Changes in hormonal concentrations after different heavy-resistance exercise protocols in women

WILLIAM J. KRAEMER, STEVEN J. FLECK, JOSEPH E. DZIADOS, EVERETT A. HARMAN, LOUIS J. MARCHITELLI, SCOTT E. GORDON, ROBERT MELLO, PETER N. FRYKMAN, L. PERRY KOZIRIS, AND N. TRAVIS TRIPLETT

US Army Research Institute of Environmental Medicine, Natick, Massachusetts 01760–5007; The Center for Sports Medicine, The Pennsylvania State University, University Park, Pennsylvania 16802; and Sports Science and Technology Division, United States Olympic Committee, Colorado Springs, Colorado 80909

KRAEMER, WILLIAM J., STEVEN J. FLECK, JOSEPH E. DZIADOS, EVERETT A. HARMAN, LOUIS J. MARCHITELLI, SCOTT E. GORDON, ROBERT MELLO, PETER N. FRYKMAN, L. PERRY KOZIRIS, AND N. TRAVIS TRIPLETT. *Changes in hormonal concentrations after different heavy-resistance exercise protocols in women.* J. Appl. Physiol. 75(2): 594–604, 1993.—Nine eumenorrheic women (age 24.11 ± 4.28 yr) performed each of six randomly assigned heavy-resistance protocols (HREPs) on separate days during the early follicular phase of the menstrual cycle. The HREPs consisted of two series [*series 1* (strength, S) and *series 2* (hypertrophy, H)] of three protocols, each using identically ordered exercises controlled for load [5 vs. 10 repetitions maximum (RM)], rest period length (1 vs. 3 min), and total work (J) within each three-protocol series. Blood measures were determined pre-, mid- (after 4 of 8 exercises), and postexercise (0, 5, 15, 30, 60, 90, 120 min and 24 and 48 h). In *series 1*, a significant ($P < 0.05$) reduction in growth hormone (GH) was observed at 90 min postexercise for all three protocols. In *series 2*, the 10-RM protocol with 1-min rest periods (H10/1) produced significant increases above rest in GH concentrations at 0, 5, and 15 min postexercise, and the H10/1 and H5/1 protocols demonstrated significant reductions at 90 and 120 min postexercise. Cortisol demonstrated significant increases in response to the S10/3 protocol at 0 min, to the H10/1 protocol at midexercise and at 0 and 5 min postexercise, and to the H5/1 protocol at 5 and 15 min postexercise. No significant changes were observed in total insulin-like growth factor I, total testosterone, urea, or creatinine for any of the HREPs. Significant elevations in whole blood lactate and ammonia along with significant reductions in blood glucose were observed. Hormonal and metabolic blood variables measured in the early follicular phase of the menstrual cycle varied in response to different HREPs. The most dramatic increases above resting concentrations were observed with the H10/1 protocol, indicating that the more glycolytic HREPs may stimulate greater GH and cortisol increases.

lactate; anaerobic; strength training; ammonia; growth factors; growth hormone; cortisol; testosterone

IN ONLY A LIMITED NUMBER of investigations have the hormonal changes consequent to acute heavy-resistance exercise in women been examined. The majority of these studies have focused on testosterone responses (9, 14, 22, 41). Although not typical, changes in testosterone concentrations with heavy-resistance exercise have been considered possible because of higher secretions of adrenal androgens in some women (1, 9). For most women, exercise-induced increases in testosterone above resting concentrations have not been observed (14, 22, 41), suggesting that other anabolic hormones (e.g., growth hormone and growth factors) may play greater roles in the anabolic adaptational mechanisms related to muscle and connective tissue growth with resistance training (2, 16, 19, 22). The exact mechanisms involved in such tissue remodeling remain to be elucidated, as do the neuroendocrine mechanisms that might help mediate such tissue growth.

The stress of heavy-resistance exercise has been shown to be an effective stimulus for both strength and muscle fiber hypertrophy (3, 16, 17, 28, 34). Furthermore, heavy-resistance stress is unique as an exercise modality in producing high levels of force through recruitment of a large percentage of the motor unit pool. It is possible that the acute physiological changes that occur in response to a given heavy-resistance exercise protocol may provide some insights into the physiological mechanisms of long-term adaptations (18). A greater appreciation of the differences among heavy-resistance exercise protocols needs to be gained to allow more specific exercise stimuli to be created when long-term training studies are undertaken. Physiological differences among various heavy-resistance exercise programs are related to the acute program variables (e.g., resistance used and length of rest period between sets and exercises) that ultimately configure the exercise stress (19–21).

In a recent study, we reported that gender differences in hormonal responses to two distinctly different heavy-resistance exercise protocols were related to a lack of a testosterone response in women and to a higher concentration of growth hormone in the early follicular phase of the menstrual cycle. Higher concentrations of growth hormone in response to a moderate-resistance [10-repetitions maximum (RM)] protocol with a short (1-min) rest period than in response to a higher resistance (5-RM) protocol with a longer (3-min) rest period have been observed (22). Thus, program characteristics related to the amount of resistance and the rest period length have been suggested to be important determinants of hormonal responses in women (22). Because of differences in total work between the two exercise protocols, our pre-

TABLE 1. *Subject characteristics*

Parameter	Value
Age, yr	24.1±4.3
Height, cm	161.6±7.6
Body mass, kg	63.4±11.9
%Body fat	24.3±6.1
$\dot{V}O_{2\,max}$, $ml \cdot kg^{-1} \cdot min^{-1}$	38.5±6.64

Values are means ± SD; n = 9 women. $\dot{V}O_{2\,max}$, maximal oxygen consumption.

vious study's design did not allow us to isolate the specific effects of the resistance used or the length of the rest period on hormonal changes in women. With men, we have previously demonstrated that these two acute program variables had very powerful independent effects on the hormonal responses to different heavy-resistance exercise protocols (21, 23). This study was designed to address the distinct need for more extensive data concerning the influence of resistance exercise variables (i.e., amount of resistance, amount of rest between sets and exercises) on hormonal responses in women. The primary purpose of this investigation was to examine the independent influence of resistance (5 vs. 10 RM) and rest period length (1 vs. 3 min) on serum hormone concentrations in women.

