Hormonal Responses from Concentric and Eccentric Muscle Contractions

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ABSTRACT

DURAND, R. J., V. D. CASTRACANE, D. B. HOLLANDER, J. L. TRYNIECKI, M. M. BAMMAN, S. O'NEAL, E. P. HEBERT, and R. R. KRAEMER. Hormonal Responses from Concentric and Eccentric Muscle Contractions. *Med. Sci. Sports Exerc.*, Vol. 35, No. 6, pp. 937–943, 2003. Intense resistance exercise can acutely increase testosterone (T), free testosterone (FT), and growth hormone (GH) concentrations, but there are few investigations concerning acute endocrine responses to concentric (CON) and eccentric (ECC) contractile actions. **Purpose:** The purpose of the study was to compare acute anabolic hormonal responses to bouts of dynamic CON and ECC contractions from multiple exercises at the same absolute load. **Methods:** Ten young men (age: 24.7 ± 1.2 yr, weight: 85.45 ± 24.2 kg, and height: 178 ± 0.2 cm) completed two trials in counterbalanced fashion consisting of only CON or ECC contractions at the same absolute workload. Subjects performed four sets of 12 repetitions of bench press, leg extension, military press, and leg curl at 80% of a 10-repetition maximum with 90-s rest periods. Blood samples were collected pre-, post-, and 15-min postexercise. **Results:** There were significant increases in GH, T, and FT and lactate for both trials, but only GH and lactate were greater for the CON trial. **Conclusion:** CON exercise increases GH concentrations to a much greater extent than ECC exercise at the same absolute load, and it is likely that greater GH responses were related to intensity rather than mode of contraction. Also, CON and ECC dynamic contraction trials at the same absolute workload elicited similar small but significant increases in T and FT, indicating that the greater metabolic stress produced by during the CON trial did not affect these hormone responses. **Key Words:** TESTOSTERONE, GROWTH HORMONE, LACTATE, ECCENTRIC CONTRACTIONS

Resistance exercise has been shown to produce acute increases in serum levels of growth hormone (GH) and testosterone (T) (10,11,17,20–22,27). These hormones have been shown to be sensitive to the stress of resistance exercise (22) and are known to effect tissues in a variety of ways, including stimulation of protein synthesis. The effects of exercise-induced increases in GH and T are dependent on a wide variety factors including rest period length (10,22), exercise intensity (10,17,22,27), exercise volume (9), and the amount of muscle mass activated during exercise (19). Shorter rest periods between sets can increase GH and T concentrations (22). Multiple-set protocols have been documented to increase GH and T levels to a greater extent than single-set protocols (9). Another factor that may affect these hormones is the type of muscle contraction involved.

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Recently, Kraemer and colleagues (19) investigated acute GH and T responses to concentric (CON) and eccentric (ECC) isokinetic contractions after 19 wk of resistance training using different dynamic muscle actions (i.e., CON, CON/CON, and CON/ECC). They found GH responses to an isokinetic CON trial were significantly higher than an isokinetic ECC trial for the CON and CON/CON, but not the CON/ECC trained groups. However, GH responses were higher after the CON than the ECC acute trials in all three groups after 4 wk of detraining. Total testosterone increased in response to both CON and ECC isokinetic tests in the CON/ECC trained group.

Isokinetic contractions have been the mode of choice in most studies of acute responses to CON and ECC muscle actions. However, normal resistance training is performed with CON and ECC contractions at a constant (absolute) load. ECC contractions have a higher physiological threshold, which is probably mediated by the greater torque-producing capacity of ECC contractions (4). Thus, at the same absolute load, CON contractions induce greater sympathetic activation (2), blood lactate levels (2,26), and motor unit recruitment (5) than ECC contractions.

