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William J. Kraemer · Robert S. Staron
Fredrick C. Hagerman · Robert S. Hikida
Andrew C. Fry · Scott E. Gordon
Bradley C. Nindl · Lincoln A. Gothshalk
Jeff S. Volek · James O. Marx
Robert U. Newton · Keijo Häkkinen

The effects of short-term resistance training on endocrine function in men and women

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Abstract This investigation examined hormonal adaptations to acute resistance exercise and determined whether training adaptations are observed within an 8-week period in untrained men and women. The protocol consisted of a 1-week pre-conditioning orientation phase followed by 8 weeks of heavy resistance training. Three lower-limb exercises for the quadriceps femoris muscle group (squat, leg press, knee extension) were performed twice a week (Monday and Friday) with every other Wednesday used for maximal dynamic 1 RM strength testing. Blood samples were obtained pre-exercise (Pre-Ex), immediately post-exercise (IP), and 5 min post-exercise (5-P) during the first week of training (T-1), after 6 weeks (T-2) and 8 weeks (T-3) of training to determine blood concentrations of whole-blood lactate (LAC), serum total testosterone (TT), sex-hormone binding globulin (SHBG), cortisol (CORT) and growth hormone (GH). Serum TT concentrations were significantly ($P \leq 0.05$) higher for men at all time points measured. Men did not demonstrate an increase due to exercise until T-2. An increase in pre-exercise concentrations of TT were observed both for men and women at T-2 and T-3. No differences were observed for CORT between men and women; increases in CORT above pre-exercise values were observed for men at all training phases and at T-2 and T-3 for women. A reduction in CORT concentrations at rest was observed both in men and women at T-3. Women demonstrated higher pre-exercise GH values than men at all training phases; no changes with training were observed for GH concentrations. Exercise-induced increases in GH above pre-exercise values were observed at all phases of training. Women demonstrated higher serum concentrations of SHBG at all time points. No exercise-induced increases were observed in men over the training period but women increased SHBG with exercise at T-3. SHBG concentrations in women were also significantly higher at T-2 and T-3 when compared to T-1 values. Increases in LAC concentrations due to exercise were observed both for men and women for all training phases but no significant differences were observed with training. These data illustrate that untrained individuals may exhibit early-phase endocrine adaptations during a resistance training program. These hormonal adaptations may influence and help to mediate other adaptations in the nervous system and muscle fibers, which have been shown to be very responsive in the early phase of strength adaptations with resistance training.

Key words Cortisol · Testosterone · Growth hormone · Sex-hormone binding globulin

W.J. Kraemer · A.C. Fry · S.E. Gordon
B.C. Nindl · L.A. Gothshalk · J.S. Volek · J.O. Marx
Noll Physiological Research Center,
Laboratory for Sports Medicine/Department of Kinesiology,
The Pennsylvania State University,
University Park, PA 16802, USA

R.S. Staron · F.C. Hagerman · R.S. Hikida
Department of Biomedical Sciences,
College of Osteopathic Medicine, Ohio University,
Athens, OH 45701, USA

R.U. Newton
Department of Exercise Science,
Southern Cross University,
Lismore NSW, Australia

K. Häkkinen
Department of Biology of Physical Activity,
University of Jyväskylä, Jyväskylä, Finland

W.J. Kraemer (✉)
Laboratory for Sports Medicine, 21 REC Building,
The Pennsylvania State University,
University Park, PA 16802, USA

Introduction

It had previously been thought that few adaptational changes take place in the endocrine system in the early phases of adaptation to heavy resistance training.

However, hormonal alterations have been theorized to influence early-phase neuromuscular adaptations (Kraemer 1992). Staron et al. (1994) have previously reported that increases in resting testosterone concentrations in men over the first 8 weeks of training are positively correlated with the changes in the myosin heavy chain [MHC] IIb transition to MHCIIa and the IIb to IIa fiber type transition. It has been observed that initial increases in strength among previously untrained men and women may be accounted for largely by the increased voluntary neural activation of the trained muscles, while muscle hypertrophy appears to lag behind in the time course of adaptation with a gradually increasing role in strength development as the training proceeds (Häkkinen et al. 1992; Deschenes et al. 1993). Furthermore, changes in muscle fibers in the initial phases of training appear to be related to alterations in the type of proteins (e.g., MHC protein isoforms) rather than a significant amount of protein accretion (Staron et al. 1989, Staron et al. 1994). Thus, the initial phase of adaptation with short-term resistance training appears to be a dynamic period of time in which neuromuscular and hormonal mechanisms of adaptation are responding to the external demands of the exercise training stimuli.