METHODS

Preliminary laboratory sessions. A minimum of 3 wk was used for experimental protocol familiarization in which resistance load verifications (5 and 10 RM) for each experimental exercise protocol were determined. Descriptive testing (e.g., body composition and maximal oxygen consumption evaluations) was also performed at this time. Each subject's percent body fat was determined using standard hydrostatic weighing (computer interfaced with a load cell) body composition methodologies as previously described (15, 44). To characterize the subject's cardiovascular fitness, maximal oxygen consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) was determined with a continuous treadmill protocol (8, 43).

Subjects. Nine healthy women participated in these studies after giving their free and informed voluntary consent. The investigators adhered to Army Regulation 70–25 and US Army Medical Research and Development Command Regulation 70–25 on Use of Volunteers in Research. Each subject had recreational experience with resistance training, but none of them was a competitive lifter. None was using any medications during the course of this study or reported any previous history of smoking or use of other nicotine products. Each subject denied any history of anabolic drug use. All of the women were deemed eumenorrheic according to previously described methods (11). Each subject had had regular 28- to 32-day menstrual cycles throughout the previous year, and none of the women had used oral contraceptives or intrauterine devices within the past year. Subject characteristics are shown in Table 1.

Experimental protocol. Two of the six protocols were randomly performed on separate days (1 and 4 days after menses) during the early follicular phase of the menstrual cycle on each of three consecutive months. Subjects did not eat anything for 6 h before each test and refrained from ingesting alcohol and caffeine for 48 h before all testing. No other strenuous exercise was performed for 72 h before each of the experimental exercise sessions. One RM testing every month demonstrated that no strength changes occurred over the course of the study. In addition, aerobic exercise was limited to 2 sessions/wk, with no training effects observed over the course of the study. Dietary analysis (Nutri-Calc, PCD System, Penn Yan, NY) for the 3 days before each experimental session was obtained from a food diary and demonstrated normal recommended daily allowances of caloric, vitamin, and mineral profiles. Macronutrient intake values were 62.1 ± 5.6% (SD) carbohydrate, 13.5 ± 2.3% protein, and 24.4 ± 6.3% fat. Fluid intake was encouraged, and hydration status was verified by monitoring urine specific gravity via a refractometer before each workout. All subjects had a urine specific gravity of <1.015 before all workouts. No significant ($P < 0.05$) differences were observed for preexercise urine specific gravity measures between the different exercise test sessions. Although it was not the purpose of the study to match diets on each test day, subjects were encouraged to eat similar diets, which resulted in the similar caloric, vitamin, mineral, and nutrient intakes observed before each test. Urine nitrogen determinations verified that all subjects were within normal positive nitrogen balance before each set of test sessions for that month.

Experimental design and exercise protocols. Each of the six heavy-resistance exercise protocols was performed in random order and by all nine subjects. Subsequent statistical analysis demonstrated no order effects. The design allowed for the quantitative examination of the effects of specific program design variables (load and rest period length) corrected for total work. Figure 1 depicts the basic experimental design of the two series of exercise protocols used in this investigation, each of which consisted of three workouts (a primary workout, a rest control, and a load control). *Series 1* was termed the strength series and was characterized by a heavier resistance (5 RM) and a longer rest period (3 min) used in the primary workout. *Series 2* was termed the hypertrophy series as it used a lighter resistance (10 RM) and a shorter rest period between sets and exercises (1 min) in the primary workout. Whereas all heavy-resistance exercise protocols produce increases in strength and muscle cell hypertrophy, the primary "strength" workout was designed to simulate the kind of lifting routine used by athletes primarily training for strength (e.g., competitive power lifters). The primary "hypertrophy" workout was modeled after the type of routine used by body builders to induce increases in muscular hypertrophy (24). *Series 1* protocols had significantly ($P < 0.05$) lower total work than did *series 2* protocols (24,501.1 ± 2,827.0 vs. 31,580.3 ± 3,278.0 J). For example, when we compared *series 1* and *series 2* protocols using 10 RM and 3 min rest, the only difference was that more total work was performed in the *series 2* protocol. Thus, we have designated symbols for the type of work (H vs. S), the resistance (5 vs. 10 RM), and the rest period length (1 vs. 3 min) so that one can see exactly where differences occur in the exercise protocol.

The primary *series 1* workout consisted of a 5-RM load

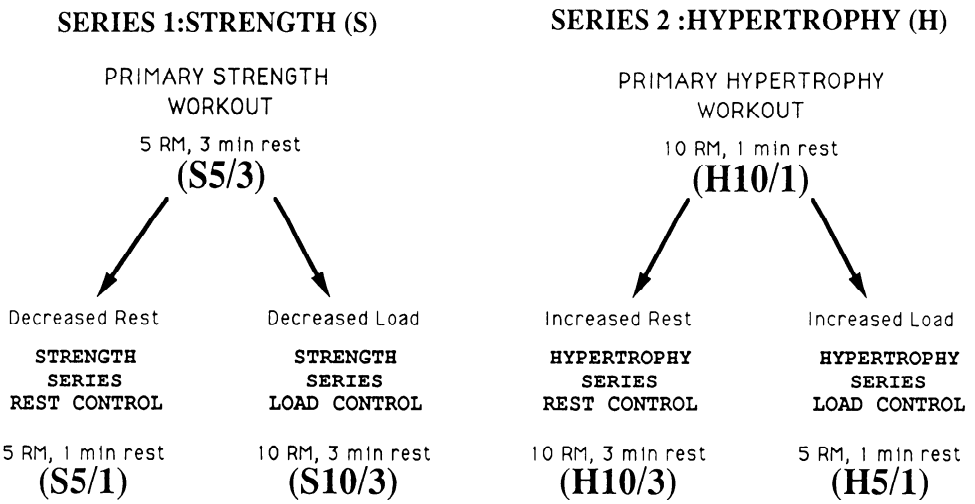

FIG. 1. Schematic diagram of experimental design. RM, repetition maximum.