We are aware of no previous investigation of the separate effects of these contraction types on anabolic hormone responses to a multiple exercise regimen against a constant workload. The purpose of the present investigation was to compare the acute GH, T, and free testosterone (FT) responses to two multiple resistance exercise protocols; one experimental trial used CON contractions and the other employed ECC contractions at the same absolute workload. Most resistance exercise protocols in studies investigating CON and ECC contractions have been isokinetic resistance exercise regimens. During isokinetic resistance exercise, velocity is held constant while resistance is free to vary. We employed conventional resistance exercise that involves the performance of dynamic, full range-of-motion contractions against a constant external load. Because most competitive athletes training for sport use the kind of resistance exercise employed in this study, the results of the present investigation are directly applicable to their condition. Because previous studies have documented that CON contractions produce greater metabolic stress than ECC contractions at an identical load, we hypothesized that the CON protocol would elicit greater GH, T, and FT responses than the ECC protocol.

METHODS

Research design. The study employed a counterbalanced design that allowed the different effects of CON and ECC muscle actions on anabolic hormones to be compared, using the same group of subjects while accounting for any order effects. The subjects completed three trials on separate days. The first trial served as a preliminary session in which the subjects' descriptive characteristics were determined and the subjects were familiarized with the equipment and exercise protocol. After a preliminary trial was conducted, half of the subjects completed a CON exercise trial followed by an ECC exercise trial; the other half of the subjects completed the ECC trial first followed by the CON trial. Seven days separated the CON and ECC trials. The main outcome measures of the study were serum concentrations of GH, T, FT, and plasma concentrations of lactate.

The study was approved by the Southeastern Louisiana University Institutional Review Board and was conducted in accordance with the policy statement of the Declaration of Helsinki. Ten adult males were recruited and provided written consent for participation in the study. Mean ($\pm$ SE) physical characteristics of the subjects for age, height, weight, and body fat percentage were 24.7 $\pm$ 1.2 yr, 178.18 $\pm$ 0.2 cm, 85.45 $\pm$ 24.2 kg, and 17.20 $\pm$ 0.5%, respectively. The subjects' 10-repetition maximum (10-RM) for bench press, leg extension, military press, and leg curl used in the CON and ECC trials were 119.32 $\pm$ 8.5 kg, 44.09 $\pm$ 3.5 kg, 83.63 $\pm$ 17.3 kg, and 20.9 $\pm$ 2.5 kg, respectively.

The subjects were screened for dietary habits and use of ergogenic aids. Inclusion criteria were 18–30 yr of age and a minimum of 3 yr of recreational weight training experience. Exclusion criteria were 1) participation in competitive bodybuilding or weight lifting for the previous year; 2) smoking; 3) taking medications that could alter test results (e.g., anabolic steroids, sympathoadrenal drugs); 4) history of pituitary, renal, hepatic, cardiovascular, or metabolic disease; 5) adherence to a reduced calorie or low fat diet, or ketogenic diet that could affect hormonal levels; and 6) use of over-the-counter ergogenic aids within the past month including creatine monohydrate, androstenedione, DHEA, or ephedra.

Preexperimental trial (session 1). Subjects completed a preexperimental session to obtain anthropometric and muscular strength measurements. The preexperimental trial served two purposes: to determine the subject's descriptive characteristics including their 10-RM and to serve as a brief familiarization protocol. First, height and weight were determined using a calibrated scale (Health-O-Meter, Bridgeview, IL). Next, percent body fat was estimated with Lange skinfold calipers using a four-site (abdomen, suprailiac, triceps, and thigh) equation (16). Subjects were then tested to determine the 10-RM for each of the four exercises: bench press (BP), leg extension (LE), military press (MP), and leg curls (LC). The 10-RM was a modification of a 1-RM protocol by Kraemer et al. (18). Briefly, a 2–3 set warm-up was performed with 5–10 repetitions, which represented 40–60% of a perceived maximal exertion. Each warm-up set was performed in a linear progression. Subjects were instructed to perform the next 1–2 sets for 5 repetitions at a weight that was approximately 80% of perceived 10-RM. A 5-RM was used for these sets to prevent fatigue before performing a 10-RM. Immediately after these sets, subjects were instructed to perform a 10-RM; if the 10-RM was not achieved, a heavier weight was chosen. Rest periods between all sets were 3–5 min. After determining the 10-RM on each exercise, the reliability of this measurement was tested by having each subject perform as many reps as possible with the determined 10-RM weight after a 10-min rest period. All subjects reached their 10-RM within three trials after their warm-up sets were performed.