The majority of studies have demonstrated that the circulating concentrations of growth hormone, cortisol, sex-hormone binding globulin (SHBG), and testosterone (only in men) acutely increase following heavy resistance exercise protocols in young men and women (Häkkinen and Pakarinen 1995; Kraemer et al. 1990, 1991, 1993a, b). Gender differences appear to be related to the greater magnitude of hormonal responses above resting concentrations for growth hormone and testosterone in men compared to women (Häkkinen and Pakarinen 1995; Kraemer et al. 1990, 1991, 1993a, b). However, women have been shown to have higher resting concentrations of SHBG and growth hormone than men (Häkkinen et al. 1990; Häkkinen and Pakarinen 1993; Kraemer et al. 1991). In addition, it has been observed that the type of heavy resistance exercise protocol utilized will have an impact on the magnitude of such hormonal responses. Workouts with greater volumes of total work which use moderate to heavy resistances (e.g., multiple sets of ten repetition maximum (RM), and shorter rest periods (1–2 min of rest between sets and exercises) have been shown to produce much higher values for post-exercise concentrations of these hormones than the use of heavier resistances (5 RM), longer rest periods (3 min), and smaller volumes of total work (Häkkinen and Pakarinen 1993; Kraemer et al. 1987, 1990, 1991, 1993a, b). Nevertheless, how the acute hormonal responses to resistance exercise are affected by training in men and women remains speculative. Therefore, the primary purpose of this investigation was to examine the hormonal responses to acute resistance exercise and to determine whether training adaptations are observed over the early phase of adaptation in an 8-week training period in untrained men and women.

Methods

Subjects

Within the context of our previous investigation (Staron et al. 1994), 8 women and 13 men participated in this part of the study to examine the effects of short-term resistance training on resting and exercise-induced concentrations of various anabolic hormones. The subjects in this study were active, healthy individuals but considered untrained as none of the subjects had not been involved in any regular exercise program or heavy resistance training. The mean ($\pm$SD) for men were: age 25.3 (3.2) years, height 1.77 (0.08) m, body mass 82.6 (17.5) kg, and % body fat 15.5 (4.5)%; and for women the values were: age 20.6 (1.5) years, height 1.66 (0.05) m, body mass 60.4 (5.8) kg, and % body fat 18.6 (6.2)%. Each subject signed an institutionally approved (University Institutional Review Board for Use of Human Subjects) informed consent document which overviewed the procedures and risks involved with the investigation. None of the subjects had any history of endocrine disorders and none was on medication or hormone therapy.

Training program

The training protocol used in this study has been reported previously (Staron et al. 1994). Briefly, the training period consisted of a 1-week pre-conditioning orientation phase followed by 8 weeks of high-intensity resistance training. Three lower-limb exercises for the quadriceps femoris muscle group (squat, leg press, knee extension) were performed twice a week (Monday and Friday) with every other Wednesday used for maximal dynamic 1 RM strength testing. Workouts consisted of two warm-up sets followed by three sets to fatigue using either a training zone of 6–8 RM (Mondays) or 10–12 RM (Fridays) for each of the three exercises with 2 min of rest between sets. The resistance used was progressively increased to maintain these training zones per set. Workouts began and ended with 10–15 min of flexibility exercises combined with calisthenics. All training sessions were monitored by a member of the research team. The subjects only performed the exercise program presented in this paper over the time period of the study.

