Acute hormonal responses to two different fatiguing heavy-resistance protocols in male athletes

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HÄKKINEN, K., AND A. PAKARINEN. Acute hormonal responses to two different fatiguing heavy-resistance protocols in male athletes. J. Appl. Physiol. 74(2): 882-887, 1993.—To examine endogenous hormonal responses to heavy-resistance exercise, ten male strength athletes performed two fatiguing but different types of sessions on separate days. In session A the loads for the leg extensor muscles in the squat-lift exercise were maximal so that the subjects performed 20 sets at 1 repetition maximum (RM) (20 × 1 RM × 100%), whereas during session B the loads were submaximal (70%) but the subjects performed each of the 10 sets until the RM (i.e., 10 repetitions/set or 10 × 10 × 70%). The recovery time between the sets was always 3 min. A decrease of 10.3 ± 4.7% (P < 0.001) occurred in the squat-lift in 1 RM during session A, whereas session B led to a decrease of 24.6 ± 18.9% (P < 0.001) in 10 RM. Increases in the concentrations of serum total and free testosterone (P < 0.05 and 0.05, respectively), cortisol (P < 0.001), and growth hormone (GH, P < 0.001) were observed during session B, whereas the corresponding changes during session A were statistically insignificant except for the relatively slight increase (P < 0.01) in serum GH level. The significant (P < 0.001) increase in blood lactate concentration during the two sessions correlated significantly (P < 0.01) with the increase in serum GH concentration. The morning values of serum testosterone and free testosterone were significantly (P < 0.05-0.01) lowered on the 1st and 2nd rest days after the sessions. The present findings demonstrate that heavy-resistance exercises cause acute endogenous hormone responses that can differ depending on the type and/or magnitude of the stress of the exercise protocol utilized.

serum hormones; fatigue; heavy-resistance exercise; blood lactate

INTENSIVE CONTINUOUS and/or intensive intermittent muscular work utilized typically during a heavy-resistance strength training session will lead to a momentary decrease in the voluntary performance capacity of the neuromuscular system (6, 7, 9, 13, 27). The magnitude of the effects of the fatiguing load on the neuromuscular system is related not only to the intensity of the exercises but also to the specific type of the fatiguing load, the recovery time between high-intensity intermittent contractions, and the subject material. Examination of certain hormonal responses to a fatiguing heavy-resistance strength training session may provide additional basic information about the acute adaptations in the human body caused by short-term intensive exercise. On the basis of earlier studies (4, 9, 16, 17), it could be expected that the anabolic hormone testosterone and growth hormone (GH) and the catabolic hormone cortisol would have an important role in this respect.

The purpose of the present study was therefore to investigate the acute response patterns of serum total and free testosterone, cortisol, and GH to heavy-resistance exercise in male strength athletes. These hormonal responses were explored by comparisons of two distinctly different but clearly fatiguing heavy-resistance exercise protocols. These protocols are utilized, although normally with fewer sets per session, either for the "neural" type of strength training, to develop primarily maximal strength, or for the "hypertrophic" type of strength training, to develop muscle strength and especially to increase muscle hypertrophy.

METHODS

Subjects. The subjects who volunteered for the study were 10 top-level Finnish male strength athletes (power lifters, body builders, and weight lifters) with the mean age of 29.7 ± 8.0 (SD) yr. Informed consent was obtained from the subjects. The athletes were from several weight categories, their mean body mass was 82.4 ± 5.9 kg, and their mean height was 178.2 ± 8.6 cm. Although these subjects were representatives of slightly different sports events, during the present experiment they were all on their preparatory training season; their overall strength training was therefore rather similar to increase their muscle mass and maximal muscular strength. The subjects were not taking anabolic steroids or other drugs that would be expected to affect physical performance or hormone balance, either for several months or years before the study or during it.

Experimental design (Fig. 1). The experimental design consisted of the control day, a rest day during which blood samples from the strength athletes were taken at 800, 1700, 1900, 2000, and 2100 h for the determination of serum hormones. One week after the subjects participated in a heavy-resistance strength training session from 1700 to 1900 h. During this training day A, the blood samples were taken repeatedly at the same time periods as those of the control day. The blood samples were also taken 1 (rest day I) and 2 days (rest day II) after training day A. One week after the same subjects participated in another training session from 1700 to 1900 h. Training day B also included blood sampling at the same respective times of the day as the control day and training day A. Training day B was also followed by 2 rest
Blood samples:  

**FIG. 1.** Experimental study design.

days, during which the blood samples were repeated in an identical manner.

