups after the initial training session. In addition, dietary intake of specific amino acids (i.e., branched-chain amino acids) have been shown to affect hormonal responses, and dietary intake during 10 weeks will certainly have an effect on changes in body composition. We did not control for amino acid or caloric intake. As mentioned previously, our primary purpose of requesting the completion of 2-day dietary logs during weeks 3 and 8 of the study was to encourage sufficient protein intake.

In conclusion, an intense 10-week resistance training program resulted in significant increases in 5-RM squat and bench press strength, arm CSA, thigh MCSA, and lean mass in a group of healthy males. As seen in previous studies, 1-minute rests between sets were associated with significantly greater postexercise TEST and CORT levels than 2.5-minute rests between sets, but only in the first week of training. Differences in plasma hormone levels after exercise in weeks 5 and 10 were not significant. These findings suggest that, at least in the early stages of a resistance training program, changes in lean tissue and strength may be mediated more strongly by factors other than the magnitude of hormonal responses induced by the training. Furthermore, if it is true that the concentrations of endogenous anabolic hormones are determinants of long-term muscle growth, then regular alterations in training protocol (i.e., periodization) may contribute to maximizing results by eliciting greater hormonal responses.

#### PRACTICAL APPLICATIONS

Many studies have shown that moderate-intensity, high-volume training with short interset rest periods induces greater acute hormonal responses in untrained subjects than high-intensity, low-volume training with longer interset rest periods. This was replicated in the current study. However, these differences are no longer significant by week 5, and they are gone by week 10. As trainees adapt to specific training protocols, continued maximal gains in strength and muscle size may necessitate regularly altering training protocols in part to maximize hormonal responses to training. Additionally, hormonal responses to various training protocols are variable, and awareness of individual responses to specific training protocols would be helpful in directing training methods.

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