Exercise test protocol, blood collections, and biochemical analyses

All venous blood samples were obtained after the 6–8 RM workout with the subjects in a slightly reclined, seated position. Subjects reported to the strength training laboratory and sat quietly for 10–15 min before the first sample was obtained. Whole blood was processed and, where appropriate, serum samples were stored at −70°C until analyses were performed. For serum, whole blood was allowed to clot at room temperature and was centrifuged at 1060 *g* for 10 min. Samples were then aliquoted into separate analysis tubes and frozen. Testing was always conducted at the same time of day for each individual to reduce the effects of any diurnal variations on hormone concentrations. Water intake was allowed ad libitum throughout the exercise protocol and during recovery. The venous blood samples were obtained from a superficial arm vein using a needle, syringe, and vacutainer assembly. Blood samples were obtained pre-exercise (Pre-Ex), immediately post-exercise (IP), and 5 min post-exercise (5-P) during the first week (T-1), after 6 weeks (T-2) and 8 weeks of training (T-3) to determine blood concentrations of whole-blood lactate (LAC), serum testosterone (TES), sex-hormone binding globulin (SHBG), cortisol (CORT) and growth hormone (GH). Serum total TES and CORT concentrations were determined in duplicate using single-antibody, solid-phase ^{125}I radioimmunoassays (Diagnostic Systems Laboratories, Webster, Tex., USA). Intra- and inter-assay variances were 3.2% and 4.1% for TES and 2.1% and 3.8% for CORT. Serum GH concentrations were determined in duplicate using a double-antibody liquid-phase ^{125}I radioimmunoassay (Diagnostic Systems Laboratories), and intra- and inter-assay variances were 3.6% and

4.5%, respectively. SHBG was determined in duplicate using a double-antibody liquid-phase ^{125}I radioimmunoassay (Diagnostic Products, Los Angeles, Calif., USA) and intra- and inter-assay variances were 2.8% and 4.9%, respectively. Immunoreactivity was measured with an LKB 1272 Clinigamma automatic gamma counter with an on-line data reduction system (Pharmacia LKB Nuclear, Turku, Finland). Hemoglobin was analyzed in triplicate using the cyanmethemoglobin method (Sigma, St. Louis, Mo., USA) and packed cell volume was analyzed in triplicate utilizing a standard micro-capillary technique. For methodological purposes the percentage changes in plasma volume were calculated according to the equations of Dill and Costill (1974). Changes in plasma volume were all less than −10% and no differences were observed between men and women or over the short-term training period. Hormone concentrations are presented as non-corrected values due to the fact that the tissues are exposed to an absolute molar concentration and more than plasma volume affects circulating concentrations (Kraemer 1992). Whole blood lactate concentrations were determined in duplicate via a Yellow Springs Lactate Analyzer (Yellow Springs Instruments, Yellow Springs, Ohio, USA). Samples were thawed only once and decoded after all analyses were completed (blinded procedure).

Statistical analysis

Multivariate analysis of variance (MANOVAs) were employed for all statistical analyses in this investigation. Repeated measures were used for all MANOVAs requiring a within-subjects analysis. Tests for normality of distribution (Kolmogorov-Smirov chi-square test) and homogeneity of variance (Levene's test) were employed for all data sets prior to ANOVA. Those data sets failing these tests were diagnosed for the appropriate transformation procedure (log transformation was deemed appropriate), transformed, and re-tested for normality and homogeneity of variance prior to the MANOVA. Post-hoc comparisons were accomplished via a Fisher's least-significant difference test. Statistical significance in this study was chosen as $P \leq 0.05$.

Results

We reported in our previous study that similar relative gains in muscle strength took place in a linear fashion in both the men and the women over the course of the 8-week training program. A significant decrease in the percentage of histochemically assessed type IIb fibers occurred across time both for the men and the women, with significance after just 2 weeks of training for women and 4 weeks for men. These changes corresponded to an observed decrease in MHCIIb (Staron et al. 1994).

Figures 2–6 presents the hormonal and blood lactate changes in response to acute resistance exercise and short-term training. In Figure 2, serum TES concentrations were significantly higher for men at all time points measured. A significant increase in men's serum TES due to exercise did not occur until T-2. A significant increase in pre-exercise concentrations of TES were observed both for men and women at T-2 and T-3. For serum CORT in Figure 3, no significant differences were observed between men and women. Significant increases in CORT above pre-exercise values were observed for men at all training phases and at T-2 and T-3 for women. A significant reduction in CORT concentrations at rest were observed both in men and women at T-3. For serum GH, in Fig. 4, women had higher pre-exercise values than men at all training phases. Figure 5 shows that no significant changes in GH concentrations with training were observed. No significant exercise-induced increases in GH above pre-exercise values were observed at any phase of training. Figure 5 shows that women had significantly higher serum concentrations of SHBG at all time points. No exercise-induced increases in men were observed over the training period but SHBG in women significantly increased with exercise at T-3. SHBG concentrations in women were also significantly higher at T-2 and T-3 when compared to T-1 values.