The four exercises were chosen because they represented two upper-body and two lower-body exercises commonly employed in normal resistance training routines. The 10-RM strength measurements have been accepted as a suitable secondary choice for determining appropriate training loads when maximal strength testing is not possible (1). The subjects participating in the study were well-trained recreational athletes who were not involved in competitive sport but whose normal training regimen consisted of bodybuilding type workouts (i.e., multiple sets, high-repetition training); thus, a 10-RM was deemed more appropriate for individuals in our study. The four exercises were performed on a resistance-training machine (BK 602 Super Jungle, Body Masters, Rayne, LA). After the 10-RM was completed for each exercise, a brief familiarization procedure for the experimental trial was conducted. Subjects performed lightweight CON and ECC repetitions to become familiar with the movements.

Subjects performed all lifts in a controlled manner; no bouncing or jerking movements were allowed. The position of all benches, seats, bars, and subject handgrip alignment were recorded and kept constant for each exercise. Before each subject was tested, two 48-inch (10 lb each) steel pipes were bolted on top of the machine bench and military press. The steel rods were placed on the machine before the 10-RM to simulate the conditions of the CON and ECC

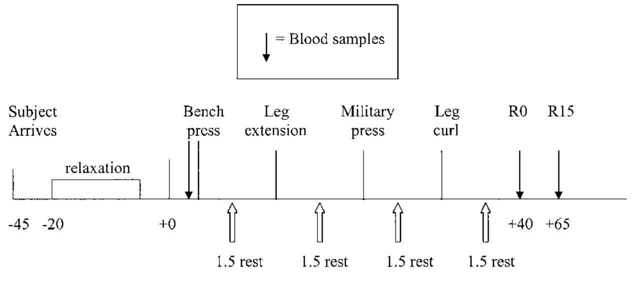

FIGURE 1—CON and ECC protocol with blood samples taken pre-, post-, and 15-min postexercise. Subjects performed four sets of 12 repetitions with 1.5-min rest periods between sets.

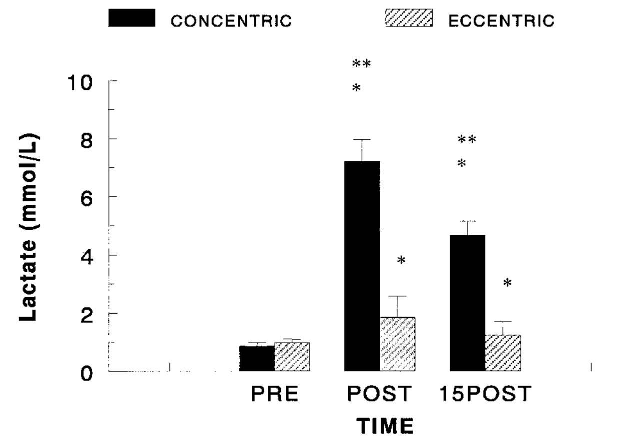

FIGURE 2—Lactate concentrations (mean ± SE) during the experimental trials for CON (*solid bar*) and the ECC trial (*hatched bar*). ** Significantly different between the CON and ECC trials ($P < 0.01$). * Significantly different from prevalue ($P < 0.01$).

trials. For each exercise, the distance the weight was displaced was determined with a metal meter stick and pointers mounted to the resistance exercise equipment in an effort to maintain constant work per repetition in subsequent sessions.

Sessions 2 and 3 (CON and ECC trials).