and a 3-min rest period between sets and exercises and was designated S5/3 [S for strength protocol (lower total work), 5 for 5-RM load, and 3 for 3-min rest period]; the load control *series 1* workout was designated S10/3 (S for strength protocol, 10 for 10-RM load, and 3 for 3-min rest period); and the rest control *series 1* workout was designated S5/1 (S for strength protocol, 5 for 5-RM load, and 1 for the 1-min rest period). This terminology was also used for designating each *series 2* protocol. The primary *series 2* protocol was designated H10/1 [H for hypertrophy protocol (higher total work), 10 for 10-RM load, and 1 for 1-min rest period], the load control *series 2* workout was designated H5/1 (H for hypertrophy protocol, 5 for 5-RM load, and 1 for 1-min rest period), and the rest control *series 2* workout was designated H10/3 (H for hypertrophy protocol, 10 for 10-RM load, and 3 for 3-min rest period). The variations in the primary workouts were examined to determine if the responses that occurred were due to single-factor changes in load or rest period length. Comparisons between a few *series 1* and *2* protocols (S10/3 vs. H10/3 and S5/1 vs. H5/1) allowed for a limited evaluation of total work effects. The exercises used, the order of exercises, and the number of sets for the primary workouts are listed in Table 2.

The grip width used by each subject was proportional to her height. Body position (e.g., grip width and joint angles) was held constant for an exercise across protocols. The matching of total work between workouts was performed by a computer program that, given a specific exercise, weight, and number of repetitions, calculated the number of repetitions required to produce the same total work as in the primary protocol using a different weight. Lifting work was calculated as wt × the vertical distance moved per repetition × no. of repetitions. The program took into consideration the vertical distance moved by both the iron plates and the centers of gravity of the lifter's body segments. These distances were obtained from measurements on the subjects and equipment when they were in the starting and ending exercise positions. Anthropometric tables were used to locate body segment centers of gravity and to estimate body segment weights from total body weight (45).

TABLE 2. *Primary heavy-resistance exercise protocols*

Exercise	Protocol	
	Series 1 (S5/3)	*Series 2* (H10/1)
Bench press	5 RM × 5 Sets	10 RM × 3 Sets
Double leg extension	5 RM × 5 Sets	10 RM × 3 Sets
Military press	5 RM × 3 Sets	10 RM × 3 Sets
Bent leg incline sit-ups	5 RM × 3 Sets	10 RM × 3 Sets
Seated rows	5 RM × 3 Sets	10 RM × 3 Sets
Lat pull down	5 RM × 4 Sets	10 RM × 3 Sets
Arm curls	5 RM × 3 Sets	10 RM × 3 Sets
Leg press	5 RM × 5 Sets	10 RM × 3 Sets

Exercises were done in order listed. Exercise protocols are given as no. of repetitions maximum (RM) × no. of sets. S5/3, *series 1* ("strength," S) protocol with 5 RM and 3-min rest periods; H10/1, *series 2* ("hypertrophy," H) protocol with 10 RM and 1-min rest periods. All exercises were performed on Universal weight machines except for *exercises 4* and *7*, which were performed using free weights.

Blood sampling. All venous blood samples were obtained with the subjects in a slightly reclined seated position. Testing was always conducted at the same time of day (0800–1000 h) to reduce the effects of any diurnal variations on hormonal concentrations. Before a resting blood sample was obtained, a 20-min equilibration period was used. Subjects knew they would not start exercising until 10 min after the resting blood sample was obtained. This procedure was shown during pilot testing to eliminate any significant anticipatory increases in resting hormonal concentrations. Water intake was allowed ad libitum throughout the exercise protocols and recovery. Furthermore, urine specific gravity measurements and dietary logs were used to screen for hydration status before each test. The venous blood samples were obtained from a 20-gauge indwelling Teflon cannula placed in a superficial arm vein kept patent with isotonic saline (30 ml/h). Blood samples were obtained preexercise, midexercise (i.e., after 4 of 8 exercises), at *time 0* (immediately postexercise), and at various time points (i.e., from 5 min to 48 h) after the exercise session, depending on the specific blood variable examined. Whole blood was processed, and, where appropriate, serum and plasma samples were stored in an ultralow freezer at −120°C until analyses were performed. Samples were thawed only once for the various analyses.

Biochemical analyses. Whole blood lactate concentra-

tions were determined in duplicate via a lactate analyzer (640, Wolverine Medical, Grand Rapids, MI). Hemoglobin was analyzed in triplicate with the cyanmethemoglobin method (Sigma Chemical, St. Louis, MO), and hematocrit was analyzed in triplicate with a standard microcapillary technique. The percent changes in plasma volume were calculated according to the equations of Dill and Costill (12). All other samples were assayed in duplicate and were decoded only after analyses were completed (i.e., they used blinded analyses). Serum creatinine and urea and plasma glucose and ammonia were all determined via colorimetric assay methods (Sigma Chemical) and a Gilford Stat Star spectrophotometer. Intra- and interassay variances were all <5 and <7%, respectively. For ammonia analyses blood was collected into prechilled plastic syringes containing EDTA (1.2 mg/ml whole blood), mixed gently, and centrifuged at 1,500 *g* at 4°C for 15 min. Each blood draw was collected via a three-way stopcock into plastic syringes. The blood for serum measures was transferred from the syringe into glass tubes, sealed, and allowed to clot at room temperature. The clotted blood was then centrifuged at 1,500 *g* for 15 min at 4°C. The resultant serum was extracted and stored in 1.5-ml Eppendorf tubes. Determinations of the different concentrations for the various radioimmunoassays were accomplished with the use of a Beckman 5500 gamma counter and on-line data reduction system. Concentrations of serum testosterone, growth hormone, cortisol, and total insulin-like growth factor I were determined by radioimmunoassays. Total testosterone was measured with ^{125}I solid-phase radioimmunoassay (Diagnostic Products, Los Angeles, CA) with a detection limit of 0.38 nmol/l. Intra- and interassay variances were calculated to be <3.0 and <5.1%, respectively. Growth hormone was measured with an ^{125}I liquid-phase radioimmunoassay with double-antibody technique (Cambridge Medical Diagnostics, Billerica, MA) with a limit of detection of 0.24 μg/l. Intra- and interassay variances were calculated to be <3.6 and <5.2%, respectively. Total insulin-like growth factor I was measured with ^{125}I double-antibody disequilibrium radioimmunoassay with a preliminary octadecasilyl-silica extraction procedure (Inc-Star, Stillwater, MN), the limit of detection being <2.0 nmol/l. Intra- and interassay variances were <4.7 and <5.2%, respectively. Serum cortisol concentrations were assayed with a solid-phase ^{125}I radioimmunoassay technique (Diagnostic Products). The intra-assay variance was <3.1%, and the interassay variance was <7.1%.