Figure 6 shows that there were no significant differences between men and women in their response of whole-blood lactate to acute resistance exercise. Significant increases in whole-blood lactate concentrations due to exercise were observed both for men and women at all training phases but no significant differences with training were observed.

Discussion

The primary findings of this investigation are that in untrained men and women a significant number of initial

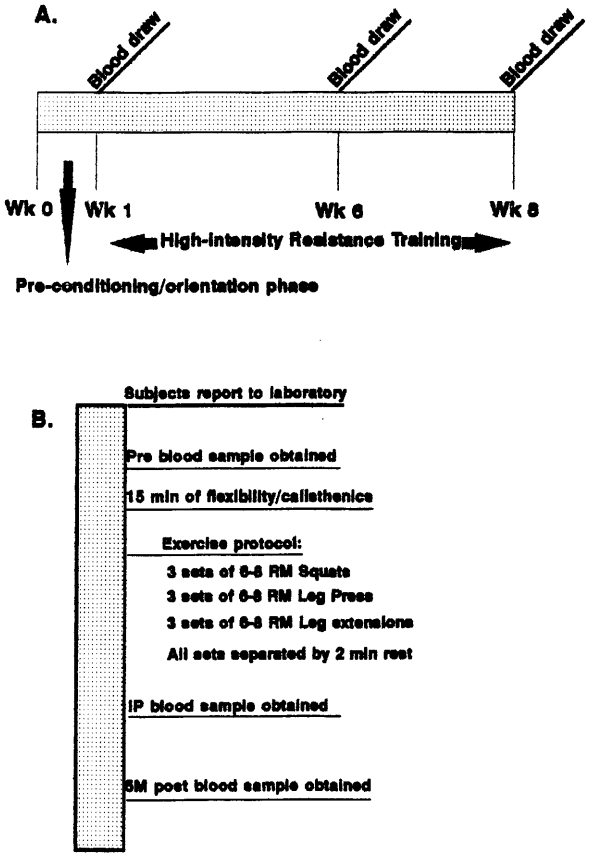

Fig 1. Training time line depicting when the exercise-induced blood draws were performed (**A**) and the time line depicting the protocol of the acute exercise bout (**B**)

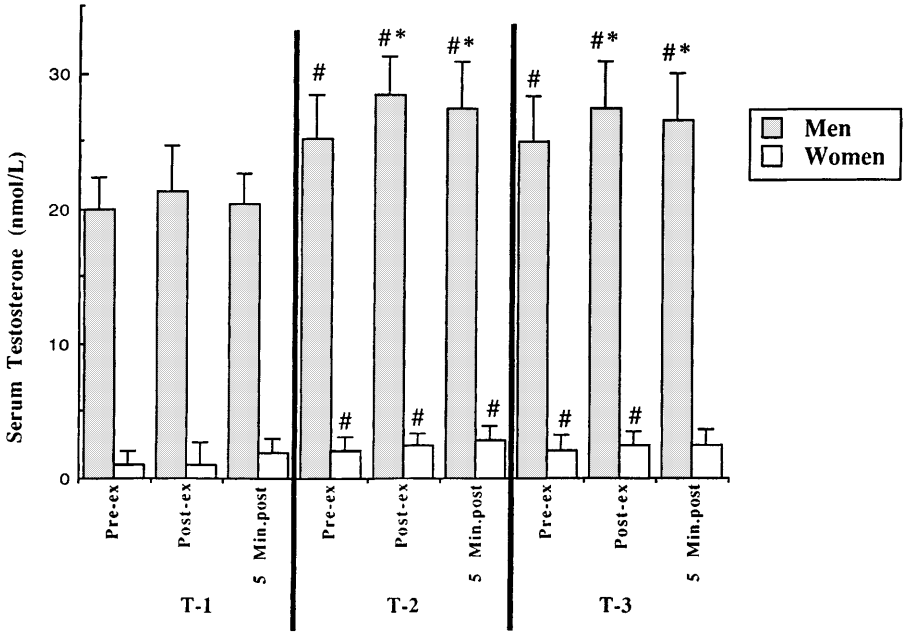

Fig. 2. Serum total testosterone concentrations for men and women pre-, post-, and 5 min post-exercise at T-1, T-2, and T-3. $^{*}P \leq 0.05$ from corresponding pre-exercise value; $^{\#}P \leq 0.05$ from corresponding T-1 value. (*T-1* First week of training, *T-2* after 6 weeks of training, *T-3* after 8 weeks of training)

