Hormonal Responses of Multiset Versus Single-Set Heavy-Resistance Exercise Protocols

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Abstract/Résumé

The purpose of this study was to compare serum growth hormone (GH), testosterone (T), cortisol (C), and whole blood lactate (L) responses to single set (1S) versus multiple set (3S) heavy-resistance exercise protocols. Eight recreationally weight-trained men completed two identical resistance exercise workouts (1S vs. 3S). Blood was obtained preexercise (PRE), immediately postexercise (0P), and 5 min (5P), 15 min (15P), 30 min (30P) and 60 min (60P) postexercise and was analyzed for GH, T, C, and L levels. For 1S and 3S, GH, L, and T significantly increased from PRE to 0P and remained significantly elevated to 60P, except for 1S. For GH, T, and L, 3S showed significantly greater increases compared to 1S. For C, 3S and 1S were increased significantly from resting at 0P, 5P, and 15P; 3S increased compared to 1S at 5P, 15P and 30P. Higher volumes of total work produce significantly greater increases in circulating anabolic hormones during the recovery phase following exercise.

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Le but de l'étude est de comparer les concentrations sanguines de lactate (L) et sériques d'hormone de croissance (GH), de testostérone (T), de cortisol (C) au cours d'une seule série (1S) et de plusieurs séries (3S) d'exercices de musculation. Huit jeunes hommes habitués à la musculation participent à deux séances de musculation (1S vs. 3S). Les séances sont constituées d'exercices qui mobilisent tout le corps. Pour la mesure de la concentration de GH, de T, de C, et de L, des échantillons de sang sont prélevés avant (PRE), immédiatement après (0P), et 5 min (5P), 15 min (15P), 30 min (30P), et 60 min (60P) après la fin des exercices. À l'une et l'autre des séances, les valeurs de GH, L, et T augmentent significativement de PRE à 0P et, sauf à la séance 1S, demeurent plus importantes qu'au repos jusqu'à 60P; les augmentations sont significativement plus importantes au cours de la séance 3S. Au cours des deux séances, les valeurs de C augmentent significativement de PRE à 0P, 15P, et 30P; les valeurs au cours de la séance 3S sont plus importantes à 5P, 15P, et 30P. Une plus grande quantité de travail amène plus d'hormones anabolisantes en circulation au cours de la période de récupération.

Introduction

The volume of heavy-resistance exercise has been shown to be an important factor in designing resistance training programs (Fleck and Kraemer, 1987; Kraemer et al. 1987). The total amount of work performed during a training session may have implications for target tissue adaptations based upon the magnitude of the hormonal response to the exercise stimuli. The anabolic hormones testosterone (T) and growth hormone (GH), catabolic hormone cortisol (C), and the metabolite lactate (L) have all been shown to be responsive to heavy-resistance exercise protocols consisting of short rest periods and multiple sets at near maximal intensity (i.e., 10 repetition maximum [RM]) (Kraemer et al., 1987, 1990, 1991). However, few studies exist that have specifically examined the impact of total work on the hormonal responses to resistance exercise in men (Kraemer et al., 1990). The importance of such data resides in the fact that some resistance exercise protocols recommended today involve the use of very low volumes of total work (e.g., one set of seven or eight exercises with 8–12 RM loads) (American College of Sports Medicine, 1990). Such protocols may not optimize the adaptive anabolic hormonal environment for target tissues.

Optimizing the effects of a particular resistance training program may well depend on the body's hormonal response to the design of the exercise protocol. Important to this protocol design is the total amount of work performed in a training session. Kraemer et al. (1990) did not observe any significant influence of total work on GH and T concentrations following exercise when multiple-set heavy-resistance exercise protocols with higher volumes (>30,000 J) of total work were examined. However, Häkkinen and Pakarinen (1993) observed significant differences in postexercise concentrations of GH and T in response to high-volume versus low-volume high-intensity resistance protocols (Sets × Repetitions × Intensity), but they did not directly determine the total amount of work (J) performed by the subjects in the different protocols. Their data demonstrate that intensity (i.e., 1 RM sets) alone cannot compensate for the lack of volume with regard to hormonal responses. Such data indicated that a threshold for the amount of total work and intensity interactions may exist for such hormonal changes. Subsequently, it was

our hypothesis that total work may well affect the hormonal responses to a heavy-resistance exercise protocol. Thus, the primary purpose of this investigation was to determine the influence of total work (J) on the acute hormonal responses to heavy-resistance exercise, comparing protocols that only differed in the total amount of work performed.