**Strength training session A.** Training session A included one exercise, a squat-lift. In the exercise the subject held the loaded barbell on his shoulders, bent his knees to a low squat position, and then stood up with the loaded barbell. Each subject performed warm-up lifts with light loads before the actual training contractions. The actual training loads were always maximum, so that the subjects performed a repetition at 100% of one repetition maximum (1 RM) altogether for 20 sets (20 × 1 × 100%). The entire duration of each maximum lift, including the eccentric and concentric phases of the contraction, was 3–6 s. The recovery time between the sets was 3 min. The loads were adjusted during the course of the session because of fatigue so that each repetition would actually be the maximum that the subject could lift at each set. If the load happened to become slightly too heavy, as it did in some cases, the lift was not repeated, but the subject was assisted slightly while he performed his maximal lift to maintain the maximal contraction time during each lift. This type of training program is periodically utilized in strength training for maximal strength (neural strength training, e.g., among weight lifters and power lifters) but with considerably fewer sets (5).

**Strength training session B.** The squat-lift was also the exercise used in training session B, which was also very exhaustive but considerably different from session A. In session B the loads in each set were submaximal (~70% of 1 RM), but the subjects performed in each set as many repetitions as possible until fatigue; in practice, this amounted to 10 repetitions. The subjects performed altogether 10 sets (10 × 10 × 70%). The recovery time between the sets was 3 min, as in session A. The loads were adjusted during the course of the session because of fatigue so that the subjects were able to perform exactly 10 repetitions at each set. If the load happened to become slightly too heavy, as it did in some cases, the subject was assisted slightly during the last 1–3 repetitions of the set while he maintained his maximum performance so that he could reach the required number of repetitions and also maintain the same contraction time. This type of training program is utilized in strength training for muscular hypertrophy and strength (hypertrophic strength training), e.g., among body builders but with fewer sets (5).

**Measurement of strength.** The load used in the squat-lift exercise was also used for recording muscle strength. In session A the load for each set was repeatedly adjusted for fatigue so that 1 RM could be recorded during the course of the session for all 20 sets. In session B the load in the squat-lift was also repeatedly adjusted so that 10 RM could be recorded for all 10 sets.

**Analytic methods.** Blood samples were drawn after 12 h of fasting and 8 h of sleep in the mornings of the control day and training days A and B, as well as on rest days I and II after the training days, at 800 h from the antecubital vein of each subject. On each day blood samples were repeatedly drawn also at 1700, 1900, 2000, and 2100 h. The subjects were instructed to maintain their normal food intake during the experiment and to have their last light meal no later than 2.5 h before 1700 h. Serum samples for the hormonal analyses were kept frozen at −20°C until assayed. The assays of serum cortisol and testosterone were performed by use of radioimmunoassay (RIA) reagent kits from Farmos Diagnostica (Turku, Finland), and those of GH with kits from Pharmacia Diagnostics (Uppsala, Sweden). Serum free testosterone concentrations were measured using RIA kits obtained from Diagnostic Products (Los Angeles, CA). The sensitivity of the cortisol assay was 0.05 μmol/l with a coefficient of intra-assay variation of 4.0%. The respective values for the testosterone, GH, and free testosterone assays were 0.26 nmol/l (6.2%), 0.2 μg/l (2.5–5.1%), and 0.52 pmol/l (4.4%). All the assays were carried out according to the instructions of the manufacturers. All samples from each test subject were analyzed in the same assay for each hormone. Blood samples for the determination of blood lactate were also taken during the course of the sessions after every third set. Blood lactate concentrations were determined using a lactate analyzer (model 640, Roche).

**Statistical methods.** Standard statistical methods were used for the calculation of means ± SD of the parameters examined. In a comparison of preexercise and postexercise, the differences between mean values were tested for significance by Student’s paired t test (two-tailed) during session A and session B. A paired t test was also utilized in comparing the mean values of the control day with those recorded at the corresponding times during the training days.