adaptations take place in the hormonal profile in the early phases of a resistance training program and that subtle gender differences exist.

Our observed increases in pre-exercise serum TES concentration with training at T-2 and T-3 in men appear to be representative of an acute homeostatic shift in TES secretion patterns in untrained men prior to exercise. These increases are likely to be coupled to the tissue growth/remodelling process that is known to occur during a resistance training program. Our prior data on the basal concentrations of TES also demonstrated that this increase occurs in men (Staron et al. 1994). Previously it has been demonstrated that longer training periods are required to increase resting TES values (Häkkinen et al. 1988). However, our data now indicate that very early-phase adaptations in untrained men may also involve alterations in the resting and pre-exercise concentrations of TES. In this investigation, the acute adaptations in the first couple of weeks of training may only have been observed because of the untrained status of our subjects.

In women we again observed an early-phase elevation of TES in the pre-exercise concentrations from T-1 to T-2 that was not observed in our prior report on basal concentrations. Previous investigations have been unable to demonstrate changes in basal concentrations of

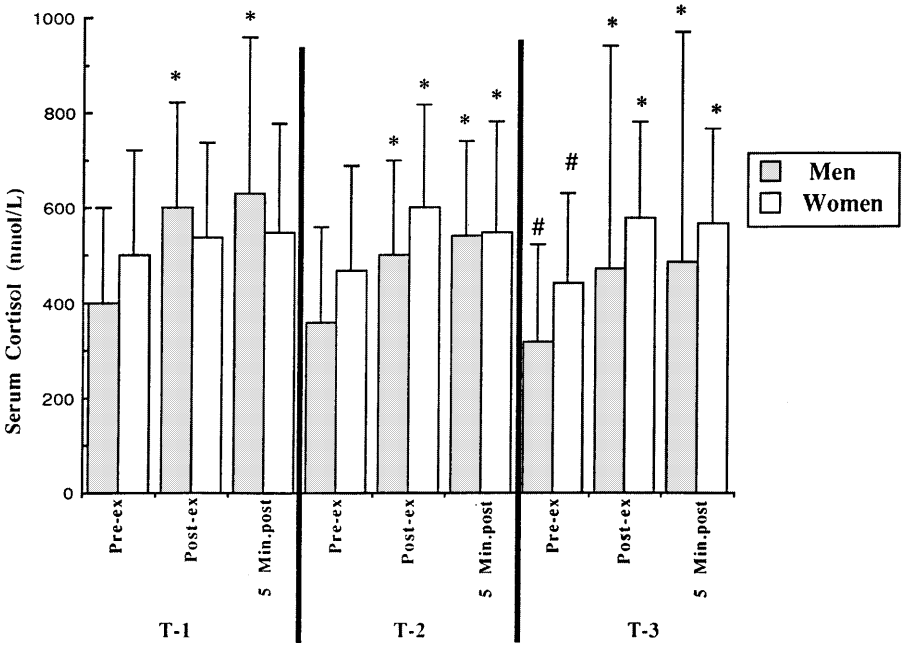

Fig. 3. Serum cortisol concentrations for men and women pre-, post-, and 5 min post-exercise at T-1, T-2, and T-3. $^{*}P \leq 0.05$ from corresponding pre-exercise value; $^{\#}P \leq 0.05$ from corresponding T-1 value