Methods

After the subjects were instructed as to the experimental risks and benefits of the investigation, each subject read and signed an institutionally approved consent form to participate in this investigation. Each subject was then medically screened by a physician prior to the beginning of the study, and none had a medical history of any endocrine disorder, orthopaedic problems, medical pathologies, or reported anabolic steroid use. None of the subjects were on any medications. The following were the physical characteristics of the 8 experimental subjects who participated in this investigation ($M \pm SD$): age = 25.4 ± 4.14 yr; height = 178.54 ± 8.24 cm; weight = 83.0 ± 10.77 kg; body fat = 15.25 ± 4.27%; and maximal oxygen consumption = 54.1 ± 4.6 ml · kg^{-1} · min^{-1}. Each of the subjects had recreational experience with resistance training (6.2 ± 1.3 yr) and were involved in total conditioning programs (i.e., aerobic endurance activities, flexibility training and heavy-resistance training).

A minimum of 2 weeks were utilized to familiarize the subjects with the experimental protocols and testing procedures. Each was monitored for appropriate resistance exercise techniques. Grip widths and positions were marked and kept constant for each exercise, and total work was determined as previously described (Kraemer et al., 1990). To gain characterization data on general fitness, maximal oxygen consumption was determined utilizing a treadmill protocol as described by Costill and Fox (1969), and percent body fat was determined by hydrostatic weighing as previously described (Kraemer et al., 1990). To characterize the muscle strength of the subjects in this study, we report two of the 1 RM values as determined on the testing equipment for the bench press (115 ± 29 kg) and the leg press (200 ± 75 kg).

EXPERIMENTAL DESIGN AND RESISTANCE EXERCISE PROTOCOLS

As shown in Table 1, two acute heavy-resistance exercise protocols were utilized. We utilized a protocol identical to our previous work in order to optimize comparisons (Kraemer et al., 1990). The same exercises were performed in the same order, with 10 RM loads individualized for each subject and 1-min rest periods allowed between sets and exercises. One protocol design utilized one set (1S) of each exercise and the other protocol design utilized three sets (3S) of each exercise. All sets were performed for a particular exercise before the subject moved to the next exercise. As in our prior research, the resistance was adjusted to maintain the target 10 RM load for each set. Total work (J) was determined for each protocol (Kraemer et

Table 1   Experimental Heavy-Resistance Protocol Used for 1-Set (1S) and 3-Set (3S) 10 Repitition Maximum Protocols

Exercise order	1S protocol	3S protocol
1. Bench press	1 × 10 RM	3 × 10 RM
2. Leg extension	1 × 10 RM	3 × 10 RM
3. Military press	1 × 10 RM	3 × 10 RM
4. Bent leg incline sit-ups	1 × 10 RM	3 × 10 RM
5. Seated rows	1 × 10 RM	3 × 10 RM
6. Wide grip pulldowns	1 × 10 RM	3 × 10 RM
7. Arm curls	1 × 10 RM	3 × 10 RM
8. Leg press	1 × 10 RM	3 × 10 RM

Note. Protocols are listed as Sets × Repititions Maximum (RM) load. All exercises were performed on a universal weight machine except for sit-ups, and arm curls, which utilized free weights.

al., 1990). Total work values for each protocol were as follows: 1S = 19,821 ± 4,121 J and 3S = 58,272 ± 9,211 J.