Statistical analyses. Statistical evaluation was accomplished by a multivariate analysis of variance with repeated measures. Subsequent post hoc pairwise differences were determined using Tukey tests when appropriate. Pearson product-moment correlational analyses were used to examine various bivariate relationships. Dependent *t* tests were used for comparisons of the total work of the two series of heavy-resistance exercise protocols. The significance level for this investigation was set at $P \leq 0.05$.

RESULTS

Overall, no systematic patterns of correlations were observed between the different variables. There was only a limited number of random significant correlations observed between growth hormone and lactate at various time points within several protocols. None of the significant correlations was observed between growth hormone and total insulin-like growth factor I. A significant correlation between all lactate and ammonia concentrations in the H10/1 protocol was observed ($r = 0.73$).

No significant differences between resting values for the blood concentrations of any of the analyses were observed. In Fig. 2 the response patterns of serum growth hormone and testosterone are shown. No significant increases above rest in growth hormone were observed in *series 1*, but a significant decrease was observed at 90 min postexercise for all three exercise protocols. In *series 2* serum growth hormone demonstrated significant increases above resting concentrations with the H10/1 protocol at 0, 5, and 15 min postexercise and significant reductions in postexercise values at 90 and 120 min postexercise for the H10/1 and H5/1 protocols. The increases observed for the H10/1 postexercise were significantly greater than corresponding time points of the other exercise protocols in *series 1* and *2*.

The changes in serum testosterone after the various heavy-resistance exercise protocols can be seen in Fig. 2*B*. No significant changes from resting concentrations were observed for any of the heavy-resistance exercise protocols.

The changes in serum total insulin-like growth factor I and serum cortisol are presented in Fig. 3. No significant changes from resting concentrations were observed for serum total insulin-like growth factor I after any of the heavy-resistance exercise protocols.

Changes in serum cortisol are shown in Fig. 3*B*. A significant increase above resting concentrations immediately postexercise for the S10/3 protocol was observed. In *series 2* serum cortisol was significantly elevated in the H10/1 protocol above resting values at midexercise and at 0 and 5 min of the recovery period. The H5/1 protocol demonstrated significant increases above rest at 5 and 15 min postexercise. The increased cortisol concentrations in the H10/1 protocol were significantly greater than the increases at measured corresponding time points for the H5/1 protocol at midexercise and immediately after exercise (0 min) and at all measured time points for the H10/3 protocol. The increases in the H5/1 protocol at 5 and 15 min postexercise were greater than the 5- and 15-min values for the corresponding H10/3 protocol. The cortisol increases in the S10/3 protocol were greater than the increases at all of the measured time points in the S5/3 protocol and greater than the increase immediately postexercise (0 min) in the S5/1 protocol. The increase in cortisol immediately postexercise for the S10/3 protocol was significantly greater than the increase at the corresponding time point for the H10/3 protocol.

The changes in plasma glucose, whole blood lactate, and plasma ammonia values can be seen in Table 3. Significant decreases in plasma glucose were observed for the S5/3 and S10/3 protocols at 90 and 120 min postexercise. In *series 2* significant decreases were observed for plasma glucose after all three heavy-resistance exercise protocols at 60, 90, and 120 min postexercise. No signifi-