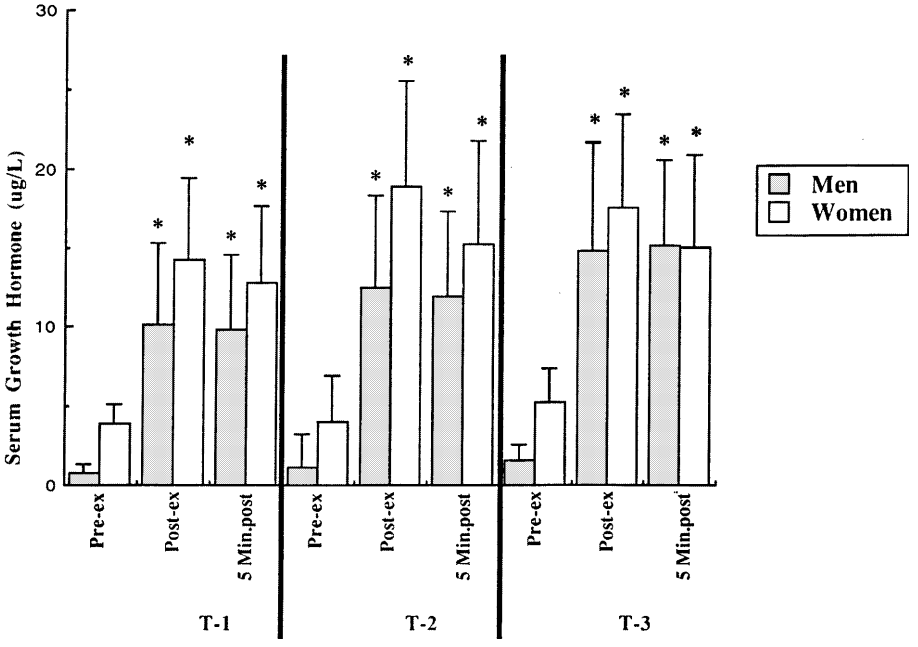

Fig. 4. Serum growth hormone concentrations for men and women pre-, post-, and 5 min post-exercise at T-1, T-2, and T-3. $^{*}P \leq 0.05$ from corresponding pre-exercise value; $^{\#}P \leq 0.05$ from corresponding T-1 value

TES with training in women in studies ranging from 3 weeks to 4 months (Häkkinen et al. 1989, 1990, 1992; Staron et al. 1994; Westerlind et al. 1987). Stoessel et al. (1991) demonstrated that there are no significant differences between untrained women and women who were members of the United States weightlifting team in terms of basal resting TES values. However, Häkkinen et al. (1990, 1992) have demonstrated that the basal levels of TES in women are related to the magnitude of muscle hypertrophy and strength development caused by training. This study has demonstrated that, in contrast to prior reports on resting basal concentrations, pre-exercise TES concentrations in women are increased after short-term resistance training. The underlying mechanism accounting for the difference in the basal and pre-exercise responses of TES concentration has yet to be fully elucidated but could be the result of predictive homeostatic regulation (Moore-Ede 1986).

A unique finding in this investigation was the observation that untrained men are able to develop an acute exercise-induced increase in TES concentration with resistance exercise. This may also be an early-phase resistance training adaptation. A lack of increases in TES following resistance exercise has been observed in a prior investigation of untrained men (Fahey et al. 1976). However, few attempts had been made to determine how