Experimental Design.   Each subject performed both protocols. A random and balanced crossover design was used to assign each subject to either start with the 1S or 3S protocol. Thus, an equal number of subjects first randomly performed either the 1S or 3S protocol. Then the subject crossed over and performed the remaining protocol to complete the testing. One week was allowed between testing sessions. As with our previous research, the subjects were allowed to workout twice during the week to maintain normal physiological function and eliminate any detraining effects on the hormones, but rested 48 hours before each test session (Kraemer et al., 1990).

Subjects refrained from ingestion of alcohol or caffeine for 24 hr before experimental exercise sessions. All testing for each subject was conducted at the same time of day (from 8:00 to 10:00 a.m.) to reduce the within-individual effect of diurnal variations on the hormonal concentration. Upon reporting to the laboratory, each subject was allowed to drink 750 ml of water 30 min prior to exercise to standardize hydration states that were checked with urine specific gravity (usg) (Kraemer et al., 1990). All subjects were considered hydrated (usg > 1.030) prior to the start of each workout.

All subjects were informed that they would not immediately start the exercise protocol after the resting blood sample was obtained. A 20-min resting equilibration period was utilized before a resting blood sample was obtained, and a 10-min rest period after PRE blood samples were obtained. This procedure has been shown to eliminate any significant anticipatory hormonal responses that may have affected the examination of exercise responses (Kraemer et al., 1990). All venous blood samples were obtained with the subjects in a slightly reclined seated position, via an indwelling cannula placed in a superficial arm vein. A saline flow of 30

ml · hr⁻¹ was used to keep the cannula patent. The subjects then performed one of the heavy-resistance exercise protocols. Samples were obtained preexercise (PRE), immediately postexercise (0P), and 5-min (5P), 15-min (15P), 30-min (30P), and 60-min (60P) postexercise. Water was allowed ab libidum during exercise and recovery.

Analytical Methods. All blood samples were processed and stored at –90 °C until analyzed. All samples were run in duplicate and were decoded only after analyses were completed (blinded analyses). Hemoglobin was analyzed using the cyanmethemoglobin method (Sigma Chemical, St. Louis, MO), and hematocrit was analyzed utilizing the standard microcapillary technique. Plasma volume shifts were calculated according to equations by Dill and Costill (1974), with the greatest values being observed pre- to postexercise, and were as follows: $1S = -10.3 \pm 4.2\%$, $3S = -12.2 \pm 5.1\%$. No significant differences were observed between protocols for plasma volume shifts. Serum concentrations were not corrected for plasma volume shifts as the target tissues are exposed to the absolute molar concentrations (Kraemer, 1992b). Furthermore, when corrected, the pattern of results remained the same.

Serum total testosterone was measured using a ^{125}I solid-phase radioimmunoassay (Diagnostic Products Corporation, Los Angeles, CA), with a detection limit of 0.38 nmol · L⁻¹. Intra- and interassay variances were calculated to be <3.2% and <4.9%, respectively. Human growth hormone was measured utilizing a ^{125}I liquid-phase radioimmunoassay with double-antibody technique (Cambridge Medical Diagnostics, Billerica, MA), with a limit of detection of 0.24 µg · L⁻¹. Intra- and interassay variances were calculated to be <4.4 and <4.9%, respectively. Cortisol was measured using a ^{125}I radio-immunoassay (Diagnostic Products Corporation, Los Angeles, CA) with a limit of detection of 0.05 µmol · L⁻¹. Intra- and interassay variances were calculated to be <4.1 and <5.1%, respectively. Whole blood lactate was measured in duplicate via a Lactate Analyzer-640 (Wolverine Medical, Grand Rapids, MI).

Statistical Analyses. Standard statistical methods were used to calculate the means ± 1 *SD* of the experimental variables. The data were analyzed using a two-way analysis of variance with repeated measures. When appropriate Tukey post hoc comparisons were used to determine pairwise differences. Significance in this investigation was set at $p \leq .05$.

Results

Growth hormone preexercise serum concentrations for 1S and 3S were not significantly different. As shown in Figure 1, 1S and 3S showed significant increases for all postexercise time points compared to PRE exercise values. There were significant differences in the magnitude of the hormonal response at all postexercise time points between 1S and 3S, with 3S concentrations showing significantly higher serum elevations.