Seven days after the preexperimental trial, the subjects returned to the weight room for session 2 or 3 after an 8-h fast. At 8:00 a.m., the subject was seated quietly for 20 min. A registered nurse then collected a baseline blood sample from an antecubital vein via venipuncture. The subject then performed four sets of 12 repetitions of the four exercises at 80% of the previously determined 10-RM in the following order: BP, LE, MP, and LC. During the CON trial, subjects lifted the weight for each repetition, whereas lowering of the weight was performed by technicians using steel bar extensions or a pulley. During the ECC trial, technicians lifted the weight stack with steel bar extensions or a pulley, and then the subject lowered the weight. All repetitions were performed to the rhythm of a metronome; the weight was lifted in 2 s and lowered in 2 s. Subjects rested 90 s between all sets and exercises. A rest period of 90 s was chosen because this interval is indicative of high-intensity weight-training sessions commonly performed. Because most bodybuilding protocols have rest intervals less than a minute between sets, we used a protocol with slightly longer rest periods (i.e., 90 s); previous data have demonstrated that a 90-s rest interval duration elicits increases in GH and T (17). After completion of the fourth set of LC, a blood sample was immediately collected, and another blood sample was taken 15-min postexercise (Fig. 1). For each blood sample, blood was collected into a 10-mL whole-blood tube for hormone analysis and a 3-mL tube with sodium fluoride and potassium oxalate for lactate determination. The 10-mL tubes were allowed to sit at room temperature for 10 min for clot formation and refrigerated for 25 min before centrifugation ($500 \times g$). Serum was aliquotted, and samples were stored at −80°C until hormone assays were performed.

Blood analyses. All blood samples were analyzed for lactate, GH, T, and FT. Lactate was determined using an enzymatic, colorimetric method (Sigma Chemical, St. Louis, MO). GH and T were determined using a sensitive chemiluminescent enzymatic immunoassay (Immulite, Diagnostic Products Corp., Los Angeles, CA); all GH and T determinations were completed in one assay. FT was measured by radioimmunoassay (Diagnostic Products Corporation). The interassay coefficient of variation for FT was 5.44%, and the intra-assay coefficients of variation for all hormones were < 5.0%.

Statistics. GH, T, FT, and lactate concentrations were analyzed using separate 2×3 (trial × time) ANOVA with repeated measures on the second factor. The trial factor represented CON and ECC trials, and the time factor represented pre-, post-, and 15-min recovery values. Statistical significance was accepted at $P < 0.05$. A Scheffé *post hoc* test was applied where appropriate. ANOVA analyses of GH, T, and FT were also followed by the calculation of eta-squared (an indication of effect size providing the amount of variance explained by specific factors in the ANOVA) and *post hoc* power analysis to determine the statistical probability of detecting differences of the observed sizes as significant given the design characteristics and number of subjects in the study.

RESULTS

Lactate. As shown in Figure 2, during both CON and ECC trials, lactate increased significantly from pre- to immediate postexercise, then decreased 15-min postexercise. The increase was more pronounced in the CON trial. The ANOVA results indicated a significant time effect and a significant trial-by-time interaction. The interaction was further investigated using comparisons of CON and ECC trials at each time point. These results indicated no significant difference at preexercise, but CON exercise produced significantly higher lactate immediately postexercise and 15-min postexercise than ECC exercise.

Growth hormone. During both trials, GH increased from pre- to postexercise, and decreased 15-min postexercise, with the increase notably greater during the CON trial (Fig. 3). ANOVA indicated a significant time effect, a significant trial effect, and a significant trial by time interaction. Follow-up

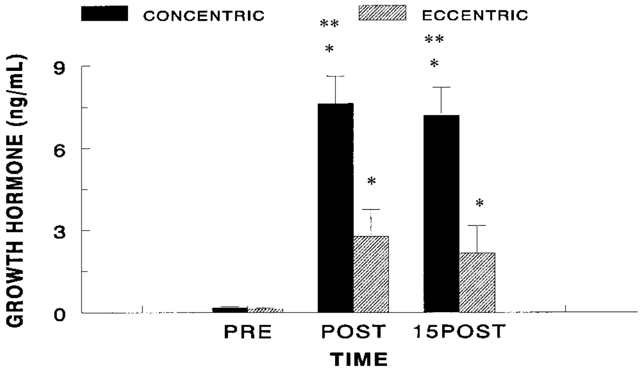

FIGURE 3—GH concentrations (mean ± SE) during the experimental trials for CON (*solid bar*) and the ECC trial (*hatched bar*). ** Significantly different between the CON and ECC trials ($P < 0.01$). * Significantly different from prevalue ($P < 0.01$).