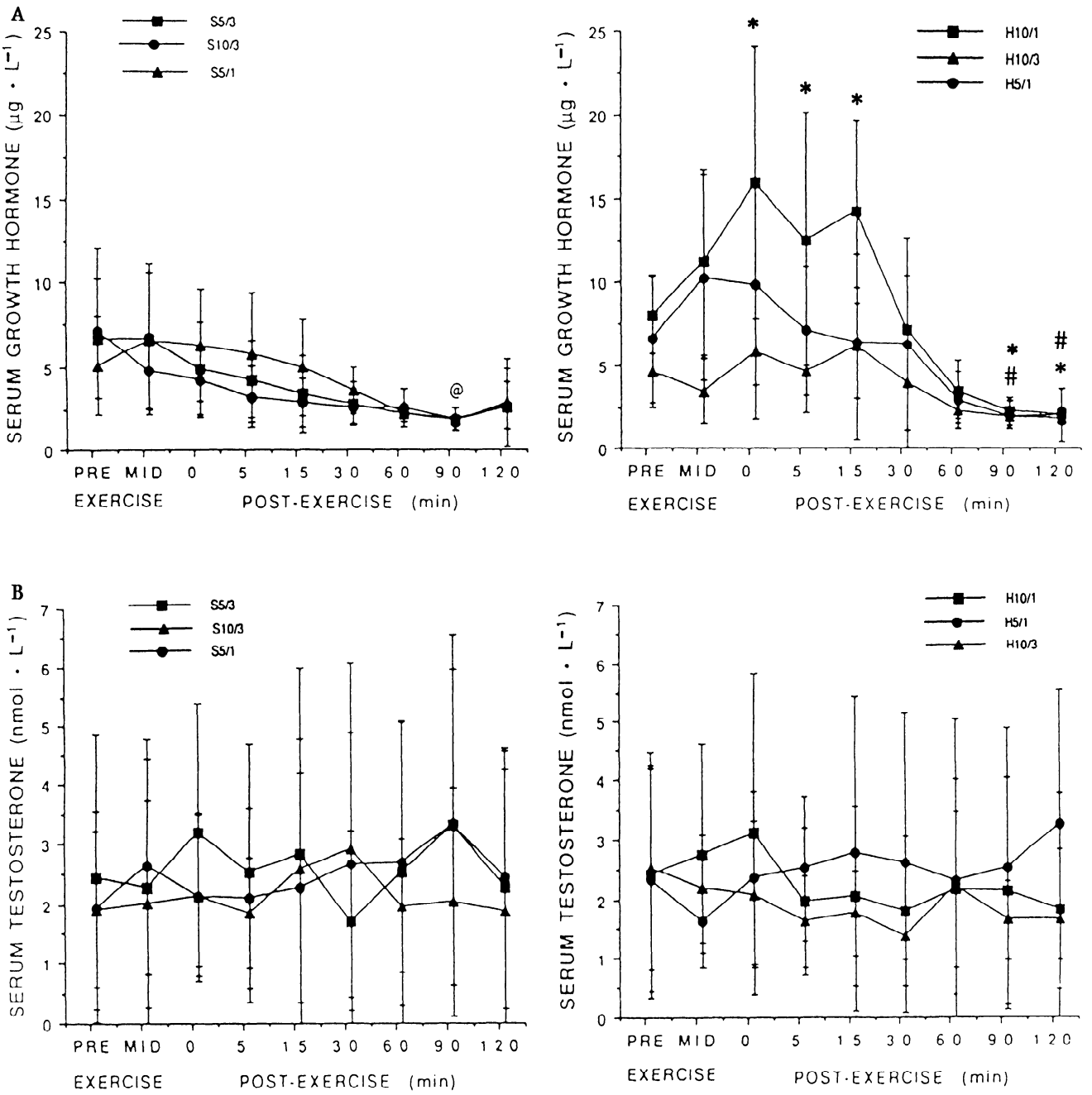

FIG. 2. Means ± SD of serum growth hormone (*A*) and serum testosterone (*B*) during *series 1* (strength, S) resistance exercise protocols (*left*) and *series 2* (hypertrophy, H) resistance exercise protocols (*right*). S5/3, S10/3, and S5/1, *series 1* exercise with 5 RM and 3-min rest periods, 10 RM and 3-min rest periods, and 5 RM and 1-min rest periods, respectively; H10/1, H10/3, and H5/1, *series 2* exercise with 10 RM and 1-min rest periods, 10 RM and 3-min rest periods, and 5 RM and 1-min rest periods, respectively. Significant difference ($P < 0.05$) from corresponding preexercise values for: @ all protocols, * H10/1 protocol, # H5/1 protocol.

cant differences between protocols were observed at measured corresponding time points.

Significant increases above resting values were observed in whole blood lactate for the S5/3 protocol at midexercise and at 0, 5, and 15 min of recovery. The S5/1 protocol demonstrated significant increases in lactate at midexercise and at 0, 5, 15, and 30 min of recovery. The H10/1 protocol elicited significant increases in lactate at midexercise and at 0, 5, 15, and 30 min postexercise. Lactate was increased at midexercise and remained elevated for 5 min after exercise with the H5/1 protocol and for 15 min for the H10/3 protocol. The H10/1 protocol demonstrated a significantly greater increase in lactate than the other *series 2* protocols except for the H10/3 protocol at 5 min postexercise. The H10/1 increases in lactate were greater than the corresponding time points for all of the protocols in *series 1*. At 5 min postexercise the increase in lactate was also greater during the H10/3 protocol than during the H5/1 protocol and all of the *series 1* protocols.

Significant increases above resting values were observed for plasma ammonia for the H5/1 exercise protocol at midexercise and at 0 and 5 min postexercise. The