**RESULTS**

**Strength performance.** A significant decrease occurred during training session A in maximal strength (1 RM) from 175 ± 34 to 158 ± 36 kg (P < 0.001; Fig. 2). This corresponded to a relative decrease of 10.3 ± 4.7% (Fig. 2) during the entire course of the session. During training session B, the decrease in maximal strength (10 RM) was 24.6 ± 18.9% (from 125 ± 24 to 91.5 ± 19 kg; P < 0.001; Fig. 2).

**Serum hormones.** The diurnal variations of the mean values of the hormones measured for the subject group during the control day are shown in Fig. 3.
The mean concentration of serum testosterone remained statistically unchanged during training session A, but during session B it increased from 23.1 ± 4.1 to 28.6 ± 5.9 nmol/l (P < 0.05; Fig. 4). The latter value was significantly (P < 0.001) higher than the corresponding value recorded during the control day. One hour after session B, serum testosterone concentration had reached its basal level (see also Fig. 3). The mean concentration of serum free testosterone also remained unchanged during training session A, but during session B it increased significantly (P < 0.05) from 65.8 ± 12.9 to 80.6 ± 27.6 pmol/l (Fig. 5).

No significant change was observed in serum cortisol concentration during training session A (Fig. 6). During session B its concentration increased (P < 0.001) from 0.37 ± 0.10 to 0.92 ± 0.13 µmol/l (Fig. 6). After the session it decreased (P < 0.001) gradually, but after 2 h it had not reached the level of the control day.

The mean concentration of serum GH increased (P < 0.01) from 0.31 ± 0.39 to 1.43 ± 0.89 µg/l during training session A, but during session B it increased (P < 0.001) from 0.16 ± 0.07 to as high as 27.7 ± 17.8 µg/l (Fig. 7). In both cases the mean values of serum GH were on the level of the control day 2 h after the termination of the sessions.

The values of the hormones on the mornings of each training day were compared with the corresponding morning values of the subsequent 1st and 2nd rest days. The levels of total and free testosterone on the rest days were significantly (P < 0.05–0.001) lower than those of the corresponding morning values of each training day (Figs. 4 and 5).

Blood lactate. The mean blood lactate concentration increased (P < 0.01) gradually during training session A from 1.9 ± 0.5 to 3.5 ± 1.2 mmol/l, whereas during session B it increased (P < 0.001) gradually from 1.4 ± 0.3 to 15.0 ± 4.0 mmol/l (Fig. 8). In both cases the mean values of blood lactate had decreased (P < 0.01–0.001) to their basal levels 1 h after the sessions.
ENDOGENOUS HORMONE RESPONSES TO EXERCISE

DISCUSSION

The primary findings of the present study were as follows. 1) Both kinds of intensive strength training sessions led to a considerable number of gradual fatiguing responses, as demonstrated by the gradual decreases in maximal strength performance. Fatigue was more remarkable during session B than during session A. 2) The acute hormonal responses during the sessions as observed by the increased serum levels of total and free testosterone, cortisol, and GH were much greater during the more fatiguing session B. 3) The decreased basal serum levels of total and free testosterone had not been recovered during the 2 rest days after the training days.

The magnitude of fatigue during various strength training sessions is known to be related not only to the intensity of the exercises but also to the type of fatiguing load (15), to the recovery time between the intermittent contractions (14, 27), and to the subject material (6, 19).
The present neural type of strength training session A resulted in a considerable decrease in strength performance. Because no electromyogram recordings were taken of the fatigued muscles, it is impossible to determine to what extent fatigue under the present experimental conditions was of neural or peripheral origin. It has been demonstrated earlier that the decrease in maximal strength during this type of high-intensity fatiguing strength training session may be associated with the decrease in the maximal voluntary neural activation of the exercised muscles (9, 13, 14). The hypertrophic type of strength training in session B led to a more remarkable decrease in strength performance than that observed in session A. Although this decrease in strength between the two sessions cannot be directly compared, one would expect that session B, associated normally with much higher lactate accumulation than session A (Fig. 8) (9, 10), would result in greater muscular fatigue. Accumulation of lactic acid inside the muscle, with decreased pH level as well as depression in \(Ca^{2+}\) transport after exhaustive exercise, may result in reduced contractile characteristics of the muscle (10, 21, 22).