In Figure 2, the responses of serum total T are presented. Again, no differences in resting concentrations were observed between 1S and 3S protocols. The
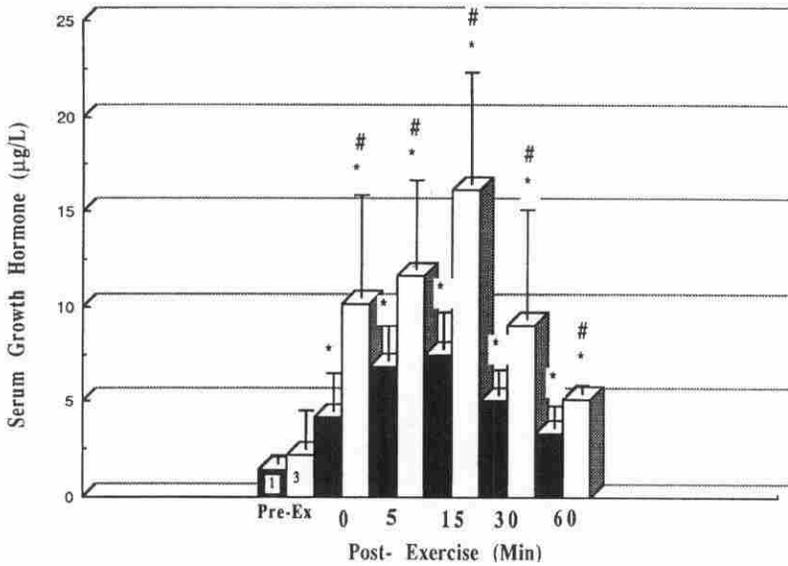
Figure 1. Serum growth hormone ($\mu g \cdot L^{-1}$). 1 = 1S protocol; 3 = 3S protocol. Pre-Ex = preexercise; 0 = immediate postexercise. * $p \le .05$ from corresponding preexercise value. # $p \le .05$ from corresponding 1S value.
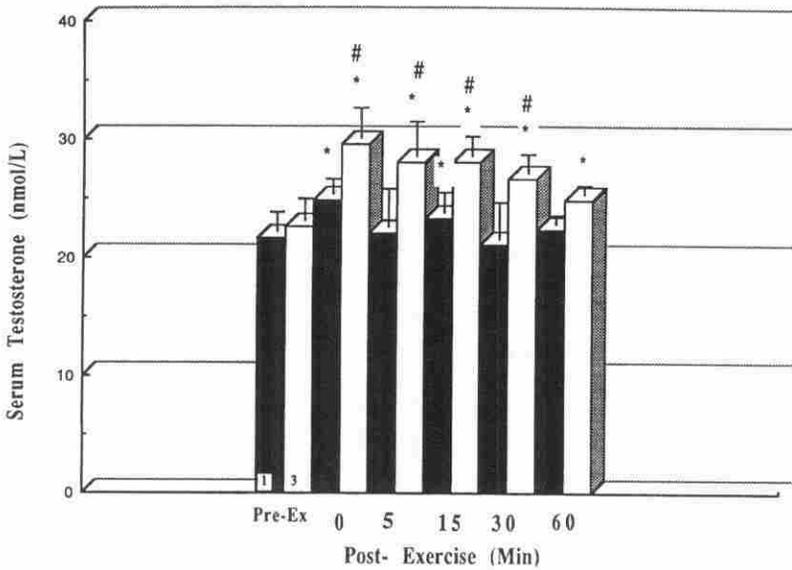