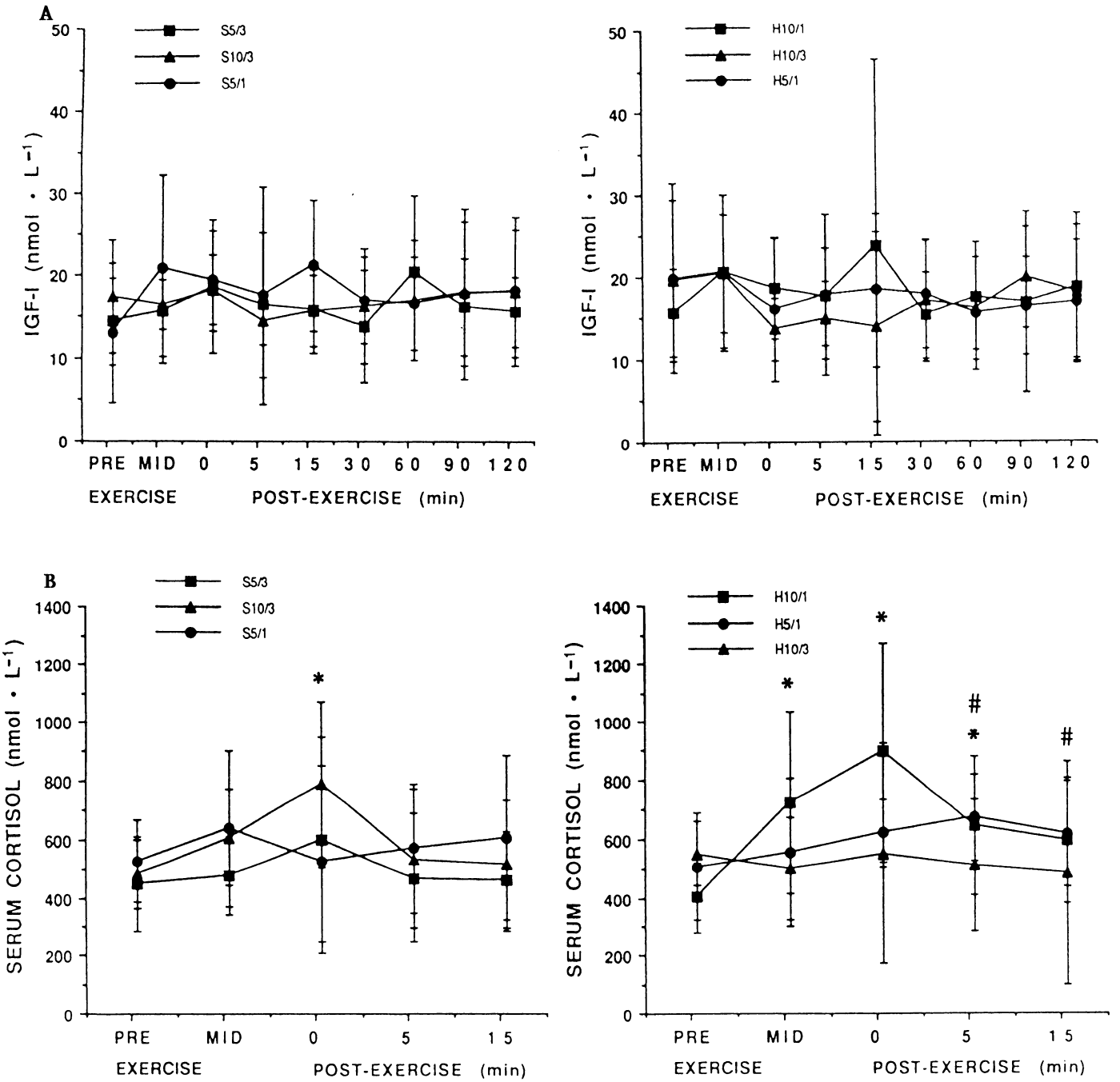

FIG. 3. Means ± SD of serum insulin-like growth factor I (IGF-I; *A*) and serum cortisol (*B*) during *series 1* resistance exercise protocols (*left*) and *series 2* resistance exercise protocols (*right*). Significant difference ($P < 0.05$) from corresponding preexercise values for: * S10/3 protocol in *A*, * H10/1 protocol in *B*, # H5/1 protocol in *B*.

H10/1 exercise protocol produced significant increases above resting values at midexercise and immediately postexercise (0 min). The increases in plasma ammonia in the H10/1 and H5/1 protocols were greater than those at corresponding time points for the S10/3 and S5/1 protocols at midexercise and immediately postexercise (0 min) and the S5/3 and S5/1 protocols at 5 min postexercise. No significant differences were observed 24 and 48 h after exercise.

Table 4 shows the responses of serum creatinine and urea. No significant changes in serum creatinine concentrations were observed after the various heavy-resistance exercise protocols up to 48 h postexercise. No changes in serum urea concentrations were observed with heavy-resistance exercise in response to any of the protocols, and no significant differences were observed 24 and 48 h after exercise.

We did not see any significant differences in plasma volume shifts between the different heavy-resistance exercise protocols. To make sure that the small nonsignificant changes in plasma volume shifts did not influence our results, we corrected all values for plasma volume changes. We found no significant differences between corrected and uncorrected concentrations. Thus, we have chosen to present the uncorrected values. This is especially important as the tissues in various biocom-

TABLE 3. *Whole blood lactate, plasma glucose, and plasma ammonia values during series 1 (S) and 2 (H) resistance exercise protocols*

	Pre	Mid	IPE	5 min	15 min	30 min	60 min	90 min	120 min	24 h	48 h
					Lactate, mmol/l						
S5/3	1.39±0.39	3.24±0.82*	2.92±1.25*	2.30±0.81*	2.21±1.09*	1.66±0.93	1.44±0.69	1.33±0.43	1.16±0.39	1.73±0.39	1.60±0.38
S10/3	1.18±0.32	1.93±0.63*	2.08±0.65*	1.72±0.52	1.51±0.39	1.20±0.22	1.15±0.34	1.05±0.26	0.94±0.15	1.26±0.57	1.14±0.25
S5/1	1.45±0.43	3.20±1.10*	4.23±2.00*	3.90±1.86*	2.38±0.93*	2.04±1.10*	1.78±0.69	1.35±0.34	1.27±0.35	1.40±0.49	1.28±0.29
H10/1	1.42±0.49	7.49±0.95*	7.57±1.69*	5.98±1.79*	4.88±1.07*	3.33±0.93*	1.94±0.69	1.58±0.38	1.35±0.26	1.36±0.46	1.39±0.51
H5/1	1.30±0.57	3.76±0.85*	3.54±1.75*	3.05±1.35*	2.51±1.12	1.96±0.85	1.22±0.33	1.17±0.32	1.18±0.24	1.18±0.27	1.23±0.29
H10/3	1.80±0.78	4.51±0.90*	4.78±1.41*	5.72±2.54*	3.34±1.10*	2.21±0.52	1.60±0.51	1.45±0.32	1.38±0.39	1.76±0.93	1.62±0.27
					Glucose, mmol/l						
S5/3	5.29±0.58	5.24±0.46	4.96±0.46	4.99±0.38	5.01±0.31	4.84±0.39	4.63±0.35	4.61±0.28*	4.75±0.29*		
S10/3	5.19±0.85	5.17±0.36	4.93±0.44	4.90±0.32	4.94±0.34	4.84±0.32	4.66±0.26	4.72±0.22*	4.72±0.23*		
S5/1	4.94±0.42	5.05±0.36	5.08±0.29	4.98±0.30	4.96±0.40	4.62±0.49	4.63±0.35	4.63±0.26	4.74±0.12		
H10/1	5.23±0.64	5.20±0.88	5.20±0.45	5.20±0.71	5.08±0.73	4.83±0.52	4.59±0.33*	4.61±0.41*	4.64±0.32*		
H5/1	5.11±0.49	5.17±0.33	5.13±0.36	4.97±0.46	5.02±0.29	4.76±0.33	4.67±0.40*	4.59±0.38*	4.68±0.28*		
H10/3	5.06±0.41	5.06±0.46	4.89±0.41	4.93±0.46	4.65±0.34	4.71±0.58	4.34±0.45*	4.53±0.24*	4.62±0.22*		
					Ammonia, μmol/l						
S5/3	190.34±130.73	156.19±55.08	265.44±186.73	157.49±76.23						142.96±110.15	129.48±93.46
S10/3	120.06±110.82	166.58±96.10	169.39±87.20	245.48±222.82						120.20±88.20	110.35±44.02
S5/1	167.44±142.76	210.71±101.38	137.75±58.15	151.87±67.75						193.69±80.20	164.12±79.36
H10/1	120.28±101.52	230.56±147.65*	239.48±181.57*	140.50±73.72						126.92±92.42	179.28±138.83
H5/1	107.16±44.85	208.98±89.40*	202.33±107.13*	199.46±88.78*						125.35±125.747	153.65±119.76
H10/3	173.77±115.07	184.30±101.62	173.93±132.33	162.44±41.42						143.34±60.44	175.75±48.98