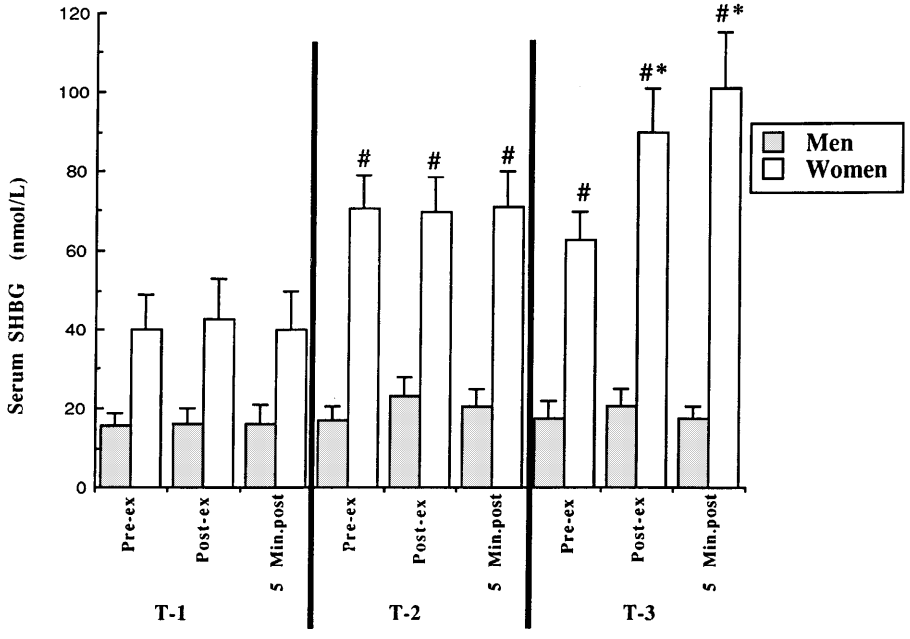

Fig. 5. Serum sex-hormone binding globulin (*SHBG*) concentrations for men and women pre-, post-, and 5 min post-exercise at T-1, T-2, and T-3. $^{*}P \leq 0.05$ from corresponding pre-exercise value; $^{\#}P \leq 0.05$ from corresponding T-1 value

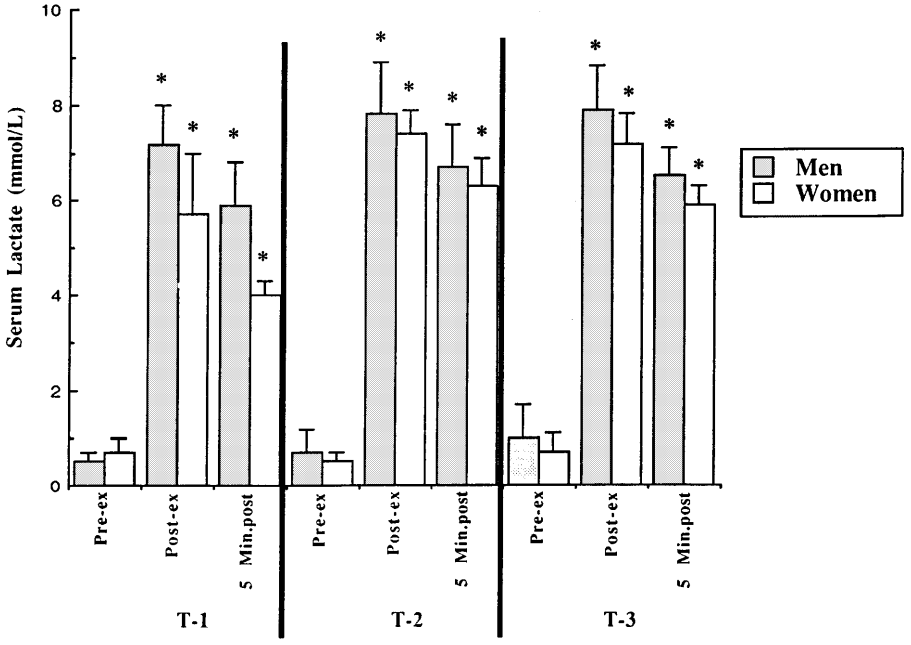

Fig. 6. Serum lactate concentrations for men and women pre-, post-, and 5 min post-exercise at T-1, T-2, and T-3. $^{*}P \leq 0.05$ from corresponding pre-exercise value; $^{\#}P \leq 0.05$ from corresponding T-1 value

training affects this response in men. Again, the training status of our subjects may have contributed to the observation of this early-phase adaptation in the exercise-induced response of TES. This training-induced adaptation to increase TES concentrations with acute resistance exercise may contribute to an enhanced anabolic environment in the early phase of training in men. It appears that a certain amount of exposure to the training stimuli may be needed in order to engage the mechanisms that mediate exercise-induced increases in TES.

The vast majority of prior work has not been able to demonstrate increases in TES with acute resistance exercise or training in women (Kraemer et al. 1991, 1993b; Weiss et al. 1983; Westerlind et al. 1987). Such findings remain consistent with data from the current study, as no significant exercise-induced increases in TES concentrations were observed. The inability to increase TES with acute resistance exercise may be a crucial gender difference which originates in adolescence, when anaerobic performance differences are first observed (Nindl et al. 1995).