Figure 2. Serum testosterone ($nmol \cdot L^{-1}$). 1 = 1S protocol; 3 = 3S protocol. Pre-Ex = preexercise; 0 = immediate postexercise. * $p \le .05$ from corresponding preexercise value. # $p \le .05$ from corresponding 1S value.
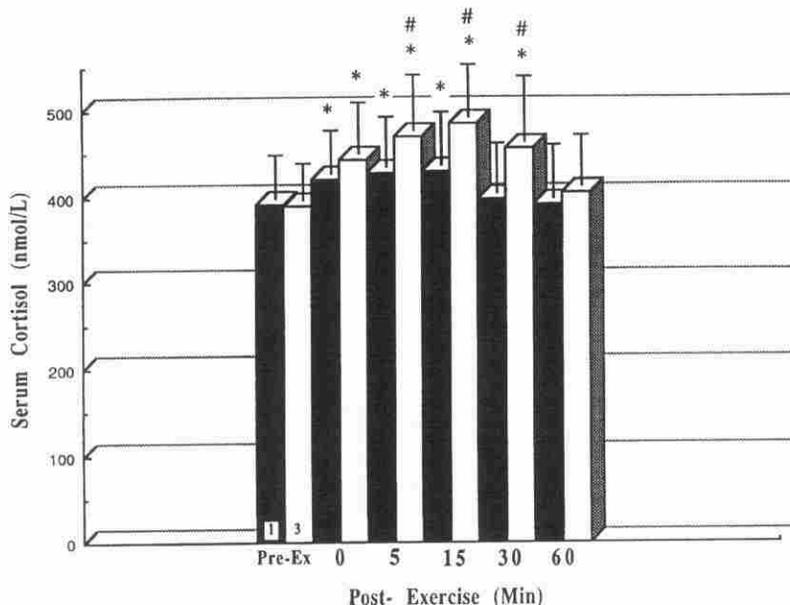
Figure 3. Serum cortisol (nmol · L⁻¹). 1 = 1S protocol; 3 = 3S protocol. Pre-Ex = preexercise; 0 = immediate post-exercise. * $p \leq .05$ from corresponding preexercise value. # $p \leq .05$ from corresponding 1S value.

3S protocol demonstrated significant increases for all postexercise time points, but the 1S protocol resulted in a significant elevation only at 0P and 15P. Again, significant differences were observed in the magnitude of hormonal responses between the 1S and 3S protocols at 0, 5, 15, and 30 min postexercise time points.

　　Preexercise C serum concentrations for 1S and 3S protocols were not significantly different. As shown in Figure 3, the 1S protocol showed significant increases at the 0-, 5-, and 15-min time points, while 3S protocols showed significant increases at the 0-, 5-, 15-, and 30-min time points. The 3S protocol demonstrated significantly higher serum cortisol values as compared to 1S protocol at the 5-, 15-, and 30-min time points.

　　Preexercise L levels for 1S and 3S protocols were not significantly different. As shown in Figure 4, all postexercise time points for 1S and 3S protocols showed elevated concentrations of plasma L, but 3S protocol values were significantly greater than those of 1S protocol at all time points.

Discussion

The primary finding of this investigation was that total work plays a vital role in determining the magnitude of increase in recovery for GH, T, C, and L concentrations in the circulating blood following heavy-resistance exercise. Although the
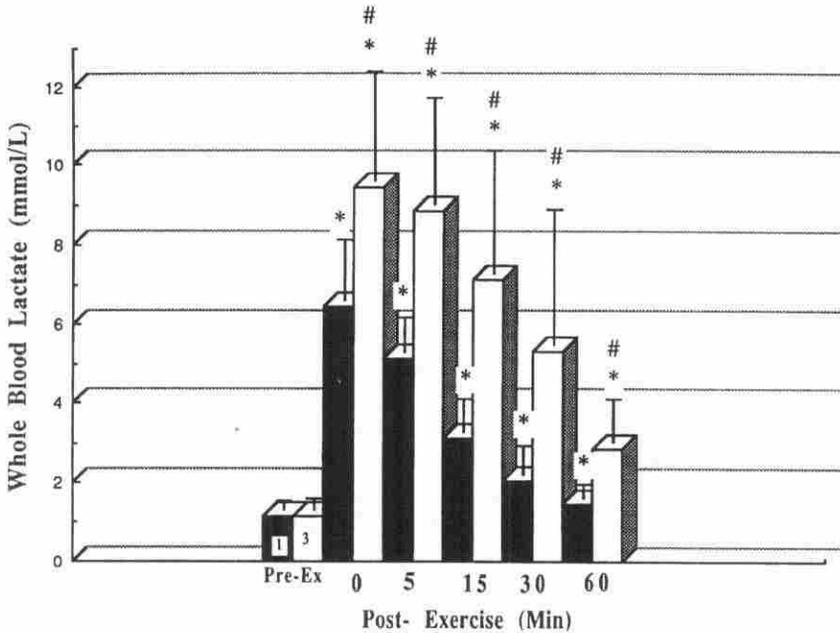
Figure 4. Whole blood lactate (mmol · L^{-1}). 1 = 1S protocol; 3 = 3S protocol. Pre-Ex = preexercise; 0 = immediate post-exercise. * $p \leq .05$ from corresponding preexercise value. # $p \leq .05$ from corresponding 1S value.