Values are means ± SD. Nos. in exercise protocols S and H are RM/length of rest period (min). Pre, preexercise; Mid, midexercise; IPE, immediately postexercise (0 min). All times are minutes or hours postexercise. * Significantly different ($P < 0.05$) from corresponding preexercise values.

TABLE 4. *Serum creatinine and urea values during the series 1 (S) and 2 (H) resistance exercise protocols*

	Pre	Mid	IPE	120 min	24 h	48 h
			Creatinine, μmol/l			
S5/3	2.78±0.38		2.84±0.62	2.45±0.52	4.62±4.09	3.58±1.26
S10/3	3.18±1.15		2.40±0.69	2.96±0.81	3.39±0.88	3.06±0.75
S5/1	2.45±0.61		4.45±2.62	2.52±0.69	3.00±1.98	2.95±0.50
H10/1	3.48±1.39		3.52±0.75	4.09±1.49	5.59±6.14	3.16±0.32
H5/1	3.45±0.71		2.83±0.78	2.33±0.73	3.27±0.69	3.47±0.65
H10/3	3.13±0.56		2.85±0.61	3.17±0.21	3.22±0.44	5.49±5.95
			Urea, g/dl			
S5/3	13.40±2.68	13.85±2.84	13.03±3.25	13.10±3.30	14.92±3.37	15.27±2.89
S10/3	13.43±2.49	14.58±2.84	13.04±2.49	15.11±3.16	14.55±3.14	14.70±3.95
S5/1	13.79±3.53	13.67±4.03	14.03±4.41	15.28±3.44	13.20±3.36	14.84±5.28
H10/1	13.23±2.50	13.53±2.76	12.97±2.23	13.88±3.19	13.55±2.12	14.09±2.38
H5/1	15.88±2.94	16.14±3.65	15.71±4.37	15.44±2.26	14.45±3.65	14.87±4.11
H10/3	14.65±3.46	14.96±4.13	15.21±5.39	14.62±3.16	13.66±3.42	13.89±2.91

Values are means ± SD.

partments and target receptors for hormones are exposed to the actual molar concentrations. As previously observed for men, peak values were not correlated with initial concentrations of the hormones (23). Changes in plasma volume shifts during recovery were almost negligible. The greatest percent changes in plasma volume were observed pre- to postexercise and were as follows for the different resistance exercise protocols: *series 1*: S5/3 −1.05 ± 4.20% (SD), S10/3 −0.05 ± 5.1%, and S5/1 −0.91 ± 4.5%; *series 2*: H10/1 −5.6 ± 4.6%, H5/1 −0.16 ± 5.21%, and H10/3 −3.5 ± 4.68%.

DISCUSSION

The primary finding in this investigation was that heavy-resistance exercise protocols did elicit differential increases in peripheral concentrations of growth hormone and cortisol but did not alter serum concentrations of testosterone or total insulin-like growth factor I. The most striking differences between exercise protocols were the marked increases in growth hormone, cortisol, ammonia, and lactate in response to the exercise stimulus configuration of the H10/1 protocol.

We have previously observed for women as well as for men that the H10/1 protocol, which produced the highest blood lactate values, resulted in a clear and sustained elevation of growth hormone concentrations from midexercise through 30 min of recovery (22, 23). This study extends our previous work with women in demonstrating that when the length of the rest period was increased to 3 min (i.e., H10/3) or when the resistance used was increased to 5 RM (i.e., H5/1), thereby shortening the duration of the set, marked reductions in the responses of serum growth hormone were observed, resulting in no increase above resting concentrations. These new data have also confirmed our previous findings of a lack of a growth hormone response to the S5/3 protocol in addition to having shown that alterations in resistance (i.e., S10/3) or rest period length (i.e., S5/1) did not effectively alter the response of serum growth hormone. These findings may be due to the much higher resting baseline of growth hormone found in women during the early follicular phase of the menstrual cycle, which further underscores the importance of the configuration of the resistance exercise stimulus to elicit a change (22). From the limited number of interseries comparisons, it appears that the total work performed did not influence this response.

Although the relative contributions of various regulatory mechanisms for growth hormone remain unclear, the increases observed might have been affected by hypoxia, acid base shifts, and breath holding (13, 36–39). These observations extend the results of Vanhelder et al. (40) and support our previous investigations (22, 23) by demonstrating that exercise that produces greater demands on anaerobic glycolysis stimulates marked serum growth hormone elevations. This suggests that factors related to anaerobic metabolism are involved in the regulatory control of growth hormone. We hypothesize that the increased acidosis resulting in marked increases in hydrogen ion concentrations may be the primary physiological cue for growth hormone release (37).