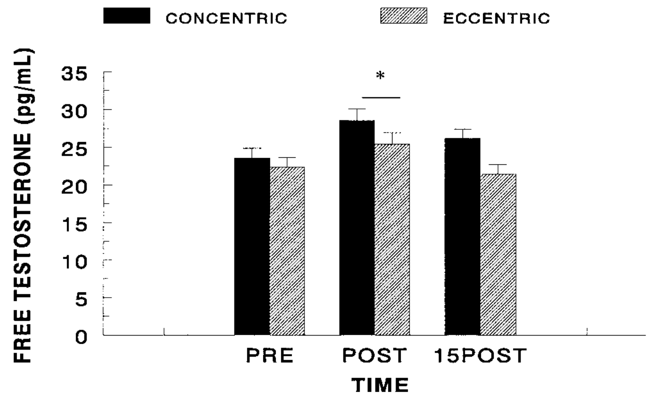

FIGURE 5—Free testosterone concentrations (mean ± SE) during the experimental trials for CON (*solid bar*) and the ECC trial (*hatched bar*). * Significantly different from prevalue ($P < 0.01$).

comparisons of the interaction indicated no significant difference between trials for GH preexercise, and significantly higher GH levels for the CON exercise trial immediately after and 15-min postexercise. The eta-squared value indicated that 37% of the variance in GH was explained by the interaction, and the observed power for this factor was 0.98.

Testosterone and free testosterone. Testosterone increased slightly during both trials from pre- to postexercise, then decreased at 15-min postexercise (Fig. 4). ANOVA analysis indicated only a significant trial effect, due to a significant increase from pre- to immediate postexercise values. No significant difference between trials was found. Eta-squared indicated 22% of the variance in T was explained by the time factor, and power to detect these differences was 0.80. By comparison, a smaller portion of the variance in T was due to differences between trials (10%), and observed power to detect this difference as significant was lower (0.40). Analysis of FT revealed similar results. As shown in Figure 5, FT increased from pre- to immediate postexercise, then decreased somewhat at 15-min postexercise during both trials. ANOVA analysis yielded only a significant time effect but no differences between

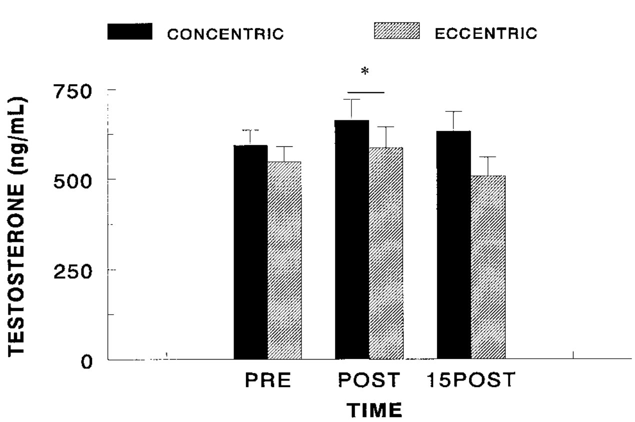

FIGURE 4—Testosterone concentrations (mean ± SE) during the experimental trials for CON (*solid bar*) and the ECC trial (*hatched bar*). * Significantly different from prevalue ($P < 0.01$). Free testosterone concentrations (mean ± SE) during the experimental trials for CON (*solid bar*) and the ECC trial (*hatched bar*). * Significantly different from prevalue ($P < 0.01$).

trials. Eta-squared indicated 40% of the variance in FT was explained by the time factor, with observed power estimated at 0.99. By comparison, only 10% of the variance in FT was attributable to differences between CON and ECC trials, and power to detect differences of this magnitude was 0.39.

DISCUSSION

This is the first study to use multiple exercises at a constant load to investigate the separate effects of CON and ECC muscle actions on circulating GH, T, and FT. We were interested in determining the separate responses to CON and ECC contractions using identical loads because common resistance exercise protocols employ constant loads for both muscle actions. Revealing separate physiological and hormonal effects of different muscle actions may lead to the development of new resistance exercise regimens tailored for different populations. We hypothesized that CON and ECC contractions performed at the same absolute load would produce different GH, T, and FT responses due to differences in metabolic stress from the dissimilar contraction modes. Our hypothesis was tenable for GH, but not for total T and FT. From the counterbalanced design, data clearly indicated when both contractile modes were performed against the same absolute resistance, the relatively more difficult CON workload produced a greater GH response; however, T and FT responses were similar for both muscle actions.