1S protocol stimulated significant postexercise elevations in the blood concentrations of GH, T, C and L, the magnitude of increase for the 3S protocol was significantly higher. These data provide some physiological evidence for a direct influence of total work on the hormonal responses to heavy-resistance exercise.

Previous studies have shown that heavy-resistance exercise produces elevations in GH concentrations (Häkkinen and Pakarinen, 1993, 1995; Kraemer et al., 1987, 1990; Lukaszewska et al., 1976; Skierska et al., 1976; VanHelder et al., 1984). In addition, when comparing multiple set protocols of different total work no differences were observed (Kraemer et al., 1990). The results of this study demonstrated that greater total work in a multiple set resistance exercise protocol stimulates higher recovery blood concentrations of GH throughout the recovery, even after 60 min following the exercise when compared to a single set protocol. The use of higher volume protocols has been observed to be common when muscle hypertrophy is a desired training effect (e.g., body builders) (Kraemer et al., 1987). The higher concentrations of GH into recovery may be partially explained by the metabolic stimulation of the workout. The higher magnitude in blood lactate concentration observed for the 3S versus 1S protocol indicates that these protocols also produce different metabolic profiles with respect to their acid–base balance

(Gordon et al., 1994). Gordon et al. (1994) demonstrated that increases in blood hydrogen ion concentrations and lactate concentrations may partially mediate GH release from the pituitary gland. Therefore, exercise protocols placing greater metabolic demands on anaerobic glycolysis (i.e., 3S protocol) might be expected to activate operational mechanisms related to metabolism that contribute to a higher stimulatory feedback to the anterior pituitary for GH release. Growth hormone has been demonstrated to be a major factor in stimulating protein synthesis, and therefore, the higher total work created by the 3S protocol may contribute to the observed training advantages of multiple sets using a 10 RM intensity for muscle hypertrophy (Kraemer et al., 1987, 1992b).

The response of total T to resistance exercise has been shown to increase concentrations immediately following exercise (Cumming et al., 1987; Guezennec et al., 1986; Häkkinen and Pakarinen, 1993; Kraemer et al., 1990; Weiss et al., 1983). Furthermore, different heavy-resistance exercise protocols have been shown to produce differential response patterns of T (Kraemer et al., 1990). The response pattern of T for the 3S protocol in this study are consistent with the pattern of changes observed in previous studies generally showing serum T concentrations being significantly elevated at the immediate postexercise time point and steadily declining throughout the duration of the recovery period (Häkkinen et al., 1988; Kraemer et al, 1990; Weiss et al., 1983).

The 1S protocol response pattern was similar to the findings of Häkkinen and Pakarinen (1993), in which the low-volume squatting protocol of 20 sets of 1RM did not show statistically significant elevations of serum T. However, the higher volume protocol used by Häkkinen and Pakarinen (1993) of 10 sets of 10 repetitions at 70% 1RM did produce statistically significant elevations of serum T. The lack of a T response in the circulating blood to the low-volume 1S protocol again demonstrates that not all resistance exercise protocols result in exercise-induced increases, despite the use of high intensity. This has also been observed by Fahey et al. (1976) in untrained men performing a low-volume, single large muscle group (dead lift) exercise protocol. Thus, mediating mechanisms related to increases in circulating T may be related not only to the amount of muscle mass activated but also to the amount of total work performed in the resistance exercise protocol.