Session B, leading to more remarkable fatigue, was associated with greater acute hormonal responses than session A. It was observed earlier that serum testosterone concentration may be increased during an intensive strength training session (4, 8, 9, 16, 17, 28). The present findings seem to demonstrate further that the magnitude of the serum testosterone response depends on the magnitude of the stress of the strength training session. All protocols do not elicit the same magnitude or duration of serum testosterone increase, even when the identical total amount of work is performed (17). Nevertheless, the skeletal muscle will be exposed to an elevated peripheral testosterone concentration, increasing the likelihood of plausible interactions with muscle cell receptors. On the other hand, increased serum testosterone levels could theoretically also be a result of decreased muscle utilization of testosterone (17). In the present study there was no significant increase in serum testosterone and free testosterone levels during session A. However, it is probable that session A also caused some response, inasmuch as it was not associated with a diurnal decrease in serum testosterone levels observed at the same respective time during the control day.

As shown in Fig. 4, the basal testosterone levels were reached within \(\simeq 1\) h after the sessions. However, after certain heavy-resistance exercise protocols, increases in testosterone may occur also later during recovery (17). Although the present testosterone response was short, it was interesting to observe that the levels of both total and free testosterone of the subsequent 2 rest days were significantly lower than the corresponding morning values of the training day. This indicates that both kinds of stressful strength training sessions may lead, in addition to acute responses, to decreased basal testosterone levels lasting a few days. This finding seems to indicate rather well the considerable degree of stress of the present strength training sessions, inasmuch as decreased serum testosterone concentration is known to retain its basal level after 1, or at least after 2, rest day after a “normal” strength training session (8).

During the more fatiguing training session B a significant increase in serum cortisol concentration was demonstrated, whereas session A did not cause an observable cortisol reaction. It was observed earlier that short-term physical exercise can increase serum cortisol levels (2, 4, 9, 18, 20, 23). Our results indicate that the reaction of serum cortisol concentration to acute exercise stress depends on the degree of stress of the exercise. Schwarz and Kindermann (23) recently observed that serum cortisol levels increased after an exhaustive incremental graded exercise and not after a 1-min anaerobic exercise. In the present study, serum cortisol levels did not return to the basal levels during the 2 h after session B. However, the morning cortisol values of the subsequent 2 rest days did not differ from the corresponding morning values of the training day. This suggests that a strength training session of the type of session B does not lead to a longer-lasting increase in catabolic hormonal activity. However, the same session led to decreased anabolic activity of testosterone during the subsequent few days, indicating in part the magnitude of the session’s stress.

It has been shown in earlier studies that serum GH levels can be increased in physical exercise (1, 12, 26). In the present study, serum GH concentrations increased during both kinds of strength training sessions. However, the more fatiguing session B induced a much greater (mean nearly 200-fold) increase than session A (mean 4.6-fold). The present data are therefore well in line with other studies showing that GH response is dependent on the type of training (9, 16, 26). In intermittent weightlifting exercises the overall volume, load, and frequency of the exercise seem to be main factors affecting blood GH levels (16, 26). The stimulus for GH secretion in physical exercise is not known. In the present study there were significant increases in blood lactate concentrations during training session B, whereas during session A lactate levels increased only slightly. Furthermore, when the results of both training sessions were combined, a statistically significant correlation between the changes in serum GH levels and those of lactate blood levels was observed (Fig. 9). This finding supports some earlier results suggesting that oxygen availability in tissues may be related to the responses of GH (16, 24, 25). However,
blood lactate itself is evidently not the determinant of this response (11, 17). Factors such as hyperventilation and breath holding may also influence these acute changes in the concentration of GH (3).

In conclusion, maximal but anaerobically different heavy exercise protocols can lead to considerable but also different gradual fatiguing responses, as demonstrated by the gradual decreases in maximal strength performance observed in the present study. Heavy-resistance exercises stimulate markedly acute endogenous hormone responses, which can also differ in magnitude depending on the type and/or the degree of stress of the exercise protocol utilized.

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