Growth hormone. Kraemer et al. (19) found GH responses to an isokinetic CON trial were significantly higher than an isokinetic ECC trial in subjects in an untrained condition and in subjects who had completed 19 wk of training using one (CON) or two (CON/CON) dynamic CON contractions each repetition. Our findings of greater GH responses to a constant load CON multi-exercise protocol are in agreement with these findings for an isokinetic single-exercise protocol.

Although it is not clear whether acute increases in GH play a role in local skeletal muscle hypertrophy, it is interesting to note that resistance exercises producing the greatest GH responses are typically hypertrophy protocols with high repetitions and short rest periods, whereas low-repetition strength-training protocols with long rest periods result in a lesser GH response (10,22). Modulators of GH secretion have been implicated from both central sites as well as peripheral sites (i.e., chemoreceptors) (6). Chemoreceptor activation of group III and IV nerve fibers mediates GH release by stimulating the hypothalamic-pituitary axis (7). Among the many potential stimulators of exercise-induced GH secretion, elevated H+ ions (6), lactate levels (22,23), and oxygen demand and availability (30) appear to play a role. For example, five sets of leg extensions with 30-s rest periods performed at 20% of a 1-RM with vascular occlusion resulted in a 290% increase in GH above baseline (29). The increased lactate resulting from tissue hypoxia may have elevated GH significantly although training volume was low. Moreover, when resistance-training protocols of equal volume yet different load/rest ratios are performed, the higher intensity protocol that produces higher lactate levels results in the greatest GH secretion (22). Lactate concentrations in the present study were higher after the CON trial compared with the ECC trial. These data are consistent with previous research (14,24) and support the contention that the ECC contractions imposed a reduced metabolic stress compared with the CON contractions. Maximal ECC strength is roughly 30–50% more than maximal CON strength (4) and requires less neural activation (5). CON exercise has been found to result in greater muscle sympathetic nerve activity than ECC exercise at the same absolute workload. The greater lactate produced during the CON exercise in the present study was likely due to greater motor unit recruitment.

It appears lactate must be elevated above a certain threshold for GH secretion to rise; however, there is debate whether lactate and/or H+ or another mechanism has a greater impact on GH release. In a recent study by Stokes et al. (28), sequential 30-s high-intensity cycling sprints separated by 1 h of recovery yielded similar lactate and blood pH responses to both sprints but a markedly attenuated GH response to the second sprint. Based on these data, the investigators considered proprioceptive feedback to be a more important modulator of GH secretion than metabolites. Similar findings have been reported *in situ* by Gosselink et al. (8) in which proprioceptive feedback through muscle spindles and golgi tendon organs caused significant increases in bioassayable GH. Collectively, these studies suggest that factors other than lactate play a role in GH release. It is possible that lactate, pH, and proprioceptive feedback all played a role in the different GH responses we noted.

It has been documented that maximal ECC resistance training increases muscular strength (3,4) and produces muscle hypertrophy (13,15). Moreover, it has been demonstrated that significant increases in muscle hypertrophy of Type I and Type II fibers are correlated with exercise-induced GH secretion (25). However, the ECC trial in the present study elicited a much lower GH response than the CON trial. There are several possible explanations for these apparent paradoxical findings. First, the ECC contractions were performed at a lower relative intensity than CON contractions and thus appear to represent an intensity effect rather than a contraction mode effect. Because most studies have used maximal ECC loading protocols to document greater hypertrophy effects of ECC contractions (13,15), those data cannot be compared to the present study in which submaximal ECC loading was used. Second, it remains to be determined whether or not the GH response to acute resistance exercise contributes to skeletal muscle hypertrophy as there are some data that support both hypotheses. Administration of GH has not been shown to effect muscle growth and strength in normal exercising men (31). However, a number of researchers have hypothesized that the brief rise in GH can cause interaction with muscle cell receptors and may aid in subsequent recovery and stimulate muscle hypertrophy (21). Finally, as with most physiological mechanisms, we would expect multiple stimuli with different degrees of effectiveness to elicit skeletal muscle hypertrophy. It is possible that testosterone is a more potent stimulus for muscle hypertrophy than GH. More research needs to be conducted in order to determine the effects of peripheral GH levels on skeletal muscle hypertrophy.