It is interesting that the 1S protocol used in this study was apparently of even greater total work (based upon Sets × Repetitions × Intensity calculations) than the protocols used by Häkkinen and Pakarinen (1993), but still no significant elevations were observed in T. It appears that some threshold for acute amounts of total work (exercise volume) may be needed to produce a central endocrine stimulus or changes in "concentrating mechanisms" that result in the elevation of T in the circulating blood (Kraemer, 1992b). How this total work relates to the intensity used remains a topic of further research as intensity alone does not appear to be directly related to the T response pattern in the blood (Häkkinen and Pakarinen, 1993). The interplay between T and GH results in an important physiological synergism between the gonadal and somatotrophic axes (Aynsley-Green et al., 1976;

Kraemer, 1992b). Our findings demonstrate that the elevation of T, like GH was influenced by the volume of total work used in a heavy-resistance exercise protocol.

Postexercise concentrations of C have been shown to be stimulated by heavy-resistance exercise protocols (Deschenes et al., 1991; Häkkinen and Pakarinen, 1993; Häkkinen et al., 1985; Kraemer, 1992a; Kraemer et al., 1987, 1991). In this investigation, both 1S and 3S showed elevated C concentrations 0P through 15P time points, with 3S showing significant elevation still at the 30P time point. While we demonstrated acute increases in C after both the 1S and 3S protocols, the absolute magnitude of change may have been even higher as the influence of circadian rhythm (i.e., which has been shown to result in a declining resting baseline over time) may have affected the absolute magnitude of the change from baseline values (Häkkinen et al., 1988; Thuma et al. 1995). Kraemer et al. (1991) demonstrated that total work may affect the response pattern of C concentrations. They observed that with a higher total work resistance exercise protocol (an identical multiple set of 10 RM resistance exercise protocol and 1-min rest periods as with the 3S protocol used in this study) significant C increases were observed postexercise, but no significant changes were observed with a lower volume resistance exercise protocol that used the same exercises but with a heavier 5 RM intensity and the same short rest period lengths (i.e., 1-min rest).

The combined results of Kraemer et al. (1991) and this investigation indicate that the response pattern of serum C may also be linked to the volume of total work. Again, it is possible that the greater metabolic demands of the 3S protocol, as demonstrated by the higher L concentration than the 1S protocol, mediates some of the responses for C via glycolytic and catecholamine stimulatory mechanisms (Kraemer et al., 1987, 1993; Van Helder et al., 1986). Higher concentrations of serum C may help spare muscle glycogen and enhance gluconeogenesis into acute recovery periods (Kraemer, 1992b; Kraemer et al., 1993).

In summary, this study demonstrated directly that total work of a resistance exercise protocol was a key factor in the responses of the endocrine system in the acute recovery period following exercise. Many factors can contribute to an increase in hormonal concentrations following resistance exercise (e.g., clearance rates, plasma volume shifts, secretion), but the external exercise variables (e.g., total work) still appear to be important for the stimulatory mechanisms to become operational (Kraemer, 1992a). A high-intensity resistance training protocol using three 10 RM sets and rest periods of 1 min stimulates higher magnitudes of postexercise elevations in circulating concentrations of GH, T, C, and L than does a 10 RM, 1 min rest, one-set protocol. Further investigation will be needed to elucidate if a threshold for the amount of work exists with regard to the hormonal responses to heavy-resistance exercise. Furthermore, the relationship between intensity and total work requires further clarification as to its effects on endocrine mechanisms. Nevertheless, these data demonstrate that the underlying hormonal responses show a different pattern of response in high and low total work heavy-resistance exercise protocols.

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