As has been previously demonstrated for men, it was demonstrated in this investigation that the blood lactate changes were significantly influenced by the rest period length and the duration of the exercise set of repetitions (22, 23). The H10/1 protocol combination, which involved a short rest period and longer duration sets, resulted in the highest elevations in blood lactate; the time to perform a 10-RM set was longer than the time needed to perform a 5-RM set. It is interesting to note that the intensity of the exercise as defined by force production was higher for the 5-RM resistance. When exercise duration was reduced or rest period length was increased, the resulting blood lactate levels were lowered. This type of response relative to the intensity of the exercise stress is unique to exercise when expressed as a function of the maximal force production capabilities of the musculature.

The reductions in blood glucose observed 60 to 120 min after the majority of the heavy-resistance exercise protocols may be due to decreases in serum growth hormone in the later stages of the 2-h recovery period (33). Growth hormone has a complex influence on carbohydrate metabolism, with its net effect being to increase blood glucose concentrations and decrease glucose utilization. Reductions in growth hormone may allow for greater sensitivity to insulin changes by increasing the affinity of

insulin for its receptor (30). Thus, growth hormone reductions may effectively inhibit mechanisms that serve to spare glucose.

Growth hormone promotes protein synthesis (25, 29). Protein catabolism, as marked by higher ammonia, increases in the H10/1 protocol by midexercise. This increased protein catabolism may have contributed to an increased signal strength for growth hormone release. The reasons for the lack of an increase in growth hormone despite increases in ammonia in the H5/1 workout are unclear but may be related to the magnitude of protein catabolism. The lack of changes in urea concentrations may further indicate limited protein degradation, as the biochemical reactions of the urea cycle may not be fully triggered. Thus, one might speculate that there was a limited protein degradation after the H5/1 resistance exercise protocol. On the basis of the work of Clarkson and Tremblay (7), who used a muscle damage model, previous strength training has been shown to provide a protective effect for muscle protein. Protein catabolism may indeed not be of a very high magnitude when the normal remodeling process of muscle after heavy-resistance exercise is underway (21). Therefore, the contribution of protein catabolism to regulatory mechanisms of growth hormone may not be very great under these conditions.

The adaptational importance of an augmented response of growth hormone to a heavy-resistance exercise protocol remains to be determined. The examination of the possible roles of certain hormones in the tissue remodeling processes may be highly dependent on the type of protocol used for exercise training and the phase of the menstrual cycle. Data from this investigation support this hypothesis by demonstrating that only a certain configuration of resistance exercise elicits increased growth hormone concentrations. The influence of each phase of the menstrual cycle on resistance exercise responses of hormones remains unknown. In general, resting and exercise-induced changes in hormone concentrations have been previously observed to be affected by the status and phase of the menstrual cycle (10, 11). It is interesting that the H10/1 protocol used in this study is characteristic of the lifting protocol used by body builders to gain optimal muscle size (24). How changes in strength would affect these responses remains unclear.

The lack of an increase in total insulin-like growth factor I in this study may have been due to the facts that growth hormone stimulates mRNA synthesis and that release of insulin-like growth factor I from hepatic sources peaks 3 to 9 h later (4, 31). Any changes with exercise are further complicated by the complex interactions with transporter proteins, attachment and release, receptor equilibrium, and receptor binding actions (5, 27, 31). Previously observed increases in total insulin-like growth factor I observed for men and women consequent to exercise are difficult to explain but may be due to a number of concentrating mechanisms in the blood (e.g., clearance rates), increases in transporter proteins, or release from other nonhepatic cells (e.g., fat cells and muscle and connective tissue cells) due to tissue disruption from exercise.

In this investigation, none of the heavy-resistance exercise protocols caused elevated levels of serum testosterone concentrations in women. It is unknown what exercise-induced mechanisms may lead to altered testosterone concentrations in women. The women in this study were recreationally trained, but a previous investigation comparing untrained and highly competitive women weight lifters found no differences in resting serum testosterone concentrations (35). Thus, acute or chronic alterations in testosterone concentrations may be dependent on individual differences and a larger contribution from adrenal sources.

The larger increases that have been observed for men appear to be mediated through the pituitary-testicular axis, either by increased secretion rates or by alterations in testicular blood flow, instead of through systematic fluid shifts or reduced hepatic clearance rates (6, 32). Although levels of androstenedione are 10-fold higher than levels of testosterone in women and are responsive to resistance exercise, testosterone and dihydrotestosterone are still the more potent musculotrophic androgens, with important target receptors. The lower levels of these androgens normally encountered in women and the absence of their stimulation by any of the different heavy-resistance exercise protocols in this study suggest why women typically do not achieve the absolute levels of upper body muscularity and strength achieved by men (3, 26, 35). Although one study has demonstrated that small increases in serum testosterone may be possible in some women (9), our study supports previous investigations in our laboratory and those of others that have found no acute effects on serum testosterone concentrations with acute exercise or training (14, 18, 20, 22, 41, 42). In women, it appears that other endogenous anabolic hormonal mechanisms may play a more prominent role in physiological adaptations to heavy-resistance training.

In summary, heavy-resistance exercise stimulated acute increases in serum growth hormone and cortisol. The differences among protocols were related to the changes in the resistance used and the amount of rest allowed between sets and exercises. The most marked increases in growth hormone, cortisol, lactate, and ammonia were observed in response to the H10/1 protocol, which was a combination of short rest periods and long-duration moderately heavy resistance. Our data indicate that it is important that the design of heavy-resistance exercise protocols used to study physiological adaptations is carefully configured because of such acute physiological differences. How resistance exercise-induced differences are affected by the menstrual cycle remains to be studied. Furthermore, the role of anabolic hormones in mediating the chronic adaptations of protein accretion and muscle hypertrophy resulting from heavy-resistance training requires further study.

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Address for reprint requests: W. J. Kraemer, Center for Sports Medicine, 117 Ann Bldg., The Pennsylvania State Univ., University Park, PA 16802.

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