With training, a reduction in resting CORT concentrations has been thought to contribute to the overall enhancement of the anabolic environment with training (Kraemer 1992). Both in men and women decreases in serum CORT concentrations pre-exercise were observed by T-3. This is a finding unique to women, as previous studies by Häkkinen et al. (1985) and Kraemer et al. (1995) have reported that resistance training only results in an overall reduction of CORT responses to exercise stress in men. Since CORT is primarily related to the degradation of protein, reductions in the amount of CORT may enhance type I muscle fiber hypertrophy, which appears to be the primary mechanism of muscle cell hypertrophy in type I fibers, which utilize reductions in the degradation of protein rather than increasing protein synthesis as a primary mechanism (Goldspink 1992). A lack of increase in CORT in response to acute resistance exercise at T-1 in women remains unclear, but it may be that an increase would have been observed later on in recovery.

The potential importance of transport proteins (e.g., SHBG) is demonstrated in this investigation. SHBG concentrations in women were higher at T-2 and T-3 than at T-1. In addition, at T-3 the SHBG levels in women were significantly elevated in response to exercise. Häkkinen and Pakarinen (1993) had demonstrated that women have significantly higher concentrations of SHBG than men and that with age this discrepancy increases further. Conversely, Häkkinen et al. (1992) were unable to demonstrate changes in SHBG (i.e., mean changes 62.7 to 66.6 nmol l^{-1}) over 3 weeks of strength training. Beyond SHBG's role as a potential anabolic compound, its role in the transport and reduced degradation as a complex with TES appears to be important when conditions which limit TES availability exist (e.g., low levels in women and decreases in men and women with age).

The data in this study demonstrate that, in young men, no apparent reduction in hormone availability exists, yet in women enhanced secretion leading to increased concentrations appears to be augmented or guarded by the increase in SHBG over this early phase of training during which there is great stimulation of anabolic processes in these women's bodies as evidenced by protein changes in the muscle (Staron et al. 1994). These data also indicate that a potential gender difference exists in this hormone's response to training in the early phase of resistance training adaptations.

GH concentration increased with acute resistance exercise but was not different over the training period. As has been observed several times before, pre-exercise

concentrations of GH were higher in women than in men but those in men increased by a much higher percentage above the pre-exercise values (Kraemer et al. 1990, 1991, 1993b; Häkkinen and Pakarinen 1995). This elevated pre-exercise value may provide an alternative anabolic mechanism by which women compensate for their lower TES concentrations (Kraemer 1991,1993b). A lack of change could be due to adaptations of other GH variants adapting differently to resistance training. There is a growing awareness that many types of GH molecules exist in, and are released from, the human pituitary gland. There are 15–20 GH variants, a value which may be higher following pre- and post-translational processing in the pituitary (e.g., phosphorylation, proteolytic cleavage) (Charrier and Martal 1988; Dor et al. 1991; Ellis et al. 1978; Schmidt et al. 1995; Stolar and Baumann 1986). These variants may differ in their biological activity. For example, it has been suggested that of the main molecular variants, those of 20 kDa and 22 kDa, the 20-kDa species exhibits ''anti-insulinic'' effects while the 22-kDa species exhibits ''insulinic effects'' (Dor et al. 1991; Schmidt et al. (1995). How heavy resistance exercise stimulates GH remains unknown. Changes in the blood's acid-base status and blood lactate concentrations have also been implicated as mechanisms behind GH release (Gordon et al. 1994). However, in a study by Schmidt et al. (1995), no relationship was reported between lactate and GH responses after exercise. The lack of training-related adaptations of lactate concentration observed in this study may account, in part, for the lack of training-induced responsiveness of GH. (Gordon et al. 1994). The type of GH produced may be important in the elucidation of adaptations to resistance training and the stimulation of other hormones such as insulin-like-growth factor-I.

In summary this investigation has demonstrated that significant alterations in pre-exercise and exercise-induced levels of hormones take place in the early phase of a resistance training program. Untrained individuals appear especially sensitive to the initial bouts of resistance exercise in the early phase of training and endocrine mechanism(s) become responsive to the workout stimuli (e.g., TES responses in men and TES and SHBG in women). These hormonal adaptations may influence and help to mediate other adaptations in the nervous system and muscle fibers which have been shown to be very responsive in the early phase of strength adaptations following resistance training.

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