Testosterone. The subjects chosen to participate in the study were well-trained recreational resistance athletes who were not involved in sport but whose normal training regimen consisted of bodybuilding type workouts (i.e., multiple sets, high-repetition training). The subjects' mean 10-RM for each exercise provides evidence their training status. We thought the use of use of untrained subjects with little resistance exercise experience could result in ambiguous findings due to inconsistent effort that would affect the anabolic hormone response. Moreover, training has been shown to affect the degree of anabolic hormone response, and we chose subjects with recreational resistance exercise experience whose responses would not represent those of a novice or those of a highly competitive well-trained athlete. We surmised that responses of active recreational athletes would best represent responses of many young males who engage in resistance training.

In a study mentioned earlier, Kraemer et al. (19) found T increased in response to the isokinetic CON test in all groups, but T also increased in response to the isokinetic ECC test in the CON/ECC trained group. Using our constant load multi-exercise protocol, we too found that T concentrations increased in response to both CON and ECC contractions, and no differences between trials were observed.

High-intensity resistance exercise, which produces large increases in lactate, results in greater increases in circulating T levels than high-volume, low-intensity protocols (10,22). Although lactate levels sharply increased for the CON trial and changed very little for the ECC trial, there were similar T responses after both trials, indicating that T responses were not greatly affected by metabolic stress with our exercise model.

Free testosterone. FT represents the amount of testosterone that is biologically available to cells because 98% of the T is bound to binding proteins (12). Approximately 40% of T is bound to SHBG, whereas nearly 60% is bound to albumin (12). Assuming binding protein concentration remains constant, an increase in T should lead to an increase in FT. FT increased significantly from pre- to postexercise in both CON and ECC trials, but there was no difference between trials. It has been previously reported that four sets of 10-RM squats result in significant increases in FT (21). In the present study, multiple exercises for both CON and ECC experimental trials resulted in small but significant increases in FT. These differ from the previous research in which no significant changes in FT were found in response to CON and ECC isokinetic tests (19). Perhaps discrepancies between our study and the previous study may be explained by the difference in muscle contractions, with standard dynamic contractions employed in the present study and isokinetic contractions used in the previous study. Other factors that may have played a role are the differences in resistance exercises employed and muscle mass used in the two studies. Thus, it appears the volume of CON and ECC dynamic contractions and muscle mass used in the present study was great enough to increase FT concentrations.

A limitation of the current study was the loads employed and the kind of resistance exercises performed. It could be speculated that a higher exercise load or exercises that recruited more motor units such as the squat or leg press would have produced different responses in circulating androgens. The magnitude of hormonal responses to exercise is proportional to the size of the muscle mass activated relative to the intensity performed (28). We used pulleys and levers to lift and lower the weight for all the exercises. During piloting of the study, we determined that four sets of 10 repetitions at 80% of a 1-RM load were too strenuous for researchers positioning the weight (in a timely manner) and for some subjects to complete the CON protocol. Four sets of 12 repetitions at a CON 10-RM load were found to be optimal to produce substantial fatigue and ensure completion of the protocol. As for choice of exercises, we chose two upper-body and two lower-body resistance exercises commonly performed on a weight-stack machine that could be used to isolate CON and ECC actions.

Conclusions. This is the first study to investigate the separate effects of CON and ECC muscle actions of multiple exercises at a constant load on circulating GH, T, and FT concentrations. CON exercise increased GH concentrations to a much greater extent than ECC exercise. The significantly higher GH concentrations after CON exercise could be mediated by increased lactate, decreased pH, proprioceptive feedback, and/or amount of muscle mass activated. It seems likely that the GH responses to the exercise protocol were probably intensity related rather than mode related. However, CON and ECC dynamic contraction trials at the same absolute workload elicited similar small but significant increases in T and FT, indicating that the greater metabolic stress produced by during the CON trial did not affect these hormone responses. Future research needs to be conducted to elucidate the ramifications of these and other endocrine responses, and to determine the mechanisms involved.

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